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Youth and Water Security in Africa

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SHORT SUMMARY

Water is the Lifeblood of Sustainable Development

The sustenance of life through nutrition, health maintenance and provision of support infrastructure across many social-economic as well as environmental sectors has clean water availability and affordability requirements. Water security is inherent in the targets of both the Sustainable Development Goals (SDGs) of the 2030 Agenda for Sustainable Development and the Africa Agenda 2063. Meeting of water quantity and quality needs is challenging in many regions due to rapidly growing population, high urbanization rates and industrial expansion in sectors such as agriculture, construction and manufacturing. As an illustration, the medium projection of Africa's 2030 population by the UN is 1.68 billion people, compared to 1.19 billion people in 2015.

Effective exploration of ideas for ensuring water security in Africa must involve tapping of intellectual resources of youth and women. This publication on Youth and Water Security in Africa, which comprises 25-refereed articles co-authored by youth including female scientists primarily from Africa, derives from collaboration among UNESCO's Division of Water Sciences, the African Ministers' Council on Water (AMCOW) and the International Science Council (ISC) Regional Office for Africa (ROA).

Scientists, engineers, researchers, and policy-makers in the water resources and security sector will cherish the data, models, designs, and policy frameworks that are included in this publication.

According to the World Water Development Report 2019, in Sub-Saharan Africa, only

24%

of the population has access to safe drinking water.

Youth and Water Security in Africa

UNESCO's Advancement of Knowledge Systems for Attainment of Water Security Aspects of Global Sustainable Development

Foreword by
United Nations Educational, Scientific and Cultural Organization (UNESCO)

The 2030 Agenda for Sustainable Development which covers seventeen Sustainable Development Goals (SDGs), is an expression of the commitment of the international community to achieve sustainable development at all levels. As evident in its mantra "leave no one behind", the Agenda is configured to benefit all people. Furthermore, the "five Ps": People, Planet, Prosperity, Peace and Partnerships, have interconnections that span all sectors of sustainable development, including natural resources such as water and ecological systems, and stakeholder issues such as meaningful engagement of youth and women in sustainable development activities. In the implementation of the Agenda, there is no alternative to consideration of social, economic, and environmental factors. Such will enable holistic and transformative efforts that will derive from a globally shared and owned Agenda. Youth are more than just beneficiaries. They are partners, agents of change and actors for the implementation of SDGs.

SDG 6 enjoins stakeholders to "ensure access to water and sanitation for all". This has particular resonance in Africa where youth constitute more than 60% of the population; infrastructure is being built up at a rapid pace, and climate change poses impacts that are uncertain in many jurisdictions due to inadequate meso-scale and micro-scale assessments. It is noteworthy that UNESCO is the operator of the Intergovernmental Hydrological Programme (IHP) which was founded in 1975 and has since been implemented in successive phases. IHP-VIII (2014-2021) is ending this year (2021), and IHP-IX (2022-2029) is being configured. The IHP identifies key water priority areas for coverage by Member States toward attainment of the targets of Agenda 2030 and related SDGs. These priorities are also of high utility to other water-related international agendas such as the Sendai Framework on Disaster Risk Reduction (DRR), the Paris Agreement on Climate Change, the UNGA Declaration on the Water Action Decade (2018-2020), the UN Decade on Ecosystem Restoration (2021-2030), the Decade of Ocean Science for Sustainable Development (2021-2030), African Union's Agenda 2063, and UNESCO's Recommendation on Open Science.

Indeed, IHP-IX aims at addressing hydrological challenges to water security through innovation that has been enabled by advances in computational power, monitoring techniques, modelling capacities, visualization, data compression and information dissemination. The 2019 Global Sustainable Development Report appropriately entitled "The Future is Now: Science for Achieving Sustainable Development", further lays credence to UNESCO's efforts on water security. Reports of the High-Level Panels on water-related aspects stress the need for evidence-based decisions in tackling challenges that are associated with the provision of water of adequate quantity and quality.

As indicated in the Third Order IHP-IX Draft of January 26, 2021 entitled "Science for a Water Secure World in a Changing Environment", planning, design and implementation of water security programmes require the creation and deployment of knowledge systems. There is the UNESCO Operational Strategy for Youth that is emerging as part of IHP-IX. Research and packaging of knowledge in configurations that can be used are critical. There is also the nexus that links water, energy, food, and ecosystems (WEFE) that must be explored through research. This rationale has led to the development of this publication on Youth and Water Security in Africa. Essentially, UNESCO is marrying two of its areas: water security and youth for advancement in a continent of critical needs in these sectors: Africa. The ramifications of water security through all sectors of Africa's economy require holistic assessments of water security (current and prospective) for the region.

UNESCO's knowledge family is quite diverse and supported by appropriate programmes. UNESCO's Water Family operates as a global network that works together to implement the organisation's strategic goals. It consists of, the World Water Assessment Programme (WWAP), IHP National Committees, Regional Hydrologists at field offices, Category 2 Centres, water-related UNESCO Chairs.

The diverse water related challenges create the need to diversify water-security programmes and projects in an interconnected world, concerning geographical distribution; engagement of various age-groups, including youth, to which the future belongs, and women, who typically bear the heavy burden of stress from domestic water scarcity; and deployment of knowledge sectors from social sciences to technology. This also applies to gender issues, being that accessibility of water to all persons is essentially a human right. Appropriately, women should be engaged more in the design, implementation and communication of research programmes, especially those that involve human subjects.

Indeed, UNESCO through its WWAP has published "Gender-responsive indicators for water assessment, monitoring and reporting (2015, 2019)". The publication presents a methodological approach to ensuring gender balance in the water sector assessment using several indicators. In trends indicated as early as the late 1990s, the International Fund for Agricultural Development (IFAD) reports in its document entitled "Rural Poverty Report 2001", that "most of the world's 1.2 billion poor people have two thirds as women, live in water-scare countries, and do not have access to safe and reliable supplies of water for productive and domestics uses". In its 2012 Report on Gender and Water, IFAD advocates "providing water infrastructure other than wells and hand pumps, not only to address health and sanitation issues but also to reduce everyday drudgery of women by providing them more time to participate in other activities". Women often experience more difficulties when publishing. According to the UNESCO Science Report 2021, women are less likely than men to be first or last authors and women authored publications receive fewer citations. This publication aims to encourage young female scientists to prepare scientific articles that address water security issues.

SDG 5 promotes gender equality and empowerment of women and girls. It is befitting that the majority of papers that are published in this publication are led-authored by young female researchers. This publication provides visibility for the scientific contributions by youth and inspires them to become more involved in the co-production and application of relevant knowledge. Today, youth are connected through technology, media and the internet. This knowledge is vital for their survival, keeping up to date with advances, and supporting the wider community. As UNESCO, we are pleased to collaborate with AMCOW and ISC ROA on youth engagement in the water sector programme. UNESCO hereby, congratulates all the authors, editors and the production team on this publication.

IHP-IX has identified five priority areas in the 2022-2029 period to be engaged to promote water security. They are scientific research and innovation; issues related to water education in the Fourth Industrial Revolution; bridging the data-knowledge gap; inclusive water management under conditions of global change; and water governance based on science for mitigation, adaptation and resilience. This special edition moves us all in these strategic directions, all of which are significant with respect to attainment of SDGs and Africa's Agenda 2063: The Africa We Want.

Shamila Nair-Bedouelle,
Assistant Director-General for Natural Sciences,
UNESCO

Toward Achievement of Water Security in Africa within the Sustainable Development Targets of Agenda 2063

Foreword by
the International Science Council (ISC) Regional Office for Africa (ROA) and the African Ministers' Council on Water (AMCOW)

Africa is a "youthful continent" with almost 60% of its population under the age of 25. This makes it essential to involve the youth on critical issues that have a bearing on the continent's future. Among them are those of water security. Water security is one of the Priority Areas of the first-ten years of Africa's Agenda 2063 (2014-2023) which covers women and youth in the aspiration to "An Africa whose development is people-driven, relying on the potential offered by African people who are engaged". In the Agenda, there are six pillars of Africa's development, namely: structural and economic transformation and inclusive growth; science, technology and innovation; people-centered development; environmental sustainability and natural resources management; peace and security; and finance and partnerships.

Several factors, most of which apply to Africa, are significant with respect to water security of any region. The most significant factors are population growth rates, population density, industrialization, growth in irrigation, water demand management and use efficiency, and ecological sustainability requirements. Typically, population growth has the most profound impact. Water stress often overlaps with a high population growth rate and high population density. As in many other global regions, water security issues overlap with those of health and nutrition in Africa. In 2016, the World Health Organization (WHO) estimated that in low-income economies, 4% of the population (about 25.5 million people) suffered from diarrhea, a water-associated disease per data on circumstances of 2015. About 60% of this population were children under the age of 5 years. Furthermore, disabilities in Africa are attributed in larger proportions to; socio-economic disadvantage rather than physical deformity, thereby affecting many more women than men. UN Women estimated in 2017 that in low and middle-income countries, women constitute up to 75% of persons with disabilities. Additionally, African women and girls are primarily responsible for travelling several kilometres each day to fetch water for house chores, including cooking and catering for the hygiene of children. Using data for 2016, WHO/UNICEF estimated in 2018 that only 58 out of 92 countries studied globally, had more than 75% coverage of drinking water in schools. In Sub Saharan Africa and Small Island Developing Countries, about 50% and more than 30% of schools, respectively, had no drinking water services. These statistics become very significant in the era of communicable pandemics like COVID-19 that requires frequent hand washing and related personal hygiene measures. Provision of affordable access to water services in slum areas of African cities is a challenge because such services are provided informally by water hawkers. According to UN-Habitat, Africa's urban population, which is currently about 1 billion people, is expected to rise by about 50% by 2030.

If Africa is to address these challenges and attain the objectives that are enshrined in both Agenda 2030 and 2063, it is essential that the efforts, engagement, and scientific contributions of youth be channeled to address water-related challenges on the continent. They should also be supported, made visible and recognized. The youth are by far beyond beneficiaries, they are the most important participants, partners, and drivers for the implementation of the SDGs 2030 and Agenda 2063. It is important that all stakeholders partner in supporting and tapping into the energy as well as experience of youth and young professionals in Africa while inspiring them to become more involved in the co-design, co-production and co-implementation of high-quality, integrated (inter- and trans-disciplinary), and solutions-oriented research on water security and application of knowledge. This book is an outgrowth of a partnership and collaborative efforts between UNESCO, the African Ministers' Council on Water (AMCOW) and the International Science Council (ISC) Regional Office for Africa (ROA).

AMCOW has embarked on many initiatives that revolves around the African Water Vision 2025 themed as "Ensuring Equitable and Sustainable Use of Water for Socio-economic Development". The shared vision is "an Africa where there is an equitable and sustainable use and management of water resources for poverty alleviation, socio-economic development, regional cooperation and the environment". The framework targeted for achievement of the vision comprises 1. Strengthening governance of water resources; 2. Improving water wisdom; 3. Meeting urgent water needs; and 4. Strengthening the financial base for the desired water future. Toward the full implementation of activities driven by this vision, AMCOW holds in high esteem its cooperation and partnership with all countries and organizations in Africa and beyond. ISC ROA on the other hand strives to convene the scientific expertise and resources needed to lead efforts on catalysis, incubation, and coordination of impactful international action on issues of major scientific and public importance, exemplified by water security. One of its four domains of impact is 'The 2030 Agenda for Sustainable Development' that seeks to improve the understanding of the globally coupled natural, physical, and social systems of our planet, and the identification of tractable pathways for sustainable and equitable development. To address these issues on the continent, ISC ROA identified four priority areas for Africa: sustainable energy; natural and human-induced hazards and disasters; health and human wellbeing; and global environmental change (including climate change and adaptation). The present collaboration between the ISC ROA, AMCOW, and the UNESCO Regional Office for Eastern Africa in producing this publication on Youth and Water Security in Africa further underpins the aforementioned operational objectives.

This book seeks to improve the visibility of the research of young scientists in Africa and position them to design solutions to address the challenges that Africa faces in the water security sector. It is hereby, believed that their contributions will increase the relevance and impact of scientific input from the young professionals as well as catalyze evidence-informed decision-making at all levels. This is a desirable outcome of continental/global policy processes related to the 2030 Agenda, especially on water issues. This also highlights the youth's role in accelerating the implementation of SDGs 2030 and Agenda 2063 through support for interactions-based research and programming at all levels of governance.

Essentially, water security is a cross-cutting issue in terms of various targets of international development agendas as well as their supporting knowledge systems. The significance of water in sustainable development is further emphasized by the establishment and operationalization of coordinating institutions and continental initiatives in many global regions. The African Ministers' Council on Water (AMCOW) continues to exemplify this action, which is why the UNESCO and ISC are hereby collaborating, in addition to the European Water Framework Directive, among others.

Heide Hackmann,
Chief Executive Officer,
International Science Council

Rashid Mbaziira,
Executive Secretary,
African Ministers' Council on Water

Coverage of Youth and Water Security in Africa

Preface/Editorial

In an interconnected world, challenges and opportunities translate across national and regional boundaries. This is particularly true for environmental phenomena in general, and hydrological circumstances in particular. Water security is a critical issue that cuts across several sectors of sustainable development: energy, food security, health, sanitation and industrial production. By her physiography and location across many climatic zones, Africa is featured by many intricate factors that affect water security. Superimposed on these factors are high population growth rates and related distribution of cities and other centres of high demand for water. Cultural and gender factors also play a role as discussed in some of the papers presented in this publication on Youth and Water Security in Africa. Both natural and anthropogenic threats to the sustainability of water resources in Africa have long been recognized as expressed in the Africa Water Vision for 2025. Broadly categorized, the natural threats are: 1. Extreme spatial and temporal variability of climate and rainfall which has now been exacerbated by global climate change; 2. Overlays of water basins over many countries with the resulting conflicts; and 3. Growing levels of water scarcity, some of which are attributable to shrinking of water bodies and desertification. The primary anthropogenic threats are: 1. Inappropriate and inadequate water governance structures, some of which do not adequately engage women and youth; 2. Environmental pollution and deforestation which degrade water resources; 3. Inadequate investment in resource assessment, protection and development; and 4. Unsustainable financing of investments in water supply and sanitation.

It should be noted that the Water Vision for Africa 2025 appropriately relates to the World Water Vision 2025 which the First Water Forum that was held in Marrakech, Morocco in March 1997, mandated the World Water Council to develop. The overlap of water security promotion approaches, techniques and models in both the technical and policy realms across many jurisdictions, is a defensible rationale for collaboration among many global and regional organizations as exemplified by the joint auspices of this publication. This enables broadening of perspectives, sharing of experience, consideration of a wider range of options, and combining of resources to address water security in Africa in ways that can also be beneficial to other parts of the world. Along with the cultivation of knowledge, this is the context for the development of this special edition collaboratively by UNESCO, the African Ministers' Council on Water (AMCOW) and the International Science Council (ISC) Regional Office for Africa (ROA).

Sustainable Development Goal 6 is an expression of the aspiration to "ensure access to water and sanitation to all", a target intended for attainment by 2030. The Africa Agenda 2063 which is a 50-year strategic framework for guidance of African sustainable development, also targets as its aspiration No. 10, "An Africa whose development is people-driven, relying on the potential of African people, especially its women and youth, and caring for children." Aspiration No. 1 targets "A prosperous Africa based on inclusive growth and sustainable development". The targets of SDGs and Agenda 2063 quoted above, promote the inclusion of youth and women as contributors and beneficiaries of sustainable development initiatives. Progress has been slow in this respect in the water security sector globally, and particularly, in Africa. As summarized by the UN Department of Economic and Social Affairs in 2020, the average global score on the implementation of integrated water resources management systems that meet standards on policies, institutions, management instruments, inclusiveness and financial requirements was 49 out of 100 and ranged from 50% to 70% in Sub-Saharan Africa, Eastern and South-eastern Asia, Northern Africa and Western Asia. It is important to encourage youth and women to serve as analysts and innovators in the water sector. The United Nations defines youth as persons aged 15-24 years but the target age range for researchers who are engaged as the primary authors of manuscripts published herein, is 25-35 years. Researchers of both age ranges were encouraged to submit manuscripts.

Gender development indices are often found to correlate positively with water resources governance systems because of the critical roles that women play in domestic water supply and management. The Dublin Principles of 1992 mandate the placement of women in the central role of water and environmental management. This is justified by the practical and culturally induced activities of women in the provision of water for livelihood activities across the sectors of household nutrition, hygiene, childcare, etc., especially, in developing regions. Generally, collection, storage and management of water are roles that girls and women play in developing countries. They often trek for long distances to fetch water for various domestic chores. Furthermore, they often play the role of caregiver during the treatment of family members who are struck by waterborne ailments. Thus, gender-responsive programmes and engagement of both women and youth groups at the analytical, planning, design and implementation stages of water security programmes are necessarily for broadening of the utility of such programmes and beneficiation of knowledge from these groups.

Concerning knowledge creation and utilization, the United Nations, through the 2019 UN World Water Development Report, recognizes that “scientific research, development and innovation are essential to support informed decision-making”. This requires the design and use of research methods that enable the acquisition of planning data that are disaggregated in terms of gender, income, ethnicity, social status and other parameters, for understanding of circumstances and design of mitigation and adaptation systems. Pleasantly, it is worthy to note that virtually all the primary authors of manuscripts in this publication belong to the youth age range, and that more than half of them are women. A more systematic scheme for designing projects and scaling their gender-responsiveness been published by the World Water Assessment Programme (WWAP) as the “Water and Gender Toolkit for Sex-Disaggregated Data”. The 2019 edition of the toolkit which was developed by UNESCO, provides the water and gender indicators and all the necessary guidelines for their application as well as a large set of questionnaires for implementation of gender and water assessments. This WWAP publication along with others, including a recently published case study on the application of WWAP indicators in Argentina, can be downloaded from the UNESCO website.

UNESCO in partnership with AMCOW and ISC ROA, has developed this publication to achieve the following objectives:

- Improve the visibility of the scientific contributions of youth that address water related challenges in Africa;
- Contribute to the advance of and address knowledge gaps on water security issues in Africa with a focus on the experience of youth and young professionals;
- Encourage the use of knowledge generated by youth to improve policy processes and governance in the water sector and;
- To inspire youth to become more involved in the co-production and application of knowledge.

Submissions were requested from youth and young researchers worldwide, as authors or co-authors of articles that would address at least, one of the sub-themes of the call for papers with a focus on Africa: Water-related Disasters and Hydrological Changes; Groundwater in a Changing Environment; Addressing Water Scarcity and Quality; Water and Human Settlements of the Future; Ecohydrology, Engineering Harmony for a Sustainable World, and Water Education, a Key to Water Security. Young researchers and youth partnered with experts to prepare and submit manuscripts. The papers published herein, are those that survived a four-stage review process that involved assessments of their originality; analytical content; relevance to water security in Africa; language adequacy and gender sensitivity; appropriateness and adequacy of illustrations; and consideration of the state-of-knowledge through citations and referencing. This publication is a contribution by the three collaborating organizations and the authors, co-authors and editors to capacity building of the future generation of leaders who will ensure the sustainability of Africa's water sector.

Hilary I. Inyang,
Editor-in-Chief,
Distinguished Professor and President,
Global Institute for Sustainable Development, Advanced Analysis and Design (GISDAAD)
Charlotte, NC, USA and Abuja, Nigeria

Acknowledgments

In order to continue to invest in and build capacity of a future generation of leaders who will ensure the sustainability of Africa's water sector, UNESCO's Division of Water Sciences partnered with the International Science Council Regional Office for Africa (ISC ROA), and the African Ministers' Council on Water (AMCOW) to issue a Call for Extended Abstracts on Youth and Water Security in Africa in 2020. The authors, whose submissions fit the scope of the planned publication, were invited to submit full manuscripts, which were then subjected to multi-staged reviews by a diverse team of experts. Conference calls and a writing workshop were organized to support authors and their co-authors on scientific writing to improve the chances of their full manuscripts satisfying quality requirements of the publication in terms of originality, technical content, and grammar. The final papers that are published herein have gone through processes that involved many policy-makers, experts and logistics support personnel. Their contributions are hereby acknowledged and applauded.

As collaborating organizations, we pay respect to Shamila Nair-Bedouelle, the Assistant Director-General of UNESCO for Natural Sciences; Gabriela Ramos, the Assistant Director-General of UNESCO for Social and Human Sciences; Heide Hackmann, the Chief Executive Officer of ISC; and Ann Therese Ndong-Jatta, the former Director of UNESCO Regional Office for Eastern Africa, for support of this initiative as evident in their contributions to the online writers' workshop that was held on October 30, 2020 in connection with this publication. We also thank Sheillah Simiyu of the ISC Leading Integrated Research for Agenda 2030 in Africa Initiative; Nomasomi Gasa, Project Coordinator, ISC ROA; and Margaret Sima Kironde, Research Intern, Africa Water Association; and all the participants of the workshop for their contribution. Special thanks go to Hilary I. Inyang, the Technical Editor-in-Chief, Distinguished Professor and President of the Global Institute for Sustainable Development, Advanced Analysis and Design (GISDAAD), and former Chair of the Africa Science Plans under ISC ROA; and the diverse editorial team of this publication, comprising, Giuseppe Arduino (UNESCO), Samuel Partey (UNESCO), Nicole Webley (UNESCO), Xinhong Li (UNESCO), Anne Lilande (UNESCO), Daniel Nyanganyura (ISC ROA), Richard L.K. Glover (ISC ROA), Miguel Gonzalez (GISDAAD), James Mbat (GISDAAD), Paul Orengoh (AMCOW), Emmanuel Uguru (AMCOW), Comfort Kanshio (AMCOW), Moshood Tijani (AMCOW), Azzika Tanko (AMCOW), Obinna Anah (AMCOW). We recognise the internal reviewer Jorge Ellis (UNESCO) and the final reviewers: Aniefon Sam Akpabio, Retired Director at the Nigerian National Regulations Enforcement Agency, Abuja, Nigeria; Jy S. Wu, Professor of Civil and Environmental Engineering, University of North Carolina, Charlotte, NC, USA; Marisol Osman, Researcher, Universidad de Buenos Aires, Argentina; Helen Barber-James, Museum Natural Scientist, Albany Museum, Makhanda, Grahamstown, South Africa; and Adanech Yared Jillo, Director-General, Basins Development Authority, Ministry of Water, Irrigation and Energy, Addis Ababa, Ethiopia.

Finally, the authors and co-authors of manuscripts that are included in this publication are congratulated and applauded for their research work and persistence in subjecting their written research work to many stages of review and revisions. They who represent youth from various African countries and their collaborators from other continents, are contributors to the achievement of both Africa Agenda 2063 and Sustainable Development Goals of the 2030 Agenda.

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A. WATER-RELATED DISASTERS AND HYDROLOGICAL CHANGES

Flood Risk Estimation of Cross River Watershed (Cameroon)/GIS Based Morphometric Analysis and Geospatial Techniques

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Abstract

Floods are among the most devastating natural hazards which cause the largest number of deaths and property damage. As they are sudden and highly unpredictable following brief spells of heavy rain, floods influence many aspects of human life. The present work used two methods to estimate the flood risk of 6 sub-watersheds (SW) delineated on the Cross River watershed (south west of Cameroon): the morphometric ranking method and the El-Shamy's approach. The study reveals that systematic analysis of morphometric parameters using Geographical Information Systems (GIS) and Geospatial Techniques (GT) can provide information to understand SW flood hazards. The results of flood risk estimation based on morphometric ranking method, shows that the total rank values for the 6 SW can be grouped into two categories of flood susceptibility : medium (41- 43) and high (44 - 47). SW_01, SW_02 represent high flood susceptibility, while SW_03, SW_04, SW_05, SW_06 represent medium susceptibility. El-Shamy's approach, shows that for the (Rb vs Dd) relationship SW_01, SW_02 are under the high flood susceptibility, whereas SW_04 are under the medium flood susceptibility and SW_03, SW_05, SW_06 are under the low flood susceptibility. However the (Rb vs. Fs) relationship shows that SW_01, SW_02 represent high flood susceptibility, while SW_04, SW_06 represent medium flood susceptibility and SW_03, SW_05 represent low flood susceptibility. The results shows that SW_01, SW_02, SW_04 and SW_06 are most susceptible to flood, therefore they must be constantly monitored in order to prevent flooding and to minimize destructive flood effects in the whole Cross River watershed.

Keywords: Flood risk estimation ; GIS ; Morphometric analysis ; Geospatial techniques ; Ranking method ; El-Shamy's approach.

1. Introduction

Freshwater is essential to inclusive, equitable and sustainable development as indirectly implied in all the Sustainable Develoment Goals (SGDs), not only Goal 6 (SDG 6). By focusing on the quality, availability and management of freshwater resources, SDG 6 *«Ensure availability* *and sustainable management of water and sanitation for all»* addresses the sustainability and confirms in the global political agenda, the importance of water and sanitation (SIWI, 2019). It also recognizes that economic prosperity and social development are closely linked to sustainable management and sharing of freshwater resources and ecosystems (UN Environment Programme, 2020) as mentioned in target 6.5 *«By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate»*. Considering that ongoing changes to the hydrological cycle increase frequency and intensity of extreme water events, for the past five years, the annual World Economic Forum Global Risks Report has included water crises in their top list of global risks. Closer examination of this list shows that nine of the top ten risks are closely linked to water (SIWI, 2019), and floods are in the top 5. Floods are among the most devastating natural hazards which cause largest amount of deaths and property damage. As they are sudden and highly unpre-dictable following brief spells of heavy rain, floods influence many aspects of human life. Due to their destructive effects and the significant expenses of mitigation efforts, floods are considered as extreme hydrological phenomena (Farhan and Anaba, 2016 ; Ozdemir and Bird, 2009 ; CEOS 2003).

Since the 21st century, integration of GIS to create flood hazard maps has been upgraded and widespread, as a result of the availability of spatial data and GIS softwares (El Maghraby and al., 2014 ; Zerger and Smith, 2003). The protection from flood hazard requires mapping of flood areas, which is very important for catchment management. The application of GIS and GT are powerful tools for the assessment of risk and management of flood hazards. These techniques are used to extract new drainage network with more details to prepare natural hazard maps which may help decision makers and planners to put suitable solutions to reduce the impact of these hazards (Abdel-Lattif and Sherief, 2012). The drainage morphometry research should be included as an essential component of hydrologic studies to increase understanding of flood hazard, and to determine appropriate mitigation mesures (Ozdemir and Bird, 2009). By using statistical correlation to determine areas under varying flood conditions, GIS and GT can show interrelation among the morphometric parameters (Abdel-Lattif and Sherief, 2012).

Morphometric analysis for flood risk estimation has led to a large number of studies to identify the relationship between basin morphometry and flood impact (Patton, 1988). Moreover, morphometric properties of drainage networks have been used to predict hydromorphic processes such as flood peaks, sediment yields and erosion rates (Farhan and Anaba, 2016; Gardiner, 1990). At the present, delineation of drainage basins and calculation of morphometric parameters can be achieved using remote sensing tools, Digital Elevation Models (DEMs), GIS softwares, and mathematical formulas elaborated by Strahler (1952; 1957; 1964). Many studies have used GIS based morphometric analysis for flood risk assessment (Farhan and Anaba, 2016; Elmoustafa and Mohamed, 2013; Youssef and al., 2011; El-Shamy 1992). The present work aim to assess the flood risk of the Cross-River watershed, using GIS based morphometric analysis and GT. Specifically, the objectives of this research are to: (1) delineate the drainage network and sub-watersheds (SW) of Cross River basin; (2) conduct the morphometric analysis for the six sub-watersheds delineated; (3) generate flood hazard maps based on two methods (morphometric ranking method and the El-Shamy's approach), to demarcate the SW with low, medium and high flood susceptibility.

2. Materials and Methods

2.1 Study area

The Cross River watershed (Figure 1) is a coastal watershed with only the upstream portion found within Cameroonian territory. It is a transboundary watershed which flows through Calabar (Nigeria) estuary in the Gulf of Guinea, after having drained approximately 75.000 km2 of basin area essentially nigerian. Entirely covered by forest, the basin is particularly watered by monsoon which penetrate widely on South West - North East axis at north of the Mount Cameroon. The geology is made up of a precambrian basement with volcanic series, together with cretaceous deposits of the Gulf of Mamfe in the east and south. The river is fed by four main tributaries with only 25 km upstream from Mamfe : the Mbu and the Mfi coming from the south, the Mainyu from the Bamboutos Caldera in the east considered as the major branch and the Me from the North (Olivry, 1986).

2.2. Data, tools and methodology

In the present study, different types of data and tools were used including : (1) Shuttle Radar Topography Mission (SRTM) data with 90 m resolution, projected to UTM 33 N ; (2) Topographic maps of the study area at 1/50000 to validate the drainage network extracted from SRTM ; (3) Terrain pre-processing of Arc Hydro tool of ArcGIS was used in the processing and creation of the studied watershed and SW. The different steps in the extraction process is present in detail in (Yusmah and Rodziah, 2014) ; (4) ArcGis-morphometric toolbox developed by Beg (2015) integrated into the ArcGIS software was used in the study for the automatic calculation of the main parameters of the morphometric analysis. These manipulations attempts to map the whole Cross River watershed and provides the complete drainage network map having 5 tributaries (Figure 1). The data were imported and processed into ArcGIS 10.5 platform for subsequent data preparation and morphometric analysis after being clipped to the study area extent. Calculations were done in the projected Universal Transverse Mercator Zone 33 N system with the WGS-84 datum (EPSG : 32633).

Space technologies are used in this work to support the full disaster management cycle (flood susceptibility) from the early warning to the early response as proposed by the United Nations Platform for Space-based Information for Disaster Management and Emergency Responses (UN-SPIDER).The two methods used in this research made use of twenty morphometric parameters of interest for flood risk estimation as presented and defined in Table 1 (see also Table 2).

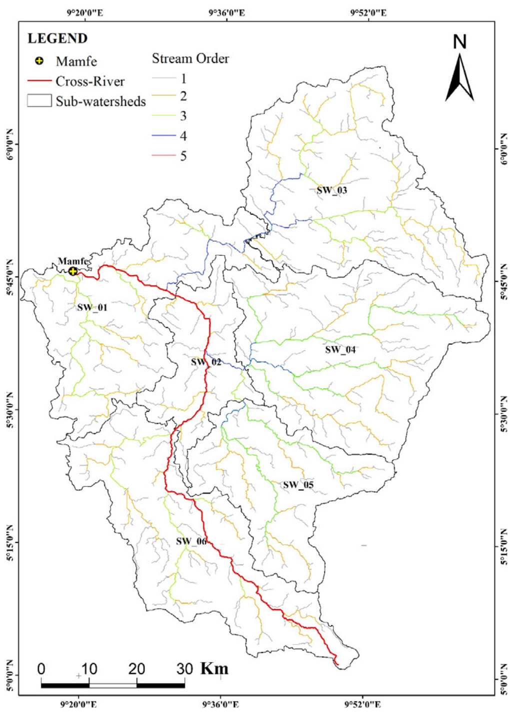

Figure 1. Stream order of the six Sub-watersheds of the Cross-River basin

Table 1. Formulas for morphometric parameters calculation

	Morphometric parameters	Formula	Author
1	Stream order (u)	Hierarchical rank	Strahler, 1964
2	Number of stream order (Nu)	$Nu=N1+N2+\ldots+Nn$	Horton, 1945
3	Length of stream orders (Lu) (ms)	$Lu=L1+L2+\ldots+Ln$	Horton, 1945 ; Strahler, 1964
4	Bifurcation ratio (Rb)	$Rb=Nu/Nu+1$	Schumm, 1956 ; Strahler, 1964
5	Basin area (A) (kms^2)	A=Projected area enclosed by basin boundary	Schumm, 1956
6	Basin perimeter (P) (kms)	P=Length of horizontal projection of basin water divide	Schumm, 1956
7	Basin length (Lb) (kms)	$Lb=1.312 \times A^{0.568}$	Nooka et al., 2005
8	Shape factor (Sf)	$Sf= Lb^2/A$	Horton, 1932
9	Compactness coefficient (Cc)	$Cc=0.2812 \times P/A^{0.5}$	Horton, 1945
10	Circularity ratio (Rc)	$Rc=4 \times \pi \times A/P^2$	Miller, 1953
11	Elongation ratio (Re)	$Re=1.128 \times \sqrt{A}/Lb$	Schumm, 1956 ; Strahler, 1952
12	Drainage density (Dd) (km/km^2)	$Dd=Lu/A$	Horton, 1932 ; Strahler, 1964
13	Stream frequency (Fs) ($number/km^2$)	$Fs=Nu/A$	Horton, 1932
14	Lenght of overland flow (Lo) (kms)	$Lo=1/2 \times Dd$	Horton, 1945
15	Total relief (H) (m)	$H= h - h^1$, where h = maximum height (m) h1 = minimum height (m)	Strahler, 1952
16	Relief ratio (Rr)	$Rr=H/Lb$	Schumm, 1956
17	Ruggedness number (Rn)	$Rn=Dd \times (H/1000)$	Strahler, 1964
18	Hypsometric integral (Hi)	$Hi=(H^{-} - H)/(H - h)$, where H^{-} = weighted mean elevation	Strahler, 1952
19	Basin slope degrees (SlopD)	$SlopD=(H/Lb) \times 60$	Farhan and Anaba, 2016
20	Geometry number (Gn)	$Gn=(H \times Dd)/Slope$	Strahler, 1958

Table 2. Morphometric characteristics of the Cross River Sub-Watersheds

Morphometric Parameters	Sub-Watersheds					
	SW_01	SW_02	SW_03	SW_04	SW_05	SW_06
A (km^2)	1129.241	522.517	1445.880	1452.879	817.521	1239.849
P (km)	287.762	181.583	231.607	201.346	175.487	252.649
Lb (km)	71.691	46.524	82.303	82.423	59.604	75.474
H (m)	1220	1186	2431	2601	1724	2184
Rr	0.017	0.025	0.030	0.032	0.029	0.029
SlopD	1.021	1.530	1.772	1.893	1.735	1.736
Rn	0.466	0.463	0.890	0.938	0.619	0.854
Hi	0.161	0.124	0.397	0.212	0.192	0.173
Gn	0.456	0.302	0.502	0.496	0.357	0.492
U	5	5	5	4	4	3
Nu	119	76	131	125	80	121
Lu (km)	431.256	203.915	529.218	523.843	293.556	485.066

Morphometric Parameters	Sub-Watersheds					
	SW_01	SW_02	SW_03	SW_04	SW_05	SW_06
Rb	5.583	3.594	8.104	21.000	9.667	14.0
Dd (Km/km^2)	0.382	0.390	0.366	0.361	0.359	0.391
Fs (Number/km^2)	0.105	0.145	0.091	0.086	0.098	0.098
Lo (km)	1.309	1.281	1.366	1.387	1.392	1.278
Re	0.529	0.554	0.521	0.522	0.541	0.526
Rc	0.171	0.199	0.339	0.450	0.334	0.244
Sf	4.551	4.142	4.685	4.676	4.346	4.594
Cc	2.433	2.257	1.730	1.501	1.744	2.038

2.3. Flood risk estimation methods

Using the GIS environment, the morphometric analysis of the Cross River watershed and the six SW have been carried out. The morphometric parameters necessary for the flood risk estimation were calculated for the six SW delineated using ArcGIS software and the mathematical formulas elaborated by Strahler (1952 ; 1957 ; 1964).

2.3.1. Morpometric ranking method

The morphometric ranking method (Table 3, Table 4 and Figure 2) used seventeen parameters where three are related to drainage network, six of these parameters describe the basin geometry, three of them depict the drainage texture and five are related to relief charactelitics. The seventeen parameters are divided into two groups : Group (I) presents ten parametes having direct proportion to risk degree, the higher the parameter value, the higher the risk degree. These are basin area (*A*), basin total relief (*H*), relief ration (*Rr*), basin slope degree (SlopD), stream order (*U*), number of stream order (*Nu*), Length of stream orders (*Lu*), drainage density (*Dd*), stream frequency (*Fs*) and circularity ratio (*Rc*). Group (*II*) presents seven parameters inversely proportional to the risk, the higher the parameter value, the lower the risk. These parameters are : ruggedness number (*Rn*), hypsometric integral (*Hi*), geometry number (*Gn*), length of overland flow (*Lo*), Elongation ratio (*Re*), shape factor (*Sf*) and compactness coefficient (*Cc*).

The equation applied for the morphometric parameters is the (Max-Min)/5 which allow these parameters to be classified into five rank categories. Rank 1 refers to the low risk while rank 5 refers to the high risk. In order to obtain a morphometric number for each SW, the morphometric parameters values of each SW were summed and normalized. The SW were then classified in terms of their risk of flood occurrence based on these summated numbers.

Table 3. Ranks score for different morphometric parameters, total score value and flooding susceptibility (Fl. Susc.)

Parameters	SW_01	SW_02	SW_03	SW_04	SW_05	SW_06
A (*)	5	4	4	4	4	4
H (*)	5	5	5	5	5	5
Rr (*)	1	1	1	1	1	1
SlopD (*)	1	2	1	1	1	1
U (*)	2	2	1	1	1	1
Nu (*)	3	3	2	2	2	2
Lu (*)	4	3	3	3	3	3
Dd (*)	1	1	1	1	1	1
Fs (*)	1	1	1	1	1	1

Parameters	SW_01	SW_02	SW_03	SW_04	SW_05	SW_06
Rc (*)	1	1	1	1	1	1
Rn (+)	4	4	3	3	3	3
Hi (+)	5	5	5	5	5	5
Gn (+)	4	5	4	4	5	4
Lo (+)	3	3	2	2	2	2
Re (+)	1	4	4	4	4	4
Sf (+)	1	1	1	1	1	1
Cc (+)	2	2	2	2	2	2
TOTAL	44	47	41	41	42	41
Fl. Susc.	High	High	Medium	Medium	Medium	Medium

(*) Group I parameters : having a direct proportion to the flood risk degree.
(+) Group II parameters : having an inverse proportion to the flood risk degree.

2.3.2 El Shamy's approach

El-Shamy's approach (Table 4, Figures 3, (1) and (2)) is a simple morphometric method to estimate the flood risk level and the hazard degree for each SW using two approaches : (1) bifurcation ratio versus drainage density *«Rb vs. Dd»* approach (Table 4, Figure 4 and Figure 6) and (2) bifurcation ratio versus stream frequency *«Rb vs. Fs»* aproach (Table 4, Figure 5 and Figure 7). Drainage density (*Dd*) refers to runoff potential, infiltration capacity of surface materials, topographic dissection, climate and land cover of the watershed. Hence, low values of (*Dd*) indicate optimal conditions for infiltration, thus decreasing runoff potential while high stream frequency (*Fs*) represents low infiltration capacity, poor vegetation cover, impermeable sub-surface materials, high relief, hence increasing runoff potential. This relationship when applied separately to each SW provide reasonable information on the flood risk estimation and recharge potential (Farhan and Anaba, 2016).

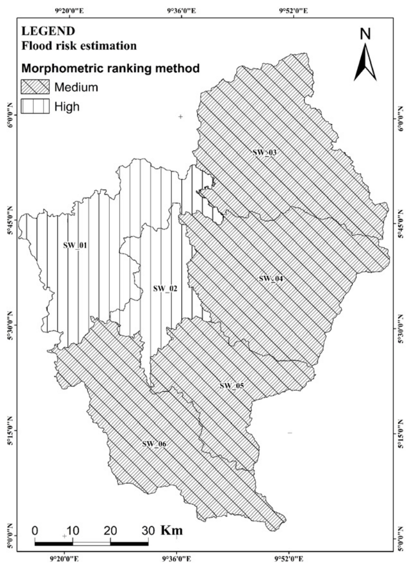

Figure 2. Flood risk estimation: Morphometric ranking method

Table 4. Classification of sub-watersheds flooding susceptibility based on the two methods used in floods assessment

Flood assessment method	Sub-watershed of high flood susceptibility	Sub-watershed of medium flood susceptibility	Sub-watershed of low flood susceptibility
Morphometric ranking method	SW_01* ; SW_02*	SW_03 ; SW_04* ; SW_05 ; SW_06*	/
El-Shamy's approach (Rb vs. Dd)	SW_01* ; SW_02*	SW_04*+	SW_03+ ; SW_05+ ; SW_06
El-Shamy's approach (Rb vs. Fs)	SW_01* ; SW_02*	SW_04*+ ; SW_06*	SW_03+ ; SW_05+

**Corelation between sub-watersheds under the two methods of flood risk assessment.*
+Corelation between sub-watersheds under the two El-Shamy's approaches (Rb vs. Dd and (Rb vs. Fs)

Plotting the results of (*Dd vs Rb*) and (*Fs vs Rb*), gives two curves which divides the area into three fields :

- Field A refers to SW with high possibility for floods, and low recharge potential.
- Field B represents SW with medium possibility for floods and medium potential for groundwater recharge.
- Field C indicates SW with low possibility for floods and high recharge potential.

If a sub-watershed has two different fields, then the appropriate classification plot has been selected. Superimposing the flood risk map produced according to the morphometric ranking method with the flood risk map generated through El-Shamy's approach (Figures 6 and 7), allows to identify: (i) the common SW falling under each category of flood risk, (ii) determine the most risky SW in terms of flooding, and (iii) recognize the SW most vulnerable to flooding and flood damage in the future.

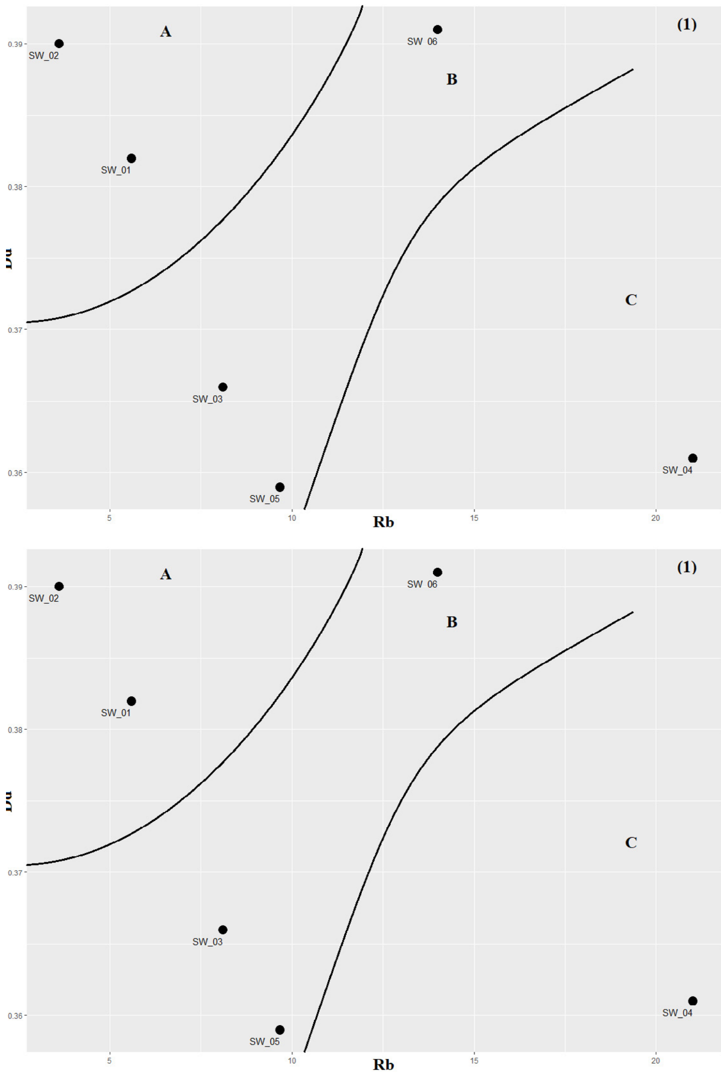

Figure 3. Flood risk estimation : El-Shamy's approaches (1) Rb vs. Dd and (2) Rb vs. Fs (A = High flood, B = Medium flood, C = Low flood)

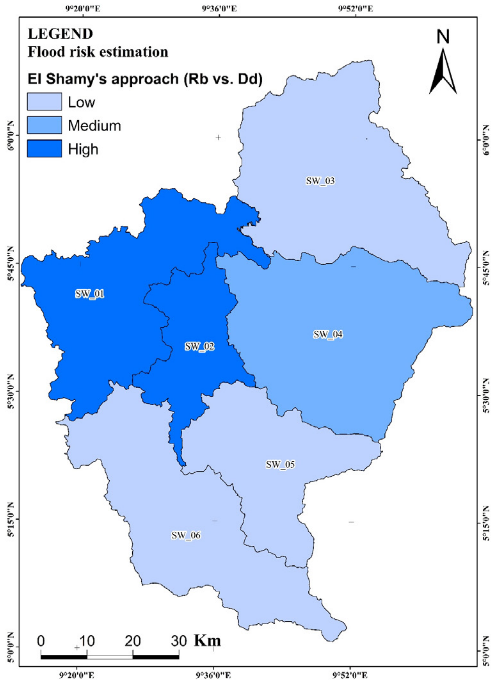

Figure 4. Flood risk estimation : El-Shamy's approach (Rb vs. Dd)

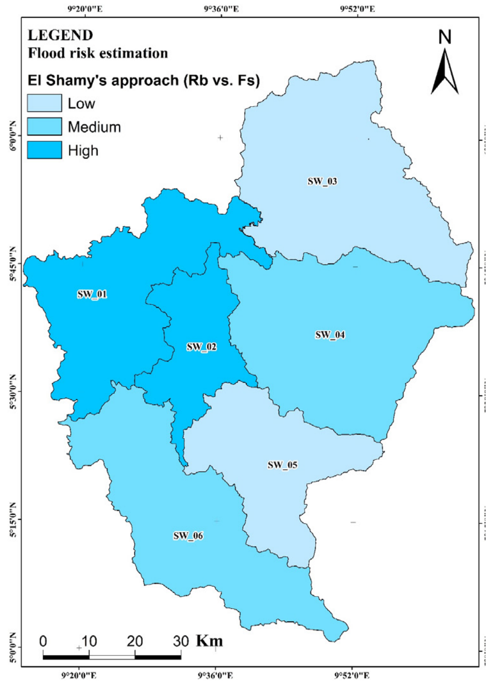

Figure 5. Flood risk estimation : El-Shamy's approach (Rb vs. Fs)

3. Results and discussion

The results obtained based on the two methods (morphometric ranking method, El Shamy's approach) used for the flood risk estimation of the Cross River watershed using GIS and GT, has made it possible to delineate the SW of the Cross River basin, which might be affected by floods of low, medium and high susceptibility. The results provide tools to decision makers to aid in the understanding of flood hazard distribution within the Cross River watershed. Such information in tend serves to identify flood prone areas by maping and to formulate flood protection in order to minimize destructive flood effects.

3.1 Flood risk estimation : Morphometric ranking method

The morphometric ranking method for the estimation of the flood risk susceptibility of the six SW delineated on the Cross River watershed, was applied for the required morphometric analysis. Table 3 present the results of this method expressing the ranking score for the seventeen morphometric parameters, with the total score value for each SW. These total score values were grouped into into two categories of flooding susceptibility, in order to generate flood risk map usisng GIS.

- High flooding susceptibility (44 – 47) ;
- Medium flooding susceptibility (41 – 43).

Regarding the six SW delineated on the Cross river basin, SW_01 and SW_02 (33.3 % of the total) represent the category of high flooding susceptibility rank. While SW_03 ; SW_04 ; SW_05 ; SW_06 (66.7 % of the total) represent the group of medium susceptibility rank (Table 3 and Figure 2). According to the results obtained with the morphometric ranking method, half of the Cross River SW are expected to suffer from high flooding susceptibility. These results also indicate that the main hazardous and threatening SW are those located near the Atlantic ocean.

3.2 Flood risk estimation : El Shamy's approach

Two methods the (Rb vs. Dd) and (Rb vs. Fs) relationships were used in this approach. In general, the value of (Rb) varies between 3.0 and 5.0 for a watershed where the influence of geological structures on the drainage network is negligible (Schumm, 1956). The (*Rb*) of the six SW range between 3.594 and 21.0, with a mean value of 10.324 for the entire Cross river watershed, this indicates a strong structural control on the drainage network of almost all the SW. In order to determine SW with low, medium and high flooding susceptibility based on the two relationships, vulnerable and expose SW were demarcated. Based on the (*Rb vs. Dd*) relationship, the SW_01 and SW_02 (33.3 % of the total) characterized the high flooding susceptibility, whereas SW_04 (16.7 %) represent the medium susceptibility and SW_03, SW_05, SW_06 (50 %) are under the low flooding susceptibility (Table 4, Figure 3.1 and Figure 4). Similarly, on the (*Rb vs. Fs*) relationship, SW_01 and SW_02 are under the high susceptibility (33.3 %) ; while SW_04, SW_06 (33.3 %) are in the medium susceptibilty category and, SW_03, SW_05 (33.3 %) are considered as low flooding susceptibility (Table 4, Figure 3.2 and Figure 5).

Comparison of maps produced using the two methods reveals that two SW are ranked under high flooding susceptibility (SW_01 and SW_02) ; two others are also ranked under medium flooding susceptibility (SW_04 for the two methods used and SW_6 for the *Rb vs. Fs* approach). The results obtained shows that SW_01, SW_02, SW_04 and SW_06 sub-watersheds are most susceptible on flood, therefore they must be constantly monitored in order to prevent flooding and to minimize destructive flood effects in the whole Cross-River watershed (Table 4, Figure 6 and Figure 7).

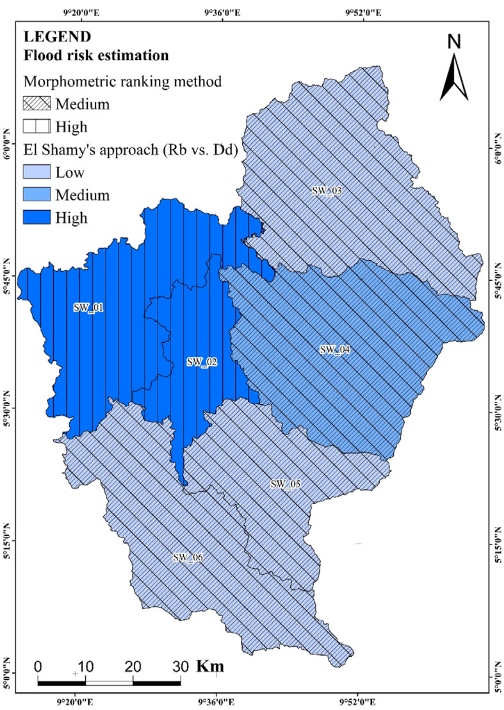

Figure 6. Flood risk estimation: Morphometric ranking method and El-Shamy's approach (Rb vs. Dd)

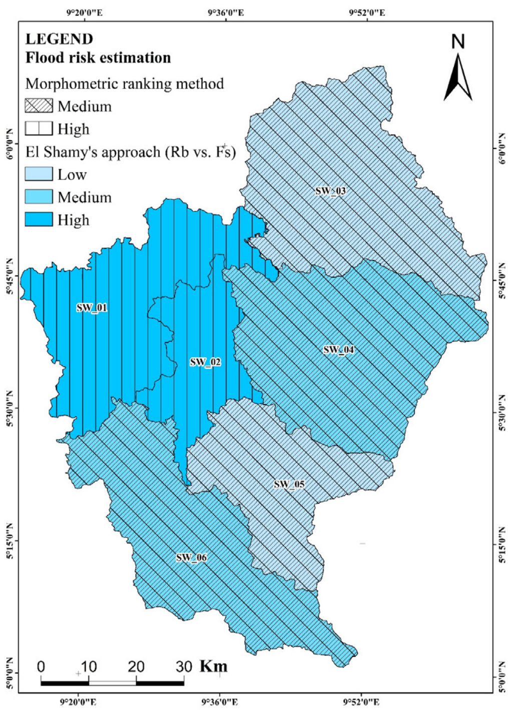

Figure 7. Flood risk estimation: Morphometric ranking and method and El-Shamy's approach (Rb vs. Fs)

4. Conclusion

In the present study, GIS based morphometric analysis and GT were used to evaluate flood risk, to compile flood hazard maps within the Cross-River watershed. The results obtained based on two methods, has made it possible to delineate the subwatersheds of Cross-River basin which might be affected by floods of low, medium and high susceptibility. The information will provide tools to aid decision makers to unterstanding flood harzard distribution within the Cross-River watershed in order to: (1) identify flood prone areas by maping ; (2) formulate flood protection measures in order to minimize destructive flood effects. Flood risk estimation based on morphometric ranking method, shows that the total rank values for the 6 SW were grouped into two categories of flooding susceptibility : medium (41- 43) and high (44 - 47) susceptibility. Sub-watersheds SW_01 and SW_02 represent the category of high flooding susceptibility, while SW_03 ; SW_04 ; SW_05 ; SW_06 represent the group of medium susceptibility. Based on El-Shamy's approach, (Rb vs. Dd) relationship showed that SW_01 and SW_02 characterized the high flooding susceptibility, whereas SW_04 represent the medium susceptibility and SW_03, SW_05, SW_06 are under the low flooding susceptibility. Similarly, the (Rb vs. Fs) relationship gives SW_01 and SW_02 under the high susceptibility ; while SW_04, SW_06 are in the medium susceptibilty and SW_03, SW_05 falls under low flood susceptibility. Comparing the maps produced using the two methods (morphometric ranking method and El Shamy's approach) reveal that two SW are ranked under high flood susceptibility (SW_01 and SW_02), two others are ranked under medium flood susceptibility (SW_04 for the two methods used and SW_6 for the Rb vs. Fs approach). The results shows that SW_01, SW_02, SW_04 and SW_06 sub-watersheds are most susceptible to flood, therefore must be constantly monitored in order to provide early warning of flooding and to minimize destructive flood effects in the whole Cross River watershed.

The study reveals that systematic analysis of morphometric parameters using GIS and GT can provide information to understand SW flood hazards, estimate flood risk and to provide support for decision-making.

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References

Abdel-Lattif A and Sherief Y (2012) Morphometric Analysis and Flash Floods of Wadi Sudr and Wadi Wardan, Gulf of Suez, Egypt: Using Digital Elevation Model. Arabian Journal of Geosciences, 5, 181-195.

FARIS BEG A. A., 2015. Morphometric Toolbox : A New Technique in Basin Morphometric Analysis Using ArcGIS. *Global Journal of Earth Science and Engineering,* 2, 21-30.

CEOS (2003) The use of earth observing satellites for hazard support: assessments and scenarios. Final Report of the CEOS *Disaster Management Support Group* (DMSG), November.

El Maghraby M, Masoud M and Niyazi B (2014) Assessment of Surface Runoff in Arid, Data Scarce Regions; An Approach Applied to Wadi Al-Hamd, Al Madinah Al Munawarah, Saudi Arabia. Life Science Journal, 11, 271-289.

Elmoustafa A and Mohamed M (2013) Flash Flood Risk Assessment Using Morphological Parameters in Sinai Peninsula. *Open Journal of Modern Hydrology,* 3, 122-129.

El-Shamy I (1992) Recent Recharge and Flash Flooding Opportunities in the Eastern Desert, Egypt. *Annals of Geological Survey of Egypt,* 18, 323-334.

Farhan Y and Anaba O (2016) Flash Flood Risk Estimation of Wadi Yutum (Southern Jordan) Watershed Using GIS Based Morphometric Analysis and Remote Sensing Techniques. *Open Journal of Modern Hydrology*, 6, 79-100.

Gardiner V (1990) Drainage Basin Morphometry. In: Goudie, A., Ed., *Geomorphological Techniques,* Unwin Hyman, London, 71-81.

High Level Political Forum (2019) Connecting the SDGs through resilient water management. Stockholm International Water Institute (SIWI) & Alliance for Global Water Adaptation (AGWA).

Horton RE (1932) Drainage-Basin Characteristics. Eos, *Transaction American Geophysical Union,* 13 : 350-361.

Horton RE (1945) Erosional Development of Stream and their Drainage Basins : Hydrophysical Approach to Quantitative Morphology. *Geological Society of America Bulletin,* 56 :275.

Miller VC (1953) A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area Virginia and Tennessee.

Nooka RK, Srivastava YK, Venkateshwara RV, Amminedu E and Murthy KSR (2005) Check Dam Positioning by Prioritization of Micro-Watersheds using SYI Model and Morphometric Analysis - Remote Sensing and GIS Perspective. *J. Indian Soc. Remote Sens.,* 33(1) : 25-38.

OLIVRY JC (1986) Monographie des Fleuves et rivières du Cameroun. *Collection Monographies Hydrologiques* ORSTOM, n° 9, Ed. MESRES-ORSTOM, Paris.

Ozdemir H and Bird D (2009) Evaluation of morphometric parameters of drainage networks derived from topographic maps and DEM in point of floods. *Environmental Geology,* 56:1405–1415.

Patton PC (1988) Drainage Basin Morphometry and Floods. In: Baker, V., Kochel, R. and Patton, P., Eds., *Flood Geomorphology,* Wiley, New York, 51-65.

Safiah Yusmah MF and Rodziah H (2014) Predicting Flow Direction of Soil Erosion Using Geographical Information System (GIS). *International Journal of Soil Mechanics & Foundation,* 1, 11-13.

Schumm SA (1956) Evolution of Drainage Systems and Slope in Badlands at Perth Amboy. New Jersey, Geological Society of America Bulletin, 597-646.

Strahler A (1952) Dynamic Basis of Geomorphology. *Geological Society of America Bulletin,* 63, 923-938.

Strahler A (1957) Quantitative Analysis of Watershed Geomorphology. Transactions *American Geophysical Union,* 38, 913-920.

Strahler A (1958). Dimensional Analysis Applied to Fluvially Eroded Landforms. Geological Society of America Bulletin, 69, 279-299.

Strahler A (1964) Quantitative Geomorphology of Drainage Basins and Channel Networks. In: Chow, V., Ed., *Handbook of Applied Hydrology,* McGraw Hill, New York, 439-476.

UN Environment Programme (2020) Supporting the Sustainable Development Goals and water.

Youssef A. M., Pradhan B. and Hassan A. M., 2011. Flash Flood Risk Estimation Along the St. Katherine Road, Southern Sinai, Egypt Using GIS Based Morphometry and Satellite Imagery. *Environmental Earth Sciences,* 62, 611-623.

Zerger A and Smith DI (2003) Impediments to using GIS for real-time disaster decision support. *Computers, Environment and Urban Systems,* 27: 123-141.

Flood Susceptibility Assessment using Geographical Information System and Multi-Criteria Analysis Technique: Case Study of Musanze City/Rwanda

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Abstract

Flooding is the most frequent and significant natural disaster occurring in urban areas. Managing flood hazards in urban areas require the integration of flood susceptibility maps in urban land use planning. This study intends to map areas that are susceptible to flooding in Musanze City, Rwanda. To achieve our goal, both Geographical Information System and Multi-Criteria Analysis Technique, were used. The five most flood-inducing criteria (i.e. Rivers, Rainfall intensity, slope, soil texture, and land cover) were also used through the Multi-Criteria Analysis Technique. Criteria were evaluated using pairwise comparison, expert's views, and later processed in a super decision software. According to the expert's views, Rivers were found to be the most influential in our study area with 0.35, followed by land use/land cover (0.23) and rainfall (0.18). All criteria were standardized and overlaid in GIS using weighted overlay analysis to produce the final flood susceptibility map. The final flood susceptibility map of the study area was categorized into 5 classes (1: Very High, 2: High, 3: Moderate, 4: Low, and 5: Very low). The map showed that 0.979% of the total area is in an area that has a very high susceptibility to flooding, 20.480% is highly susceptible to flooding, 64.245% of the total area is moderately susceptible to flooding, 14.294% of the area is in low susceptibility to flooding and 0.002% of the area has a very low susceptibility to flooding. The results of this study could be used as a supporting tool, in the field of urban land use planning, to reduce the impact of flooding on vulnerable social assets and the most vulnerable people including women, children, and elderly persons.

Keywords: Flood susceptibility, Pairwise comparison, Multi-Criteria Evaluation, Musanze, Rwanda.

1. Introduction

Flooding from rivers is the most recurrent and costly natural disaster that not only affects countries worldwide but also provokes significant social, economic, and environmental stress and instability (Rincón et al., 2018). The impact of increasing levels of urbanization requires deep assessment along with careful mapping of areas with flood hazards to help prepare and support urban and regional planning to promote better growth management around the world (Yeganeh & Sabri, 2014). The management of Floods is needed not only to prepare a legitimate response to the significant damage floods create on urban social, economic, and environmental aspects of our lives but also for better exploitation and proper management of land (Danumah et al., 2016). Flood hazard Maps are efficient tools for urban planners and policymakers because they guide and supplement master plans of urban areas. Additionally, they can be a blueprint in the implementation of flood hazard mitigation measures in urban areas that are prone to flooding hazards (MIDIMAR, 2015). Jha et al. (2011) argued that planning the formation of new settlements and buildings for the urban extension requires the mapping of urban flood mapping risk areas to prevent flood impacts from occurring. Geographical information system (GIS) is a useful tool that can be used in flood hazard mapping and other natural hazard analysis (Rahmati et al., 2016). All types of disasters have a spatial component (Ouma & Tateishi, 2014), therefore Geographical Information System (GIS) with the integration of Multi-Criteria technique are effective tools in evaluating different factors to generate flood susceptibility maps. There are primary techniques such as ranking, rating, and pairwise comparison used to assign weight to the factors selected during flood risk assessment (Yeganeh & Sabri, 2014). However, the Multi-criteria evaluation (MCE) method is the most used; it is used in several studies as it allows the weighting of identified sets of criteria (Ouma & Tateishi, 2014). The combination of GIS and multi-criteria techniques in flood risk assessment assists in evaluating alternative plans that may facilitate cooperation between concerned parties and present many advantages. One of the main advantages is that the approach produces a reliable flood risk map with a low cost of money/capital and less time (Rincón et al., 2018).

Rwanda is among the fastest urbanizing countries in Eastern Africa. The Government of Rwanda is targeting to promote urban growth and increase the proportion of urban dwellers from 10 percent to 35 percent by 2024 (GoR, 2011). However, flood hazards are among the main threats to Rwanda's urban areas. The most affected sectors of flood hazards are urban infrastructures, energy, transport, health, and agricultural sectors (REMA, 2017). Musanze city is located in the central part of Musanze District, and the city is affected by frequent flooding resulting from water emerging from volcanoes and classic torrential rivers in the Musanze city (WGR, 2018). Referring to Musanze city annual growth rate of 1.8 percent and basing on the projected target to reach an urbanization level of 35 percent by 2024 with an annual growth rate of about 7.7 percent (Government of Rwanda and GGGI, 2015), Musanze city is still lacking a flood hazard potential mapping for the planning of future direction of the city's growth. Although the National Risk Atlas of Rwanda identified flood risk areas, a detailed assessment on the local level was recommended to help policymakers and decision-makers plan and implement an effective flood management system (MIDIMAR, 2015). Therefore, this study is a flood susceptibility model to be based on in planning for Musanze city's urban growth. It is also an important aspect to be based on in reducing the risk caused by flooding in urban areas.

2. Materials and methods

2.1. Description of the study area

Musanze city is situated in the central part of Musanze District, approximately 110 Km from Kigali. The city is among the five significant secondary Cities in Rwanda with a total urban population of 99,387 (REMA, 2017; NISR 2012).

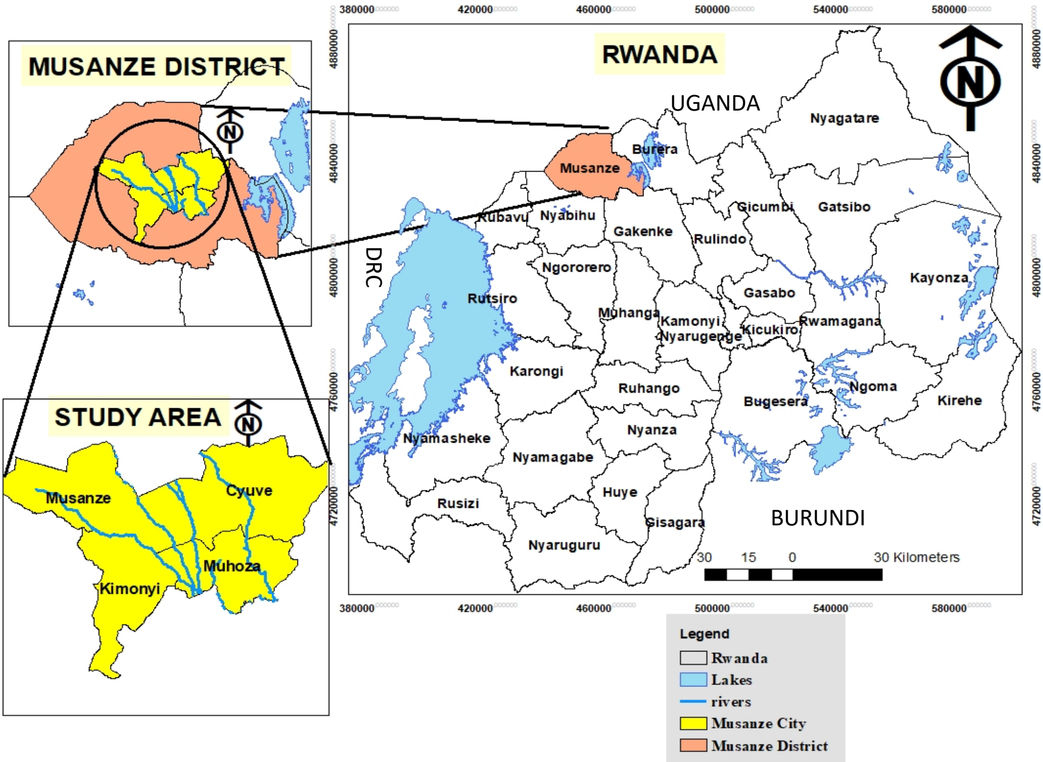

Figure 1: Musanze District in Rwanda (Right) and location of Musanze city (Lower Left)

Referring to the District Land Use and Development Plan, the city is composed of four (4) Sectors comprising Muhoza, Kimonyi, Cyuve, and Musanze. The sectors of Musanze city are graded amongst the most densely populated above the national population density which is estimated at 416 population/sq.km (NISR, 2012). The city is surrounded by classic torrential rivers that transport water from heavy rainfall in the volcanoes areas and with other flood influencing factors, water from volcanoes areas frequently inundated their proximity urban areas (WGR, 2018).

2.2. Data acquisition and processing

The following identified data were used: Administrative boundary of urban sectors, rivers, rainfall, population density, DEM Rwanda (10mx10m), floodplain points, soil texture, and land cover. To obtain this data, both primary and secondary data sources were used. The criteria used in this research were selected using a literature review method. Data layers were acquired from different resources as described in table 1. The data was processed using GIS and Multi-Criteria Analysis Technique. Criteria were ranked and weighted using experts and scientific perspectives and processed in the Super Decision software 2.8 version. The ArcGIS 10.4.1 was used in classification through spatial analysis tools. Criteria were classified as 1: Very High, 2: High, 3: Moderate, 4: Low, and 5: Very low. All the standardized criteria were combined using weighted overlay analysis and thematic maps produced to show flood susceptibility maps. The model was validated using ground-truthing points from existing floodplain areas.

Table 1: Source of data

No	Layers data	Source of data
1	Administrative boundary(Urban Sector)	Administrative boundary layers created in 2006 by the Ministry of Local Government (MINALOC), further adjusted/updated by NISR in 2012 in the process of census mapping. Later, The NISR staff adjusted administrative boundaries in the GIS lab with the Rwanda Natural Resource Authority.
2	Rivers	Layer of Rivers was delivered by Musanze District One-stop Centre. The layer was generated through mapping done by Rwanda Environmental Management Authority in 2008.
3	Rainfall	Rainfall data used was provided by the Centre for Geographic Information Systems and Remote Sensing (CGIS - UR). Data from 3 weather stations located in Musanze City were interpolated to create a continuous raster rainfall data inside our study area.
4	Land cover (LULC)	Land use/ land cover layer was acquired through the Regional Centre for Mapping of Resources for Development (RCMRD) *(http://opendata.rcmrd.org/)*.
5	Soil Texture	The soil texture data layer was generated through the Rwanda soil map layer of MINAGRI.
6	DEM (10m of resolution)	University of Rwanda Centre for Geographic Information System and remote sensing.
7	Flood plain Area	Catchment-based landscape Restoration Opportunity Mapping Decision Support System data from Water for Growth Rwanda and Water for Growth Rwanda.

2.3. Flood hazard criteria weighting

To weight criteria, this study used the Analytic Network Process (ANP) method in the Super Decision software environment based on the experts' views regarding criteria. The ANP method is a holistic approach that is widely used (Soroudi et al., 2018). This method consists of comparing several criteria to show the significance of each criterion compared to another. For comparing criteria, a scale of comparison from 1-9 was used to show how significant a criterion is over another (Saaty, 2006). The data layers of all criteria were rasterized and reclassified. The weighted overlay tool from ArcGIS version x 10.8 was used to generate the final flood risk map.

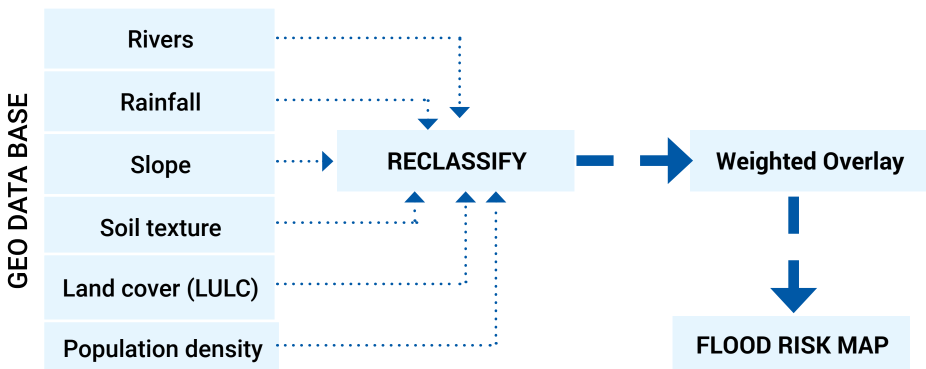

Figure 2: Flood Hazard susceptibility mapping workflow

3. Results

The results of the pairwise comparison are highlighted in table 4, as rivers were found to be the most influential criterion with high weight compared to other used criteria. The weights of the criteria were generated after inserting the experts' views and performing the pairwise comparison in the super decision software. The Rankings were allocated based on the level of susceptibility regarding each sub-criteria.

Table 2: Results used to create flood risk map

Criteria	Weight	Sub-criteria	Ranking and Naming(susceptibility)
Rivers	0.35	<100 m	1:Very High
		100m-300 m	2:High
		300m-500m	3:Moderate
		500m-1500m	4:Low
		>1500 m	5:Very low
Rainfall	0.18	1,284mm - 1,290mm	5:Very low
		1,290mm - 1,294mm	4:Low
		1,294mm - 1,298mm	3:Moderate
		1,298mm - 1,302mm	2:High
		1,302mm - 1,309mm	1:Very High
Land use/Land cover	0.23	Settlement	1:Very High
		Sparse Forest/cropland	3:Moderate
		Moderate Forest	4: low
		Dense forestry	5:Very low
Slope	0.17	1-3%	1:Very High
		3-10%	2:High
		10-15%	3:Moderate
		15-20%	4:Low
		20-70%	5:Very low
soil texture	0.07	20 - 35% clay	5:Very Low
		>35% Clay	1:VeryHigh

4. Discussion

4.1. Flood susceptibility regarding criteria

4.1.1. Flood susceptibility map regarding rivers

Concerning the flood susceptibility map regarding rivers, the map in figure (a), shows that close to the area to the rivers, there is more susceptibility to flooding. This criterion plays a significant role in flood risk mapping areas because the areas that are most affected are those located near rivers due to the overflow of rivers (Rahmati et al., 2016). In Musanze City, there are rivers such as Rwebeya, Muhe, and Susa that carry water runoff from heavy rainfall in the volcanoes during rainy seasons and cause a lot of damages and losses to the people living downstream mainly because of the quantity of water flowing and its velocity. Therefore, this criterion was found to be important in our study. The distances to the river were identified referring to the distance intervals proposed by Yeganeh et al. (2014); where he considered the following distances: a) <100 m, b) between 100 and 500 m, c) between 500 and 1500m and d) >1500 m.

4.1.2. Flood susceptibility map regarding land cover (LULC)

The map in figure (b) shows existing land use in our study area. Settlement is the area that is more susceptible to flooding regarding other land-use types. According to Rijal et al. (2018), understanding land-use land-cover patterns is the key to enhance flood hazard resilience in formed urban areas. This is supported through Rahmati et al. (2016) and Yaganeh et al. (2014), who argued that residential areas and other impervious surfaces such as roads, increase flooding while vegetation areas such as forests have the potentiality of reducing flooding.

4.1.3. Flood susceptibility map regarding rainfall

Rainfall in our study is ranging between (1,284mm- 1,309mm). The map in figure(c), shows that, the more the area is exposed to high amounts of rainfall, the more it is exposed to flooding. This was supported through Yaganeh et al. (2014), who argued that the higher the amount of precipitation in the area, the more the susceptibility to higher flooding.

4.1.4. Slope

The slope susceptibility map in figure (d), illustrates flood susceptibility regarding the slope in our study area, because of the impact that it has on the velocity runoff and the effect of slope on flood hazard intensity. The flat terrain increases food hazard damage and retains a high amount of runoff water for a long period (Wondim, 2016; Yeganeh & Sabri, 2014). This criterion played a significant role in defining surface runoff velocity and vertical percolation and consequently affecting flood susceptibility (Rahmati et al., 2016).

4.1.5. Soil texture

The flood susceptibility regarding soil texture on the map in figure (e), is performed regarding the percentage of clay in the soil. The more the percentage of clay in soil the less the infiltration and thus high the susceptibility to flooding (Mornya, 2010). Soil texture has an important impact on flooding since the physical properties of the soil, for example, soil texture influences the infiltration capacity, and the flood hazards upsurges with the reduction of soil infiltration capacity (Wondim, 2016).

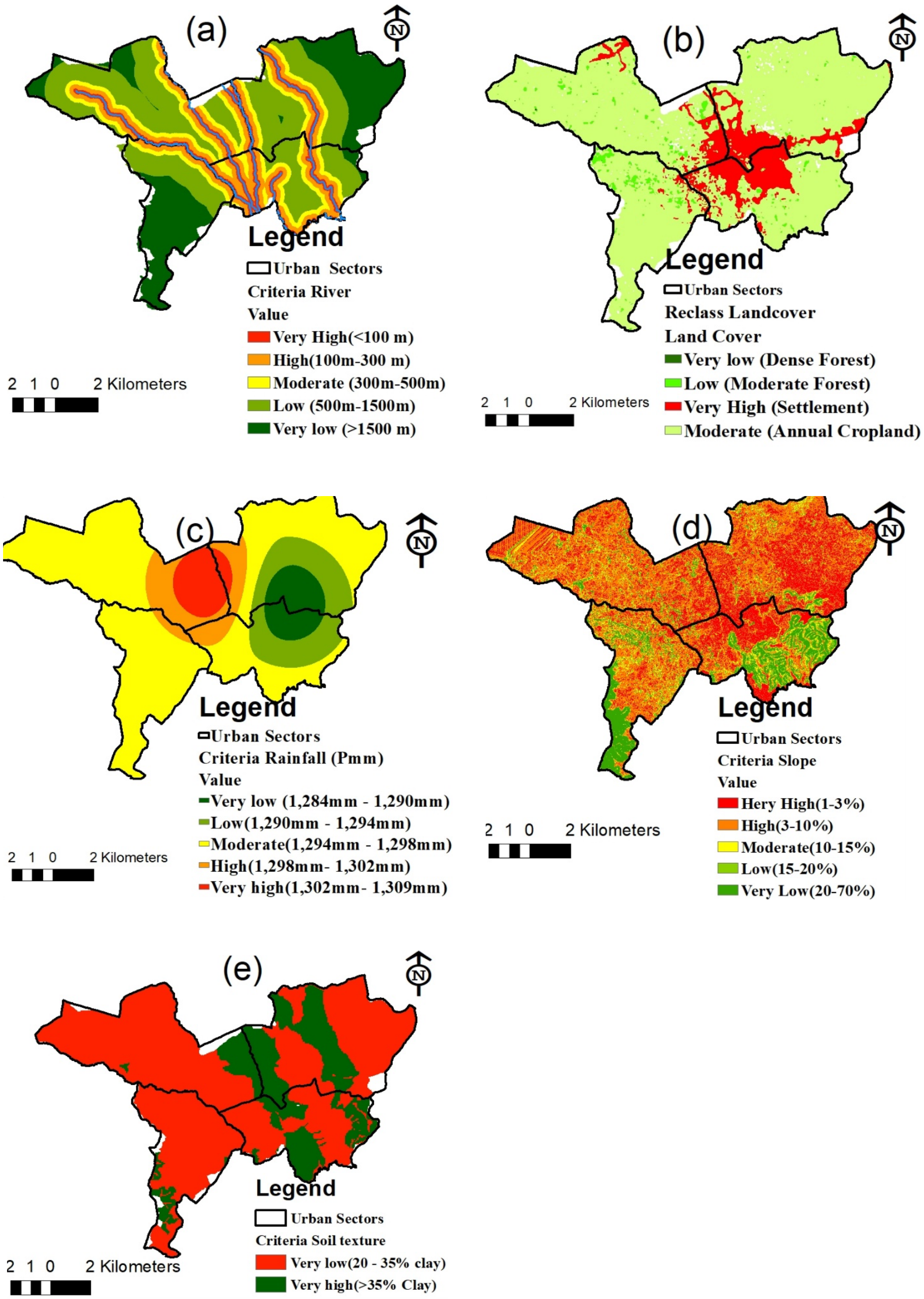

Figure 3: All criteria maps

4.2. Flood susceptibility and model validation

The map in figure 4(a) is the overlay product of all criteria maps in figure 3. The map is categorized into 5 flood susceptibility classes, where 1: Very High, 2: High, 3: Moderate, 4: Low, and 5: Very low. The results showed that 0.979% of the total area is very high, 20.480% is highly susceptible to flooding, 64.245% of the total area are moderately susceptible to flooding, 14.294% of the area are in Low susceptibility to flooding and 0.002% of the area is very low susceptible to flooding. The map figure 4(b) shows the point used in the validation of the model, 191 ground-truthing points were taken in the existing flood plain and 156 of the points meaning 81% of the total points were found to be located in high and very high flood susceptible areas. These results show that our output module is reliable.

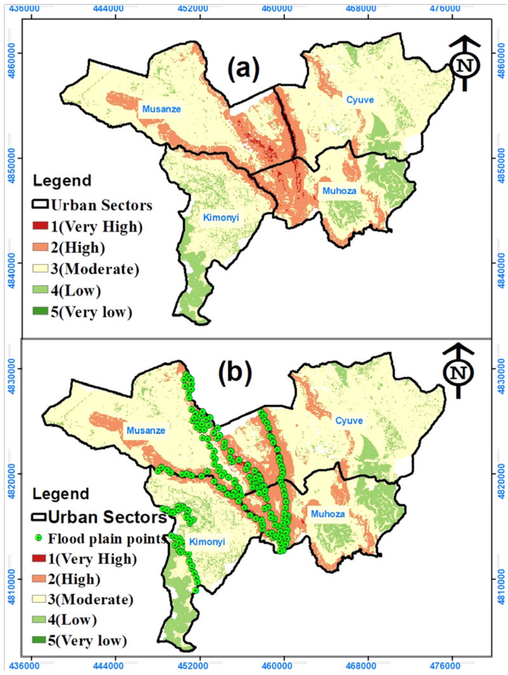

Figure 4: Flood susceptibility maps & validation

5. Conclusion

Overall, flood susceptibility mapping using the Geographical Information System and Multi-Criteria Analysis Technique is more reliable since both are powerful tools that could be used in flood hazard mitigation and urban land use planning sustainability. This study used the Geographical Information System and Multi-Criteria Analysis Technique, to identify different levels of flood susceptibility areas in Musanze city. To achieve that goal, flooding most influencing factors (referred to as criteria in this study) such as rivers, rainfall, DEM Rwanda (10mx10m), soil texture, and land cover were used. Those flood influencing criteria were weighted and rivers (0.35), land use/land cover (0.23), and rainfall (0.18) were found to be the most influential according to the experts' perspectives. Flood susceptibility maps were created for each criteria and then combined by using a weighted overlay tool. The final map result categorized in 5 classes (i.e. 1: Very High, 2: High, 3: Moderate, 4: Low, and 5: Very low), showed that 0.979% of the total area is very high, 20.480% is highly susceptible to the flooding, 64.245% of the total area are moderately susceptible to flooding, 14.294% of the area are in Low susceptibility to flooding and 0.002%. The results of this study are valuable assets that could be used in planning and implementing appropriate land use in identified high and very high flooding susceptible areas of growing Musanze City. It is also a contribution and a model that could be used in Kigali City and other secondary cities of Rwanda in sustainably addressing the problems of flooding. This model will contribute in addressing the gap in integrating flood susceptibility mapping in existing planning.

References

Danumah, J. H., Odai, S. N., Saley, B. M., Szarzynski, J., Thiel, M., Kwaku, A., Kouame, F. K., & Akpa, L. Y. (2016). Flood risk assessment and mapping in Abidjan district using multi-criteria analysis (AHP) model and geoinformation techniques, (côte d'ivoire). *Geoenvironmental Disasters,* 3(1). https://doi.org/10.1186/s40677-016-0044-y

Ebisu, T. A., & Minale, A. S. (2013). Solid waste dumping site suitability analysis using geographic information system (GIS) and remote sensing for Bahir Dar Town, North Western Ethiopia. *African Journal of Environmental Science and Technology*, 7(11), 976–989. https://doi.org/10.5897/AJEST2013.1589

Government of Rwanda. (2011). Green Growth and Climate Resilience. *The Way Forward in International Climate Policy,* October, 100. Retrieved from http://repository.ubn.ru.nl/bitstream/handle/2066/135304/135304.pdf. Cited 12 July 20203

Government of Rwanda and the Global Green Growth Institute. (2015). *Republic of Rwanda National Roadmap for Green Secondary City Development National Roadmap for Green Secondary City Development.*

Jha, A., Lamond, J., Bloch, R., Bhattacharya, N., Lopez, A., Papachristodoulou, N., Bird, A., Proverbs, D., Davies, J., & Barker, R. (2011). Five Feet High and Rising: Cities and Flooding in the 21st Century. Policy Research Working Paper, May 2011, 1–68. https://doi.org/10.1596/1813-9450-5648

Ministry of Disaster Management and Refugee Affairs. (2015). *The National Risk Atlas of Rwanda.* 197. Retrieved from https://www.gfdrr.org/sites/default/files/publication/National_Risk_Atlas_of_Rwanda_01.pdf. Cited 12 July 20203 3

Mornya, A. A. (2010). Identification of potential landfill sites by using GIS and multicriteria method in Batam, Indonesia. *3rd International Graduate Conference on Engineering, Science, and Humanities, November.*

National Institute of Statistics of Rwanda. (2012). 2012 *Population and Housing Census. November.* https://microdata.statistics.gov.rw/index.php/catalog/65/download/508.pdf. Cited 12 July 20203 3

Ouma, Y. O., & Tateishi, R. (2014). Urban flood vulnerability and risk mapping using integrated multi-parametric AHP and GIS: Methodological overview and case study assessment. File:///D:/EcologicFOOT/Urban_Flood_Vulnerability_and_Risk_Mapping_Using_I.Criteria2.PdfWater (Switzerland), 6(6), 1515–1545. https://doi.org/10.3390/w6061515

Rahmati, O., Zeinivand, H., & Besharat, M. (2016). Flood hazard zoning in Yasooj region, Iran, using GIS and multi-criteria decision analysis. Geomatics, Natural Hazards and Risk, 7(3), 1000–1017. https://doi.org/10.1080/19475705.2015.1045043

Rwanda Environmental Management Authority. (2017). State of Environment and Outlook Report.

Rijal, S., Rimal, B., & Sloan, S. (2018). Flood hazard mapping of a rapidly urbanizing city in the foothills (Birendranagar, Surkhet) of Nepal. Land, 7(2). https://doi.org/10.3390/land7020060

Rincón, D., Khan, U. T., & Armenakis, C. (2018). Flood risk mapping using GIS and multi-criteria analysis: A greater toronto area case study. *Geosciences (Switzerland)*, 8(8). https://doi.org/10.3390/geosciences8080275

Saaty, T. L. (2006). Decision making — the Analytic Hierarchy and Network Processes (AHP/ANP). *Journal of Systems Science and Systems Engineering,* 13(1), 1–35. https://doi.org/10.1007/s11518-006-0151-5

Soroudi, M., Omrani, G., Moataar, F., & Jozi, S. A. (2018). Modelling an integrated fuzzy logic and multi-criteria approach for land capability assessment for optimized municipal solid waste landfill siting yeast. *Polish Journal of Environmental Studies,* 27(1), 313–323. https://doi.org/10.15244/pjoes/69576

Water for Growth. (2018). *IWRM Programme Rwanda.* March, 2018–2024. https://doi.org/10.1016/0040-1951 (76)90047-0

Wondim, Y. K. (2016). *Flood Hazard and Risk Assessment Using GIS and Remote Sensing in Lower Awash Sub-basin, Ethiopia.* 6(9), 69–86. https://iiste.org/Journals/index.php/JEES/article/view/32924

Yeganeh, N., & Sabri, S. (2014). Flood vulnerability assessment in Iskandar Malaysia using multi-criteria evaluation and fuzzy logic. *Research Journal of Applied Sciences, Engineering and Technology,* 8(16), 1794–1806. https://doi.org/10.19026/rjaset.8.1167

B. GROUNDWATER IN A CHANGING ENVIRONMENT

The use of GIS and Remote Sensing Techniques to Delineate Groundwater Potential Zones in Hard-rock Terrain: A Case from Zenaga Inlier, Morocco

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Abstract

Remotely sensed data have been noticeably applied across a broad range of fields. These data provide earth's surface observations with a fair resolution, making it possible to decipher details about the subsurface. Groundwater occurrence often manifests in numerous features on the surface that are easily measured by remote sensing technologies. The main objective of this research is to delineate the groundwater potential zones using geospatial data and multi-criteria analysis in the Zenaga inlier (Southeast of Morocco). The area is characterized by an arid climate and fractured water-bearing hard rock. The study combined several thematic layers categorized into five main factors (geomorphology, lithology, lineament density, rainfall, and vegetation cover) in a GIS environment in order to map groundwater potential zones. The adopted approach has yielded different potential zones classified into five groups, very high (0.9%), high (11.17%), moderate (22.76%), low (44.88%), and very low (20.26%). The generated map of groundwater potential zones has been validated with field checks by wells and boreholes scattered, but randomly chosen throughout the area with satisfactory yield rate and showed consistency with the method. Considering the particularities imposed by this case study: the financial limitations of the region, and an emerging socio-economic development, as many agricultural cooperatives and start-ups are being initiated by youth and women, this indexing approach proved to be the most rapid and cost-effective assessment tool for groundwater exploration and management.

Keywords: Remote sensing, Hard rock aquifer, GIS, Groundwater potential zones, Morocco.

1. Introduction

In Morocco, the concern about water resources is growing as a result of population growth, climate change, and the alarming signs of groundwater resources depletion at an unsustainable rate in some areas of the country (Hssaisoune et al. 2020). Within the semi-arid area, southern regions are likely to be the most affected by water scarcity, due to the increasing demand, and to the changing climate with irregular and low rainfall (Hssaisoune et al. 2020), which particularly characterizes Zenaga inlier in the southeast of Morocco. This area suffers from surface water shortage, yet it relies mainly on agricultural activities for socio-economic development, through groundwater pumping. However, groundwater in this particular area happens to be trapped in hard rocks, forming a rather discontinuous aquifer, which is considered a challenge amongst hydrogeologists in their exploration, with the unpredictable hydrodynamic parameters they imply (Lachassagne 2008). This often manifests in the area in a contrasting behaviour of neighbouring wells. Groundwater is therefore highly site-specific, and its distribution depends on multiple discrete and perplexing features. Furthermore, there are also constraints on the availability of relevant data since no such studies have ever been conducted over the area.

Remote sensing data have captured the interest of hydrogeologists, thanks to their ability to reveal earth surface information of hydrological relevance (Lachassagne 2008; Singhal 2008), which helps to extract features that influence aquifer recharge and show evidence of groundwater occurrence (Jagannathan et al. 2000), such as surface morphology (topography, deformations, lithological contacts...) and water bodies (lakes, streams...). Hence, many groundwater exploration studies have shown how much these data can be significant in that regard (Waters et al. 1990). Geographic information systems (GIS) have also been promoted as a powerful tool for analysing and quantifying the multivariate aspects of groundwater occurrence, and it made the art of image interpretations broadly open to new ideas, time-saving and cost less as opposed to traditional hydrogeological survey methods (Meijerink et al. 2007). The various studies that were conducted to delineate potential productive aquifers of this type focusing on image interpretations, have almost all considered the same criteria. The main factor is the lineament density, which is likely a sign for fractures, faults, or joints in stratigraphic formations (Gupta and Srivastava 2010; Madrucci et al. 2008). They play a major role in several geoscience applications, especially in groundwater exploration. Sander (2007) mentions that after using lineament interpretation in Ghana, the success rates in a village well program increased from 57% to 70%, significantly reducing the drilling costs.

This paper aims to evaluate the utility of remotely sensed data in hard-rock aquifer exploration, through the extraction of surface information related to the recharge potential of this type of aquifer, in order to map the groundwater potential zones (GWPZ). As for a growing economy, this research would support individuals and agricultural cooperatives within the area by reducing the drilling failure of productive wells.

2. Study area

2.1 Geographical and hydrological settings

The study area located in *Drâa* watershed, is a plain in the central Anti-Atlas of Morocco, between 30° 14' 46" N and 30° 38' 25" N latitude, 7° 7' 20" W and 7° 30' 14" W longitude, approximately 76 km south of Ouarzazate. It is an integral part of the *Drâa* watershed and encompasses two rural communes: Iznagen and Ouisselsate, and Taznakht as an urban commune, with a total area of 809 km^2 (Figure 1).

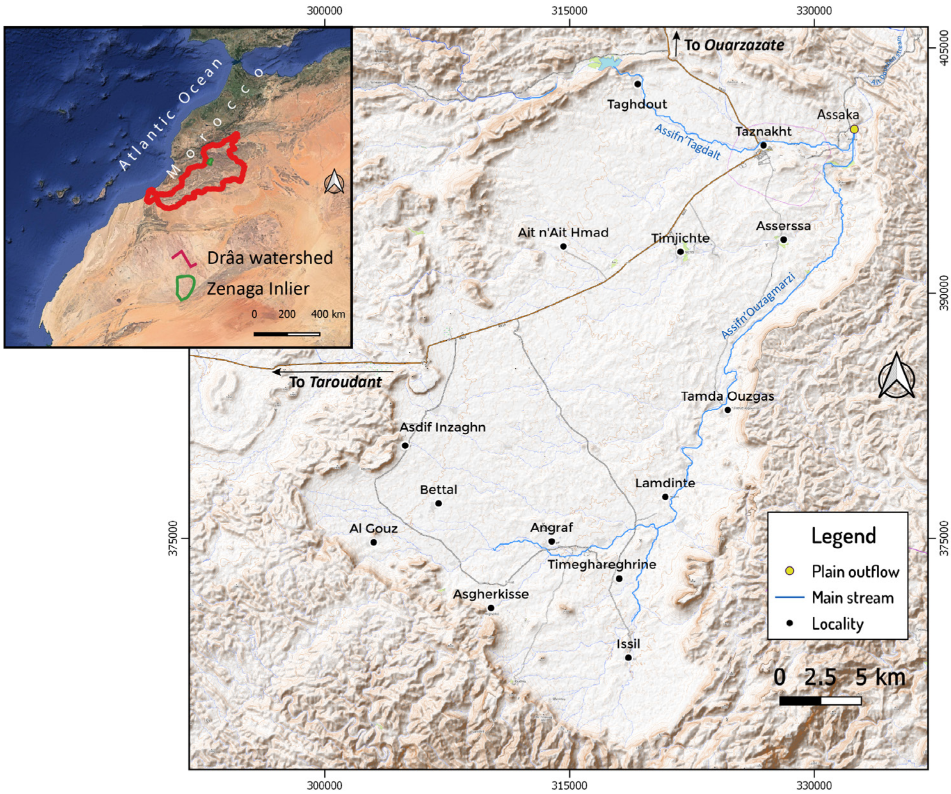

Figure 1. Geographic location of the Zenaga inlier within the Drâa watershed. The outlet point at Assaka, receiving flows from both Assif n'Tagdalt and Assif n'Ouzagmarzi streams

The semi-arid and Saharan climate are the two prevailing factors in the Zenaga inlier, with warm summers and cold winters. The temperature fluctuates both daily and seasonally with an annual average of 19 °C and an average annual rainfall of 161.9 mm with one rainy season from November to February. However, precipitation is highly variable in terms of frequency, duration, and intensity and is characterized by high spatial heterogeneity. Nonetheless, the plain of Zenaga lacks spatially distributed rainfall measurements, with only one station located at its outlet in *Assaka.*

The elevation ranges from 1353 to 1913m, with a slope slowly decreasing towards the northeast and surrounded by high elevation. However, the plain is part of *Ait Douchen* sub-watershed, draining to the outflow point at *Assaka* through two main streams: *Assif n'Tagdalt* and *Assif n'Ouzagmarzi*, which both receive their inflow from the Anti-Atlas Mountains, and drain into the *Oued Ait Douchen* stream. It should be also noted that the *Assif n'Tagdalt* is regulated with a small dam to the northwest of *Taghdout* village for irrigation water supply (Figure 1).

The area has sparse vegetation and lack of surface water, and the groundwater represents the main source for drinking and irrigation. Nevertheless, the fertility of the soil is adequate and has an excellent prospect to extend exploitation, especially for some species such as saffron. This product is used as a spice. The region of Siroua produces more saffron than anywhere in Africa. It is planned to increase areas of land with saffron crocus production, however the lack of funds to finance such agricultural projects is a great obstacle. On the other hand, the area suffers from severe drought and limited water resources, on which the socio-economic development of the region depends.

2.2. Geological settings

The plain of Zenaga is one of the largest inliers of the Anti-Atlas. It lies below the EW-oriented Anti-Atlas Major Fault, the basement rock is a crystalline igneous and metamorphic formations aged Paleoproterozoic, that constitute the northern margin of the West African Craton (WAC), which is so likely to be affected by tectonic events (Thomas et al. 2002). The overlaying materials consist of Neoproterozoic rocks, mainly quartzite and limestone intruded with dykes of dolerite (Saïdi et al. 2001). Recently, Ikenne et al. (2016) noticed the presence of Mesoproterozoic overlaying materials. It is represented by limestones and quartzites in the inlier of Zenaga (Figure 2).

3. Material and methods

3.1. Material

Different data sets were acquired and have been processed and analysed in order to extract information about each factor related to groundwater potential recharge. These factors were spatialized over the area of Zenaga inlier.

The information of the elementary datasets covering the study area used to compute the GWPZ are summarized in Table 1. They include a Digital Elevation Model (DEM), a scene of a multispectral image, and all the geological maps that were carried out in the study area, the coordinates of the outlet were also surveyed. Additionally, 67 points of wells and boreholes have been surveyed to perform a validation of this approach.

3.2. Methods

The methodology is an exhaustive extraction of information about multiple factors that are involved in the process of predicting groundwater potential zones (GWPZ) within the study area. The data acquired for this study offers a variety of surface information related to groundwater occurrence, which has been sorted into the following factors: Lineament density (LD), Geomorphology (GM), Soil permeability (K), Precipitation (P), and Vegetation density (VD).

First of all, some pre-treatments have been implemented to correct any imperfections or flaws that the data sets may contain concerning this specific research, including geometrical rectification, radiometric enhancement, Principal Component Analysis (PCA). Secondly, a GIS environment was useful for each factor to be spatialized over the study area and in their weighted combination in order to calculate the Index of GWPZ.

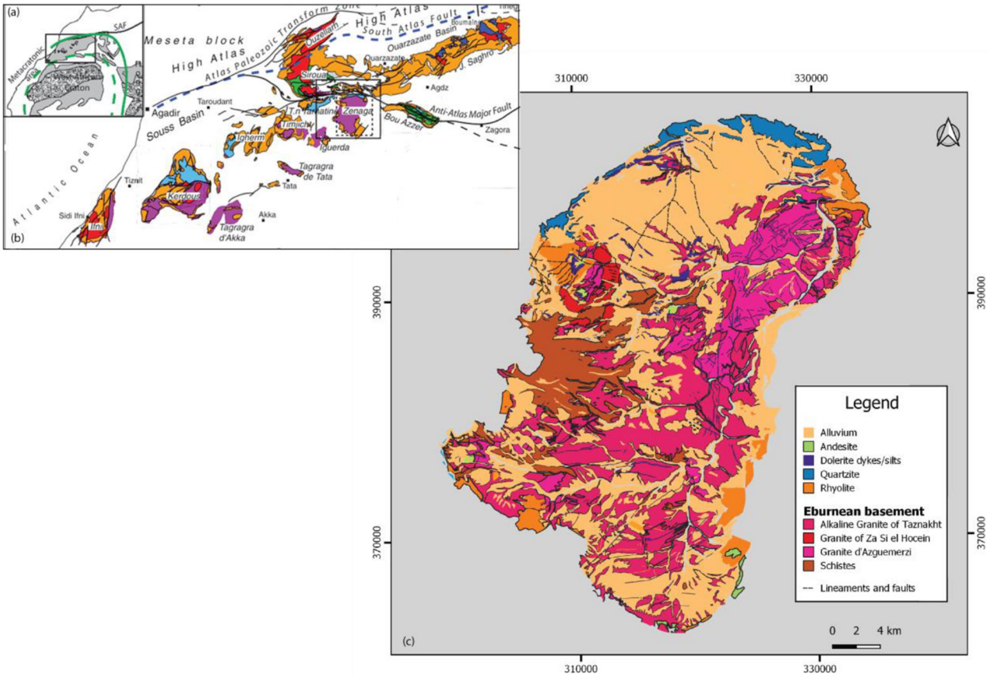

Figure 2. (a) Schematic geological map, illustrating the geological structures in Morocco, (b) the Anti-Atlas (Thomas et al. 2002), and (c) the major rock materials in Zenaga inlier

Table 1. Data set used for the groundwater potential zone (GWPZ) characterization

Dataset	Source	Acquired date	Format	Spatial resolution
Digital elevation model (DEM)	USGS EROS Center at: https://earthexplorer.usgs.gov/	March 13th, 2020	TIFF	30m
Geological maps	The Moroccan Ministry of Energy and Mining	March 13th, 2020	JPG	1:50.000
Sentinel-2A Image	Copernicus Data Hub System at: https://scihub.copernicus.eu/	April 19th, 2020	JPG2000	10m, 20m, 60m
TRMM_2B31 v7 data	EarthData website at: https://disc.gsfc.nasa.gov/datasets	May 1st, 2020	HDF	5km x 5km
Watershed outlet Coordinates (Assaka)	Surveyed with GPS	March 13th, 2020	Point (X, Y)	-
Wells/boreholes observations	The Hydraulic Basin Agency of Draa-Oued Noun database	June 20th, 2020	Point (X, Y,Z)	-

Figure 3 shows in a schematic form, the various methods used in this study for the extraction process for each factor, and also for the identification of the GWPZ.

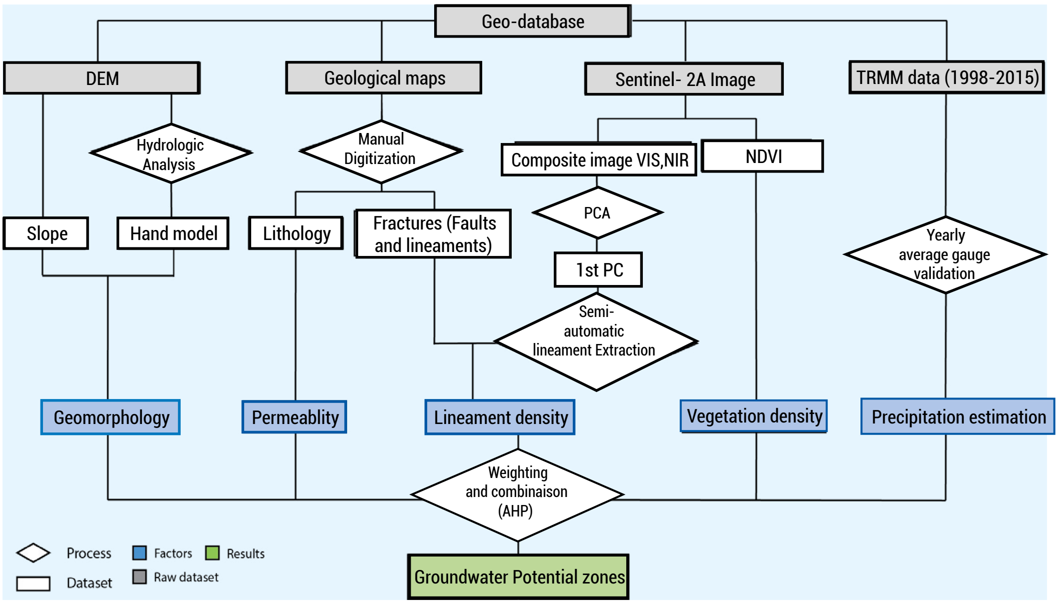

Figure 3. Summarized flowchart of the spatial analysis of each factor and the multi-criteria analysis to GWPZ identification

3.2.1. Geomorphology characterization

The geomorphology has been characterized as to define landform classes of different recharge potential, which is linked to the residence time of water and to the amount of water susceptible to percolate into the ground. The landform classification was based on two topographic parameters: The Slope and the Height Above Nearest Drainage (HAND). However, both of them were derived from the DEM only.

The HAND is a model that normalizes the topography according to the nearest drainage channel, by assigning to each cell the vertical distance to the nearest drainage point (Nobre et al. 2011). The procedure to generate a HAND model consists of two main operations: (1) the computing of the nearest drainage map based on the drainage accumulation grid and (2) the association of each drainage cell to all the DEM cells draining to it, then the difference is calculated to build a normalized elevation. The HAND model has proven to be highly correlated to water table levels, hence it is widely used to distinguish landforms based on hydrological properties. However, for a discontinuous aquifer, which is the case in this study, the HAND model was coupled with the slope through a conditioner for each pixel to define the geomorphology in the study area with landforms of different recharge potential namely waterlogged, wetland sloped, hillslopes, and plateaus (Table 2).

Table 2. Geomorphology classes defined in the study area

Landform classes	HAND(m)	Slope (degree)
Waterlogged	0-5	-
Wetland	5-15	-
Hillslope	> 15	> 7
Plateau	> 15	< 7

3.2.2. Lineament density extraction

A lineament is simply defined as any feature that appears as a line due to an abrupt contrast variation in pixel values on an image, which generally expresses any sort of linear feature or surface on the ground (Waters et al. 1990). They are important geological features that are considered as a key indicator of groundwater and petroleum prospection (Gannouni and Gabtni 2015; Mabee et al. 1994; Solomon and Quiel 2006). The presence of lineaments acts as a secondary porosity that allows water movement which results in increased aquifer recharge and therefore can give a clue for groundwater potential zone (Sankar 2002). Lineaments are originated from two types of sources. Firstly, lineaments may occur due to tectonic activity, this kind of lineaments usually corresponds to faults, joints, and/or lithological boundaries. The second type is due to man-made features including roads, crop field boundaries, or any kind of variations in land-use patterns, which is not useful in a hydrological study, and the issue is when they are being also generated through automatic extraction of lineaments. And so, there is often a necessity to exclude them for more consistent information, and a knowledge of the area would also help in this process.

For this study, both semi-automatic and manual extraction have been conducted. The features were later merged to generate lineament density in the area of study. Firstly, a semi-automatic extraction has been performed on the data stored into one principal component which had been constructed out of the bands (2,3,4) for the visible, band (8) NIR, band (8a) Narrow NIR, and the band (12) SWIR. As they were identified by (Javhar et al. 2019) for generating the greatest amount of lineaments for Sentinel-2A data. An experimental test was also performed to determine the optimal threshold values for edge detection and curve extraction for an automatic lineament extraction, which was carried out with the LINE module provided by PCI Geomatica software. And each time the output was validated to the lineaments present in the geological maps to verify how much they coincide. The parameters shown in Table 3 are the combination chosen for this research. The derived lineament map has been compared to ground truth to remove lineaments that correspond to non-geological features (roads, field boundaries, etc.), and lineaments due to mineral contrast (dykes, lithological contact) were also discarded using the available geologic maps and ortho imagery.

Table 3. Threshold parameters of the LINE module used for the study

Threshold Parameters and Units	Unit	Value defined
RADI (filter radius)	pixel	8
GTHR (Edge Gradient Threshold)	range, 0–255	60
LTHR (Curve Length Threshold)	pixel	20
FTHR (Line Fitting Threshold)	pixel	3
ATHR (Angular Difference Threshold)	degree	15
DTHR (Linking Distance Threshold)	pixel	20

A manual extraction, based on the geological maps of 1:50000 has also been done, and more lineaments, faults, and folds were digitized. Those were surveyed in the field and thus, are more concrete than those extracted automatically. However, both manually and semi-automatically extracted lineaments were merged into one layer to generate a density of lineaments for the study area.

3.2.3. Rainfall spatialization

The study area suffers from a lack of in-situ measured rainfall data. Therefore, remotely sensed measurements were considered in this study to assess rainfall estimations. the product is provided by The Tropical Rainfall Measurement Mission (TRMM), which uses multiple sensors that provide global and regional scale estimations of rainfall and allows the spatiotemporal monitoring of rainfall variability (Huffman et al. 2007). Nevertheless, these data have been evaluated in many studies around the world (Su et al. 2008) including Morocco (Ouatiki et al. 2017), which had examined its correlation to the punctual gauge measurements, and deduced that a significant correlation is only achieved in larger time scale (i.e., annual rainfall). Since the precipitations are spatially variable, these data have allowed outlining the rainfall rate in the area, based on the monthly estimations from 1998 to 2015.

3.2.4. Vegetation density

Since the area of study has limited surface water, the majority of irrigated areas rely on groundwater supply, therefore, they are more likely to be located near productive wells. Nevertheless, vegetation's absence is not necessarily a sign of lack of water-bearing zones. This factor has been taken into consideration depending on the fact that most cultivated fields are close to productive aquifers.

The normalized difference vegetation index (NDVI) has been calculated in order to extract the density of vegetation using the Red and the InfraRed bands, which are the two extremities of the amount of reflectance for the vegetation. Additionally, a buffer zone from 0 to 200 m was constructed around vegetation areas based on their density.

3.2.5. Weighting and combination of the factors

In order to combine the selected factors considered for this study, it is vital to apply a standardization of the values on a common scale before any calculation of groundwater potential zones. Every class in each factor was ranked a value from 1 to 5 if the classes are discrete. Otherwise, if the factor has continuous values, they were divided into 5 separate classes equally. The factors are then ready to be combined under a GIS environment using a multicriteria analysis to assign weights to each factor regarding GW favourability. The procedure is summarized in Figure 4.

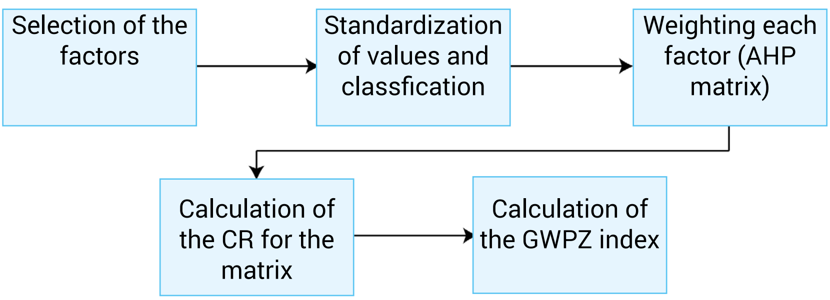

Figure 4. The procedure of the AHP used to delineate groundwater potential zone

Table 4. The matrix of pairwise comparison of the factors considered in this study

Factor	GM	LD	K	P	VD	Geometric mean	Weight (W)
GM	1	2	3	3	4	2.35	0.38
LD	1/2	1	3	3	4	1.78	0.29
K	1/3	1/3	1	3	3	1.00	0.16
P	1/3	1/3	1/3	1	2	0.59	0.10
VD	1/4	1/4	1/2	1/2	1	0.44	0.07
Sum	2.42	3.92	7.83	10.50	14.00	6.16	1.00

Notes: GM: Geomorphology, LD: Lineament density, K: Soil Permeability, P: Precipitation rate, VD: Vegetation density. With CR= 0.07349.

The method used to prioritize factors in this study is the Analysis Hierarchy Process (AHP) developed by (Saaty 1987), it has multiple applications for multicriteria analysis (MCA) and helps in decision making. Its principle is to construct a matrix of pairs of elements (i,j) of order n equals to the number of factors to be weighted (Table 4). The matrix holds pairwise comparisons from the elements in rows with respect to all the elements in the columns (a_{ij}). The condition is that the matrix should be reciprocal with $a_{ij}= 1/a_{ji}$. For instance, if an assumption was made that lineaments are three times more important than the lithology, the value 3 should be entered in the position (i,j), while the reciprocal value in position (j,i) should take the value 1/3. These judgments should be examined by calculating a consistency ratio (CR) of the matrix, which should be less than 0.1 as suggested by (Saaty 1987).

In this study, the comparison was based upon the following:

- A literature review (Shekhar and Pandey 2015 and references therein)
- The particularities that the study area imposes.
- A matrix that was suggested to then be validated by experts in hydrology and geology.

GIS environments allow the computation of pixel values from layers with different weights. Using the AHP, the groundwater potential index (GWPI) is expressed by equation (1):

$$GWPI = (W_{GM} \times R_{GM}) + (W_{LD} \times R_{LD}) + (W_{K} \times R_{K}) + (W_{P} \times R_{P}) + (W_{VD} \times R_{VD}) \qquad (1)$$

Where W represents the Normalized weight of each factor, and R represents the relative rank of each of its corresponding classes.

4. Results and validation

4.1. Spatialized factors

4.1.1. Geomorphology

The HAND model coupled with the slope, allowed to characterize the geomorphology of the Zenaga inlier, and since this area has a low topographic difference, the most present landforms in the study area are waterlogged and wetland whereas highland features (i,e. Hillslope and Plateaus) tend to approach the borders of the plain (Figure 5 a and b). Plateaus have been noticed to be consisting mainly of rhyolitic materials.

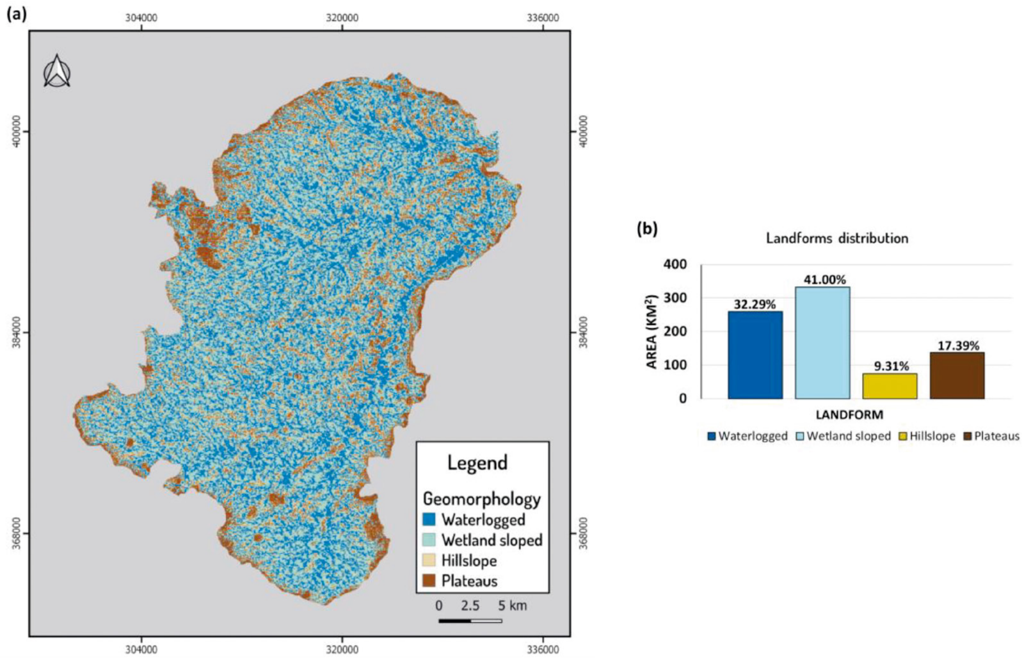

Figure 5. (a) Geomorphology thematic map within the study area showing the different landforms, and (b) their respective area

4.1.2. Lithology

A lithology layer was elaborated under a GIS environment (Figure 6), by digitizing the geological maps that cover the Zenaga inlier. The classification of lithological formations based on their permeability has been prepared thanks to different literature sources, and four major classes were defined (Table 4).

Table 5. Lithology classes in the study area

Lithology class	Permeability (hydraulic conductivity)
Andesite, Tuffs.	Very slow
Rhyolite, Rhyolitic complex.	Slow
Gabbro, Diorite, Migmatite, Granite, Quartzite, Schists, Dolerite, Limestone.	Moderate
Alluvium, Silts, Dolomite, Conglomerate.	Rapid

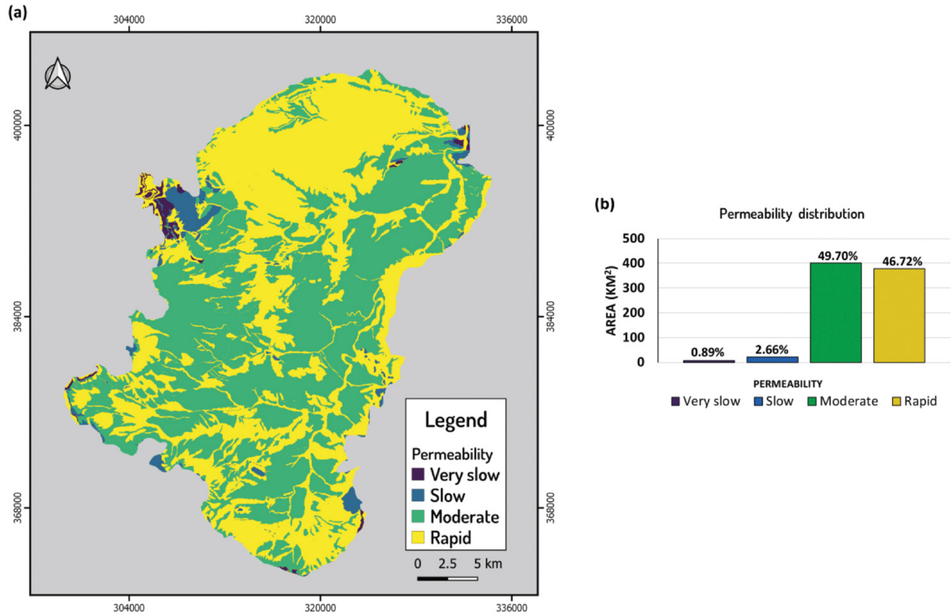

Figure 6. (a) Thematic map of soil permeability, and (b) the distribution of each class in the study area

4.1.3. Lineament density

Figure 7a shows the density of lineaments in the study area, which are concentrated in the Northern part and the South-western part of the plain.

The rosaceous diagram of lineaments extracted from both the multispectral image and the geological maps has been also constructed and showed that their trending is comparable, as shown in Figure 7b and 7c. The E-W (East-West) direction is the main trend for the semi-automatically extracted lineaments, whereas, for the manually extracted, SE-NW (Southeast - Northwest) and ESE-WNW (East-Southeast - West-Northwest) appear to be dominant.

It is obvious that most of the lineaments are in granite, gabbro, and rhyolite rocks located in the northeast part of the study area, and almost no lineaments were extracted in schist rocks.

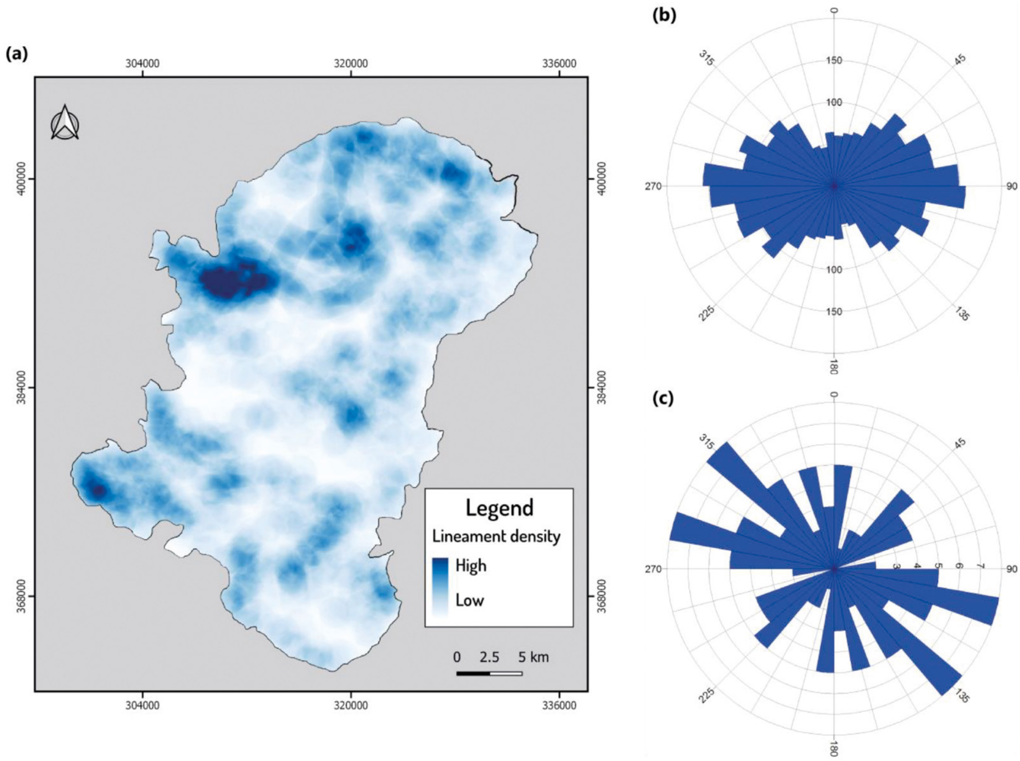

Figure 7. (a) Density of lineaments in the study area with the rosaceous diagram of lineaments direction for (b) the semi-automatically extracted and (c) the manually digitized

4.1.4. Rainfall rate

The average annual rainfall from 1998 to 2015 provided by TRMM data has been used to spatialize the rainfall rate over Zenaga inlier as shown in Figure 8.

The available meteorological station has served as a local validation of these estimations, with a direct comparison against the average of the annual gauge measurements during the same period. The kriging interpolation was carried out for these data to generate continuous estimations over the area of study.

The results show that the average annual precipitation does not exceed the 200 mm in the quasi-totality of the surface of the plain (Figure 8). Exceptionally, the precipitation exceeds 300 mm in the northern and in the south-western parts, both characterized by mountains landscape.

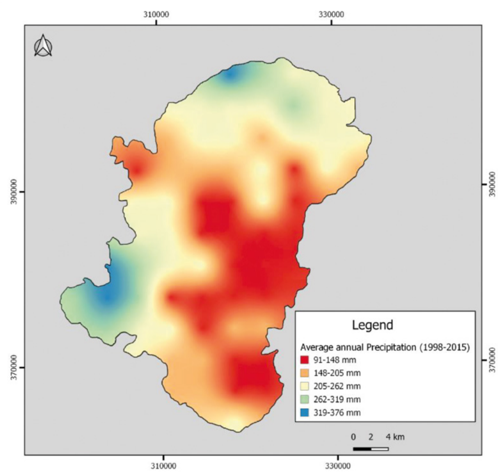

Figure 8. Average annual precipitation from the period 1998-2015 within the Zenaga inlier

4.1.5. Vegetation density

The NDVI of the area of Zenaga is disproportionately below 0.15 (Figure 9b).

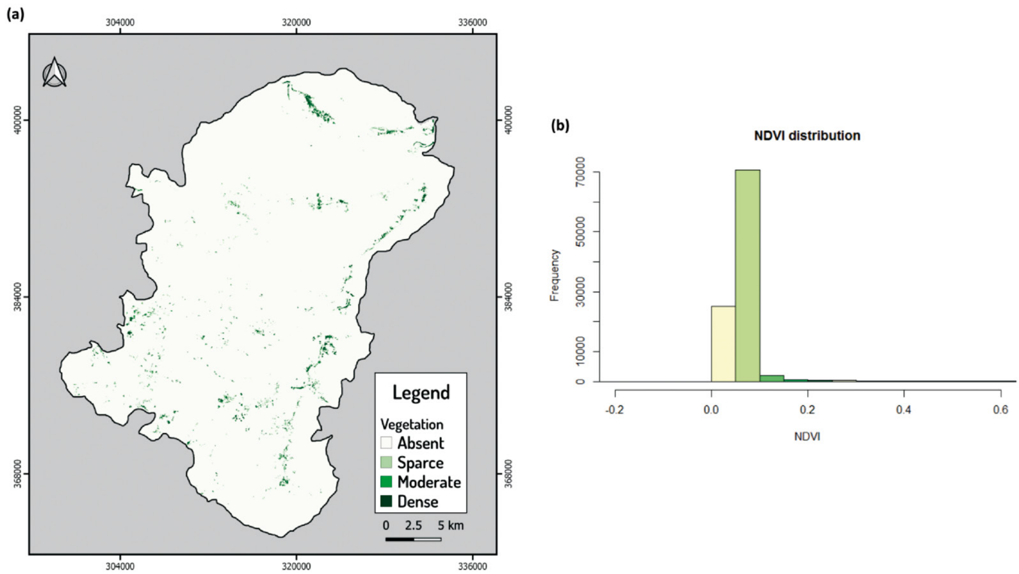

Figure 9. (a) The spatial distribution of the vegetation in the Zenaga inlier and (b) the histogram of the NDVI values

Because of long-term droughts, the vegetation occupies a minor portion of 3%. Additionally, a considerable part of agriculture used areas are still potentially rain-fed.

The correlation of the vegetation distribution with the stream pattern, which is developed along the floodplain, is obviously due to agriculture irrigation (Figure 9a).

The resulting vegetation extent maps, produced automatically using the classification method, have been validated against real vegetation extents delineated through a visual analysis offered by ortho-imagery of high resolution.

4.2. Groundwater potential zones

The groundwater potential map resulted from the multi-criteria analysis of the different factors representing GWPZ has been calculated in a GIS environment as shown in Figure 10, and reclassified in a range from 1 to 5 based on the GWP index. Values near 1 represent unfavourable areas, values from 2 to 3 represent a moderate potential area, and the values from 3 to 5 represent the high potential of groundwater. However, the results reveal that the majority of the Zenaga plain has low groundwater potential (360 km^2). High, and very high potential zones represent only 11.17% (89.9 km^2) and 0.9% (7.23 km^2) of the area respectively (Figure 10b). The zones that exhibit the highest potential according to this approach are located in the west of the *Ait n'ait Hmad* village, specifically in the lowlands around 5 km away from the above-mentioned village, which is known for a high lineament density, and highly fractured Paleoproterozoic (Granite of Azguemerzi and Migmatites) and Neoproterozoic rocks (Granite of Taznakht).

Additionally, the areas to the east of the *Taghdout* village have been also identified for the very high potential of GW. However, the north region is generally surrounded by a high potential zone that can be identified along the north side of the *Assif n'Tagdalt* stream until the north of *Taznakht*, which consists of quaternary sediments (Silts, Screes, and alluviums). An outcropping basement with fractures is found in the southwest of the plain, around the *Al Gouz* village. The rocks are dated to the Paleoproterozoic (Granite, mica schist, Migmatites, Paragneiss), and are also identified as potential aquifers.

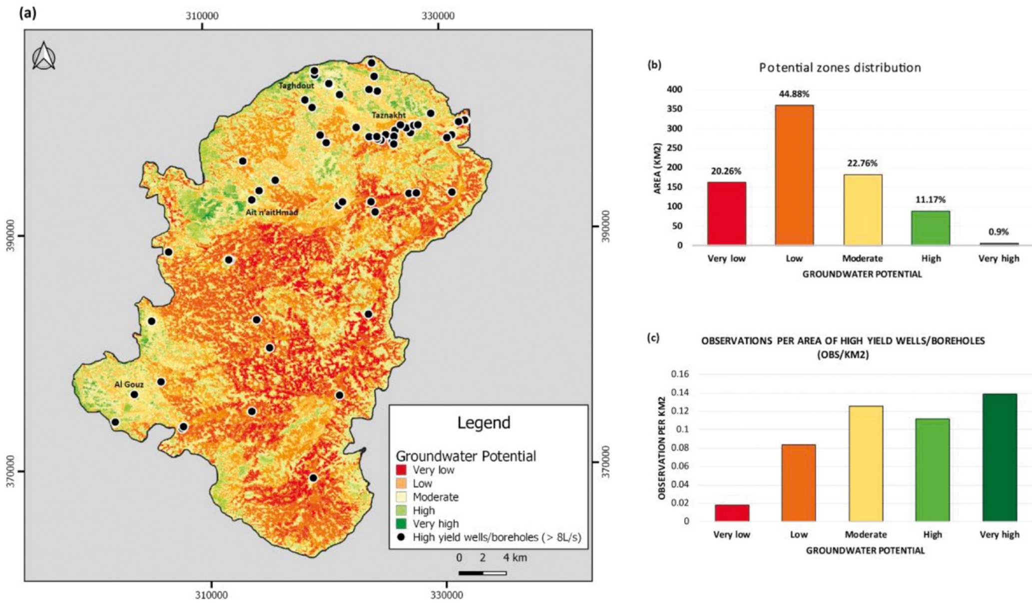

Figure 10. (a) Thematic map of the GWPI calculated throughout the Zenaga inlier using the AHP analysis. Green spots represent the high potential of GW, orange, and red tint represent low and very low potential areas respectively, (b) potential class proportions of the area of study, and (c) the distribution of high yield wells/boreholes per each potential area in the Zenaga Inlier

4.3. Quantitative validation

In such a discontinuous aquifer, the stored water is thought to be limited in quantity (Lachassagne 2008; Sikakwe 2018), which makes its discharge rate vary significantly during the pumping period. It is, therefore, imprecise to consider a given area being of low potential based only on the flow rate of the pre-existing wells within it. Hence, a validation that relies on the variation of the discharge rate of the surveyed wells as a reference to the GWP classes would not seem to be suitable for this case, especially for wells currently being exploited. This study instead has targeted all of the wells with a satisfactory yielding (more than 8 L/s) within the study area and used them as a reference. Nevertheless, the wells were spatially randomized, but have been chosen to be scattered all over the area as shown in Figure 10.

To evaluate the groundwater favourability map, a quantitative validation was performed with well data of high yield in 67 observations known in the study area. For this purpose, the database of the Hydraulic Basin Agency of Draa-Oued Noun was accessed to extract high yield wells within the area. However, 23 wells were recently surveyed in a period of 3 days. Samples from the surveyed wells were verified their quality and their compliance with drinking and irrigation water standards before being used to validate the results of this approach.

The observations were overlain using a GIS environment to the generated GWPZ to identify the corresponding potential to each of the data points, the purpose is then to make a quantitative verification of the obtained results. Figure 10c shows an obvious relationship between the potential zone and the number of high yield wells surveyed, as only 33 of the wells are located in zones with very low and low potential, despite their high occupied area of more than 75%. Hence, the groundwater favourability map shows a decent coherence between the identified potential of groundwater occurrence and high yield wells according to the proposed validation method. However, the most reliable way to validate the thematic potential GW map is to install new wells in each area of different classes indicated by the study and check the productivity of these wells, which will require having sufficient funds.

5. Discussion

Since the study has helped to delineate GW recharge zones in the Zenaga plain, many aspects of GW management and water consumption may rely on these results for decision making, and therefore, improve the villages' socio-economic conditions through a sustainable drinking water supply and irrigation in favour of the local population, by increasing the successful drilling rate of productive wells, which is still performed arbitrarily by individuals without any consultation of hydrology experts.

Nevertheless, some limitations should be noted concerning the approach to delineate water-bearing zones in a hard rock aquifer. Firstly, the field-based techniques were not considered in this study, such as the hydro-geophysical measurements, for a better understanding of the deep-seated structures and estimation of the depth to basement rocks or the geological structures (Patra et al. 2016). In terms of the dataset quality used in the study, the main issue is the lack of a high-resolution data, which is necessary to make our results more accurate and detailed.

The data used in the present study are free to access, and their spatial resolution is considered mediocre compared to what the current technologies can grant.

6. Conclusion

According to the suggested approach, Zenaga inlier, consisting of fractured hard rock materials underlaid with a crystalline basement, encompasses a few unexplored zones with high GW potential, receiving the streamflow of the Ait Douchen basin.

Although the groundwater occurrence is controlled by complex geological features, and is often poorly understood, which make the groundwater shielded against remote sensing measurements, the present approach appears to be suitable for the area, considering the bare hard rock, and the visible and easy to extract geological features within the Zenaga inlier.

Furthermore, the cost-free approach would ensure the long-term sustainability of water resources for a community with such financial constraints, and thus, contribute to the socio-economic improvement of the area, by reducing the drilling failure rate of productive wells, and through a consistent decision making to protect and manage the water supply and the irrigation.

In addition, when a larger set of data is available, it is suggested to implement machine learning methods, such as the artificial neural network that helps the prediction of a hydrologic phenomenon, especially for non-linear variables, such as rainfall, runoff, streamflow, evapotranspiration, etc., depending on the specific hydrological application, the research question, and data availability.

Acknowledgments

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References

Gannouni, S. and Gabtni, H. (2015). Structural Interpretation of Lineaments by Satellite Image Processing (Landsat TM) in the Region of Zahret Medien (Northern Tunisia). Journal of Geographic Information System. doi: 10.4236/jgis.2015.72011

Gupta, M., and Srivastava, P.K. (2010). Integrating GIS and remote sensing for identification of groundwater potential zones in the hilly terrain of Pavagarh, Gujarat, India. Water International. doi:10.1080/02508061003664419

Hssaisoune, M., Bouchaou, L., Sifeddine, A., Bouimetarhan, I., and Chehbouni, A. (2020). Moroccan groundwater resources and evolution with global climate changes. Geosciences (Switzerland). 10(2). doi.org/10.3390/geosciences10020081

Huffman, G.J., Adler, R.F., Bolvin, D.T., Gu, G., Nelkin, E.J., Bowman, K.P., Hong, Y., Stocker, E.F. and Wolff, D. B. (2007). The TRMM Multisatellite Precipitation Analysis (TMPA): Quasi-global, multiyear, combined-sensor precipitation estimates at fine scales. Journal of Hydrometeorology. doi.org/10.1175/JHM560.1

Ikenne, M., Söderlund, U., Ernst, R.E., Pin, C., Youbi, N., Aouli, E.H., and Hafid, A. (2016). A c. 1710 Ma mafic sill emplaced into a quartzite and calcareous series from Ighrem, Anti-Atlas – Morocco: Evidence that the Taghdout passive margin sedimentary group is nearly 1 Ga older than previously thought. Journal of African Earth Sciences. doi.org/10.1016/j.jafrearsci.2016.08.020

Krishnamurthy, J., Mani, A., Jayaraman, V., and Manivel, M. (2000). Groundwater resources development in hard rock terrain-an approach using remote sensing and GIS techniques. International Journal of Applied Earth Observation and Geoinformation. doi:10.1016/s0303-2434(00)85015-1

Javhar, A., Chen, X., Bao, A., Jamshed, A., Yunus, M., Jovid, A., and Latipa, T. (2019). Comparison of multi-resolution optical Landsat-8, Sentinel-2 and radar Sentinel-1 data for automatic lineament extraction: A case study of Alichur area, SE Pamir. Remote Sensing. doi.org/10.3390/rs11070778

Lachassagne, P. (2008). Overview of the Hydrogeology of Hard Rock Aquifers: Applications for their Survey, Management, Modelling and Protection. In Ahmed, S., Jayakumar, R., and Salih A. (Eds.), Groundwater Dynamics in Hard Rock Aquifers: Sustainable Management and Optimal Monitoring Network Design. doi.org/10.1007/978-1-4020-6540-8_3

Mabee, S.B., Hardcastle, K.C., and Wise, D.U. (1994). A Method of Collecting and Analyzing Lineaments for Regional-Scale Fractured-Bedrock Aquifer Studies. Ground Water. doi:10.1111/j.1745-6584.1994.tb00928.x

Madrucci, V., Taioli, F., and de Araújo, C.C. (2008). Groundwater favorability map using GIS multicriteria data analysis on crystalline terrain, São Paulo State, Brazil. Journal of Hydrology. doi:10.1016/j.jhydrol.2008.03.026

Meijerink, A.M.J., Bannert, D.N. Batelaan, O., Lubczynski, M., and Pointet, T. (2007). Remote sensing applications to groundwater. In IHP-VI Series on Groundwater. United Nations Educational, Scientific and Cultural Organization (UNESCO). Retrieved from http://unesdoc.unesco.org

Nobre, A.D., Cuartas, L.A., Hodnett, M., Rennó, C.D., Rodrigues, G., Silveira, A., and Waterloo, M. (2011). Height Above the Nearest Drainage – a hydrologically relevant new terrain model. Journal of Hydrology. doi.org/10.1016/j.jhydrol.2011.03.051

Ouatiki, H., Boudhar, A., Tramblay, Y., Jarlan, L., Benabdelouhab, T., Hanich, L., El Meslouhi, R. and Chehbouni, A. (2017). Evaluation of TRMM 3B42 V7 rainfall product over the Oum Er Rbia watershed in Morocco. Climate. doi.org/10.3390/cli5010001

Patra H.P., Adhikari S.K., and Kunar S. (2016). Remote Sensing in Groundwater Studies. In: Groundwater Prospecting and Management. Springer Hydrogeology. Singapore. doi.org/10.1007/978-981-10-1148-1_2

Saaty, R.W. (1987). The analytic hierarchy process-what it is and how it is used. Mathematical Modelling. doi.org/10.1016/0270-0255(87)90473-8

Saïdi, A., Sagon, J.P., Hafid, A., Arboleya, M.L., Saquaque, A., Rizki, A., and Julivert, M. (2001). La série de Zenaga (Anti-Atlas, Maroc) : pétrologie et structure des formations métamorphiques paléoprotérozoïques (Serie of Zenaga (Anti-Atlas, Morocco) : petrology and structure metamorphic formation of paleoproterozoic). Géologie Méditerranéenne. doi.org/10.3406/geolm.2001.1717

Sander, P. (2007). Lineaments in groundwater exploration: A review of applications and limitations. Hydrogeology Journal. doi.org/10.1007/s10040-006-0138-9

Sankar, K. (2002). Evaluation of groundwater potential zones using Remote Sensing data in upper Vaigai river basin, Tamil Nadu, India. Journal of the Indian Society of Remote Sensing. doi.org/10.1007/BF02990644

Shekhar, S., and Pandey, A.C. (2015). Delineation of groundwater potential zone in hard rock terrain of India using remote sensing, geographical information system (GIS) and analytic hierarchy process (AHP) techniques. Geocarto International. doi.org/10.1080/10106049.2014.894584

Sikakwe, G.U. (2018). GIS-based model of groundwater occurrence using geological and hydrogeological data in Precambrian Oban Massif southeastern Nigeria. Applied Water Science. doi.org/10.1007/s13201-018-0700-3

Singhal, B.B.S. (2008). Nature of Hard Rock Aquifers: Hydrogeological Uncertainties and Ambiguities. In Ahmed, S., Jayakumar, R. and Salih, A. (Eds.), Groundwater Dynamics in Hard Rock Aquifers: Sustainable Management and Optimal Monitoring Network Design. doi.org/10.1007/978-1-4020-6540-8_2

Solomon, S., and Quiel, F. (2006). Groundwater study using remote sensing and geographic information systems (GIS) in the central highlands of Eritrea. Hydrogeology Journal. doi:10.1007/s10040-006-0096-2

Su, F., Hong, Y.N and Lettenmaier, D.P. (2008). Evaluation of TRMM Multisatellite Precipitation Analysis (TMPA) and Its Utility in Hydrologic Prediction in the La Plata Basin. Journal of Hydrometeorology. doi.org/10.1175/2007JHM944.1

Thomas, R.J., Che, L.P., Gresse, P.G., Harmer, R.E., Eglington, B.M., Armstrong, R.A., De Beer, C.H., Martini, J.E.J., De Kock, G. S., Macey, P. H., and Ingram, B. A. (2002). Precambrian evolution of the Sirwa Window, Anti-Atlas Orogen, Morocco. Precambrian Research. doi.org/10.1016/S0301-9268(02)00075-X

Waters, P., Greenbaum, D., Smart, P.L., and Osmaston, H. (1990). Applications of remote sensing to groundwater hydrology. Remote Sensing Reviews. doi.org/10.1080/02757259009532107

Assessing the Potential of Groundwater Recharge: Case Study of Palla road Wellfields, Botswana

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Abstract

A feasibility study on the assessment of managed aquifer recharge in the Palla Road wellfields, situated in the Bonwapitse and Serorome Catchment area, Botswana, was conducted. Botswana is characterized by a semi-arid climate, and most of the country's anthropogenic activities are highly dependent on groundwater which can lead to over extraction thus, depleting the aquifers. Many countries, including Botswana, need to explore several water resources in order to augment the available surface water resources and to overcome the imbalance between water supply and water demand, one of the alternatives being Managed Aquifer Recharge (MAR). This research is based on spatial observations that involved the use of soil water balance and QSWAT + models to identify and assess the potential areas suitable for managed aquifer recharge in Palla Road wellfields. The following datasets were used as input files for the models: land cover, flow direction, hydrologic soil group, the soil available water capacity and climate data. The models were ran using climate data for a period of eleven years (2008-2019) respectively and the groundwater recharge was found to be prominent in three (3) years viz; 2008, 2012 and 2016 respectively in the soil water balance model. The suitable groundwater recharge zones were found to be in the central and south-eastern region of the Bonwapitse and Serorome catchment area for both models. High annual groundwater recharge values, high precipitation and low values of evapotranspiration were observed in the region when using the QSWAT+ model.

Keywords: managed aquifer recharge, groundwater, soil water balance model, QSWAT + model, Botswana

1. Introduction

Globally, water demand has been increasing over the past few decades due to population increase as well as the increasing water use per capita. The majority of the worlds freshwater is found underground, it attributes to about 30% of the supply NGWA (2020). Groundwater also provides drinking water to about 50% of the global population and accounts to 43% of all the water that is used for irrigation. Moreover, 2.5 billion people depend on groundwater solely for their basic human needs Hassan (2018). Furthermore, groundwater plays an essential role in ensuring the attainment and implementation of the United Nations Sustainable Development Goals (SDGs). Conti (2016) affirms that groundwater is the most abstracted raw material on earth. However, globally, groundwater resources are limited, and are declining in terms of quality and quantity due to contamination and climate change impacts (Singh et al., 2019).

Groundwater use differs depending on its location; the country and region depending on the climate, water availability, financial resources and socio-economic development of that locality Igor (2004). Crawford (2016) categorizes Botswana as a semi-arid country located in Southern Africa with most of the country (about 70%) covered by the Kalahari Desert, with an annual rainfall average rainfall of less than 250mm. As a result, this makes the country to be classified as water stressed. Igor (2004) explained that over two-thirds of Botswana's rural and urban population, industry and livestock water demand is satisfied by using groundwater resources.

The rate of groundwater recharge differs depending on different parameters that is, the characteristics of the aquifer. Groundwater recharge is part of the basic hydrological cycle through precipitation (Akter, 2020). According to Rashid (2003), semi-arid countries such as Australia, Namibia and Botswana have put more emphasis on surface water resources although they depend mostly on groundwater resources however, gradually they are gradually recognizing groundwater. Moreover, Caroline (2017) enlightened that continual increase in population as well as climate variability experienced in Botswana has led to a great use of groundwater thus putting greater stress than ever before on groundwater resources. In addition to that, water scarcity is a major challenge for the development of Botswana therefore artificial aquifer recharge is amongst the most effective ways to store groundwater Caroline (2017).

Groundwater is relatively cleaner than surface water resources in terms of water quality. Therefore, it is imperative to do an investigation of it. In addition to that, Maliva (2020) put an emphasis that groundwater quality is of good quality that is generally better than the available surface water supplies. Water Resources Institute (WRI) projections by Luo et al. (2015) indicated that Botswana's water stress by the year 2040 will be high. Moreover, Botswana is facing water security challenges that have put pressure on the available water resources. Therefore, MAR serves as one of the key initiatives to improve the implemented water supply strategies. The research aims to do a feasibility study on water storage assessment and to identify aquifers that have the potential to store artificial groundwater recharge, this is important for present and future water demands and also to ensure the protection of groundwater, thus prudent water resource management will be achieved. This has led to artificial groundwater recharge to be considered by Linhe et al. (2020) among other alternatives to better water stress and its adverse effects in Botswana. The Soil Water Balance and QSWAT + model will be used for the analysis of the Palla Road wellfields, potential for artificial groundwater recharge.

2. Materials and methods

Palla Road also known as Dinokwe, is located in the Eastern part of Botswana as shown in Figure 1, lies between latitudes 22°S and 25°S and 25°E and 28°E longitudes. It is situated in the transboundary Limpopo River Basin, which according to the Global Water Partnership, (GWP, 2011) fact sheet is shared between four countries: Botswana, Mozambique, South Africa and Zimbabwe. In total, there are 72 transboundary aquifers in Africa, which cover about 42% of the land Nijsten et al. (2018). Furthermore, the Limpopo Basin is considered to be very important for water resources in Botswana as most of the dams are situated in the basin. Also, Serorome River Valley is regarded to be the most prominent topographic feature in the area, it is a broad and ephemeral tributary river channel draining towards the Limpopo River. Due to this, the Bonwapitse River is a major tributary in the Serorome river valley.

2.1 Study area

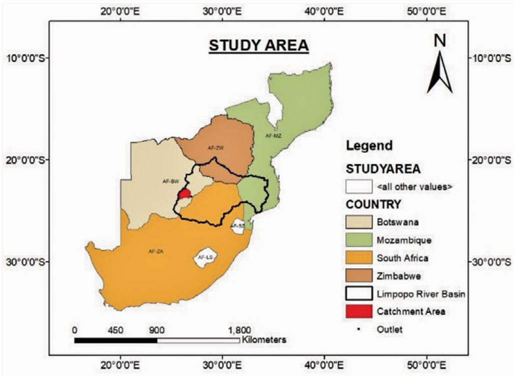
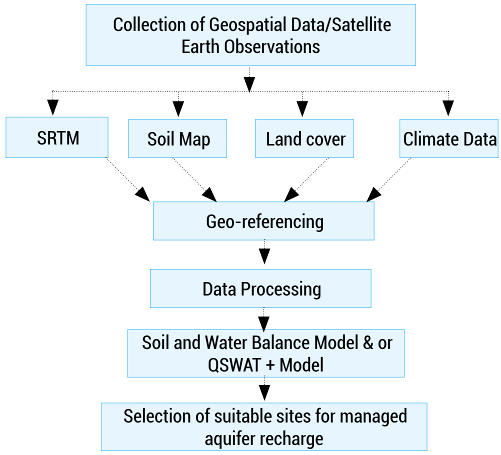


Figure 1. Representing the study area

2.2. Graphical methodology/data collection and preparation



3. Results

Spatial data were used to analyze the groundwater recharge in the Palla Road wellfields. The soil water balance model was run for a period of eleven years, from (2008-2019) in order to determine the suitable zones (sites) for managed aquifer recharge at the Palla Road wellfields. Many regions in the Palla Road wellfields are considered to be suitable for artificial recharge based process, particularly in the central and south eastern regions. From the simulation the model ran in a three step time series and three recharge maps were configured for the year 2008, 2012 and 2016 respectively as shown in Figure 2, Figure 3 and Figure 4 below.

The identification of suitable sites for MAR was based on the following criteria for the input files: flow direction map, soils hydrologic soil group, soils available water capacity and the land cover. The input files together with climate were evaluated using ArcGIS. As a result, the year 2012 showed a high value of groundwater recharge 77.37 inches= 1965.2mm represented in Figure 3. Following which, the year 2012 which had a groundwater recharge value of 74.48 inches= 1891.8mm in Figure 4 and thereafter the year 2008 where the recharge was 18.52 inches=470.4 mm. These figures show the suitable regions which are proposed as viable sites for MAR. The unsuitable areas with a very low annual recharge are found to be in the north eastern parts of the Serorome and Bonwapitse Catchment areas.

All of the tested criteria input files (flow direction map, soils, hydrologic soil group, soils available water capacity, land cover and climate) show that there is varied groundwater recharge over the years.

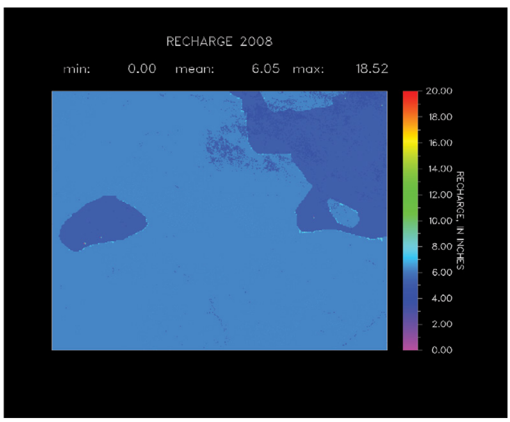


Figure 2. Representation of the groundwater recharge for the year 2008

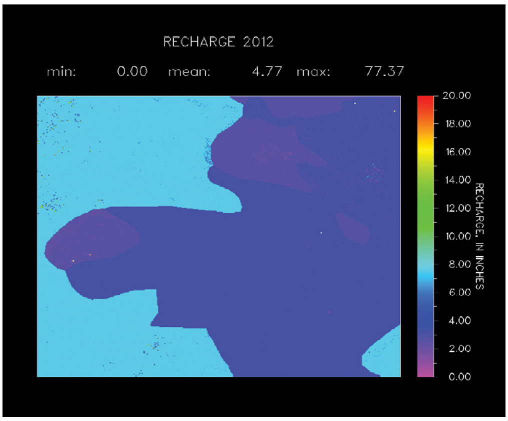


Figure 3. Representation of the groundwater recharge for the year 2012

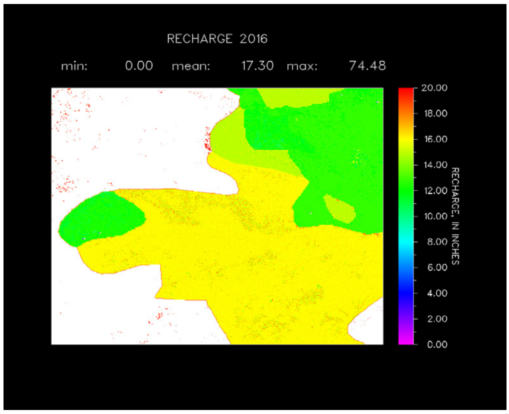


Figure 4. Representation of the groundwater recharge for the year 2016

3.1. Using QSWAT+ model

The QSWAT + Model was run for a period of eleven years from (2008-2019). The results show that the annual average aquifer recharge of the Palla road wellfields, located in the Bonwapitse and Serorome catchment area, ranges from about 250mm to 330mm as shown in Figure 5. Simulation of the amount of precipitation for the period of eleven years was also done as shown in Figure 6. The Figure 6 shows that there are three distinct regions of high, medium and low precipitation. High values of precipitation for a total duration of eleven years are found in the northern part of the catchment ranging at about 4750mm, medium precipitation found along the central part of the catchment has values range at around 4430mm and low values are found to be 4370mm located at the far south and western part of the catchment.

The evapotranspiration (ET) map of Bonwapitse and Serorome catchment is represented by Figure 7. High rates of ET were observed in the northern parts of the catchment area. This is represented in Figure 8, it shows the potential ET. Figure 9 shows the percolation that occurs in the area.

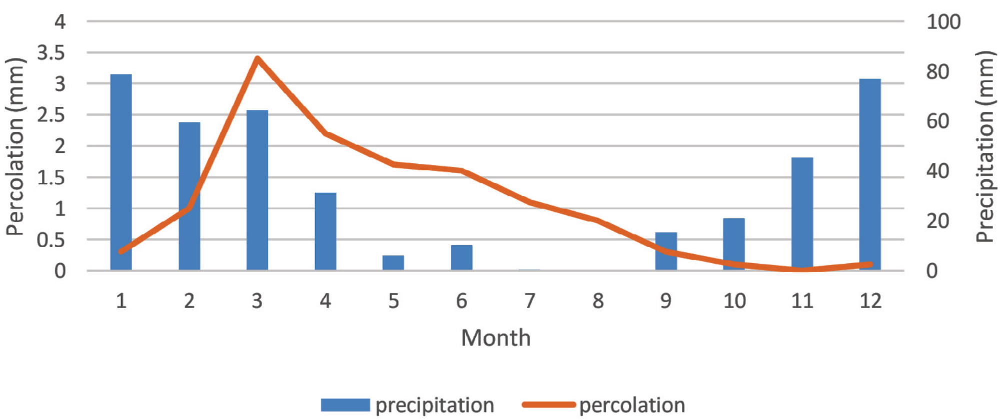


Figure 5. Basin mean monthly precipitation and percolation in the Bonwapitse and Serorome Catchment

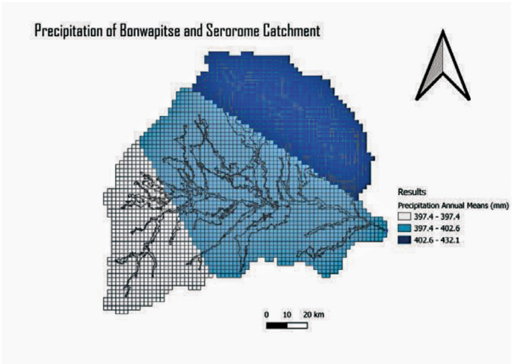


Figure 6. Precipitation of the Bonwapitse and Serorome Catchment

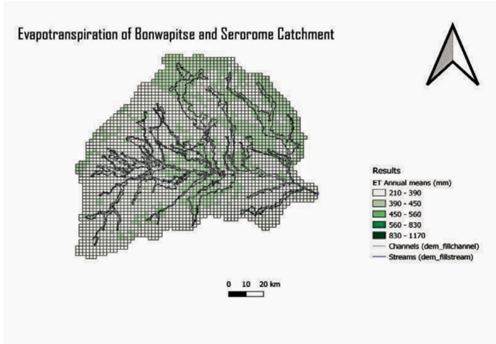


Figure 7. Evapotranspiration of the Bonwapitse and Serorome Catchment Area

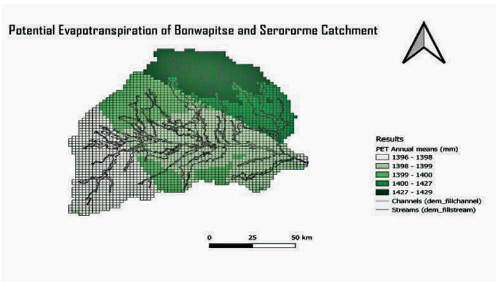


Figure 8. Potential Evapotranspiration of the Bonwapitse and Serorome Catchment Area

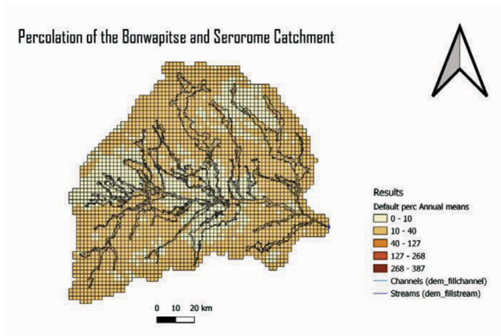


Figure 9. Percolation in the Bonwapitse and Serorome Catchment area

3.2. Basin water balance out put

The water balance output for the Serorome and Bonwapitse Catchment area are represented by the figures below Figure 10, 11 and 12 respectively. The figures are a representation of the annual mean water balance, precipitation vs percolation chart and precipitation and evapotranspiration chart.

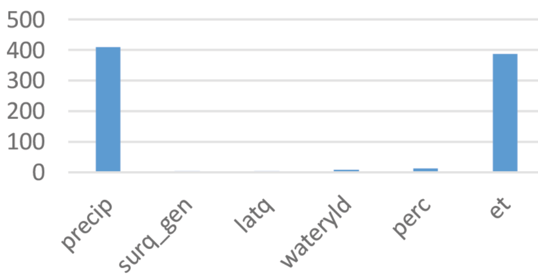


Figure 10. Mean Annual Water Balance (2009-2019)

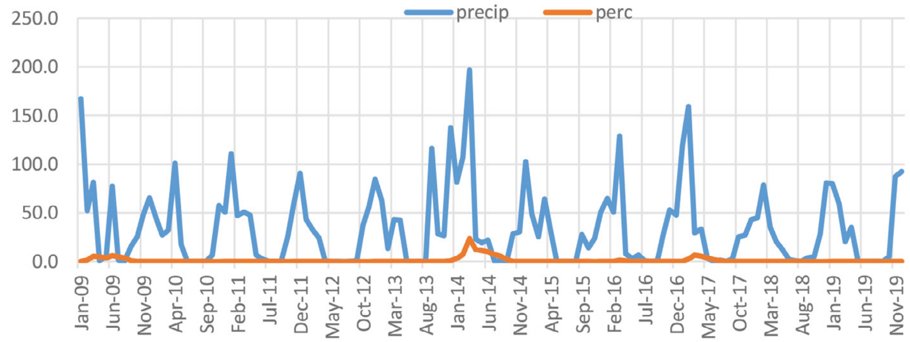


Figure 11. Precipitation and Percolation in the Bonwapitse and Serorome Catchment Area

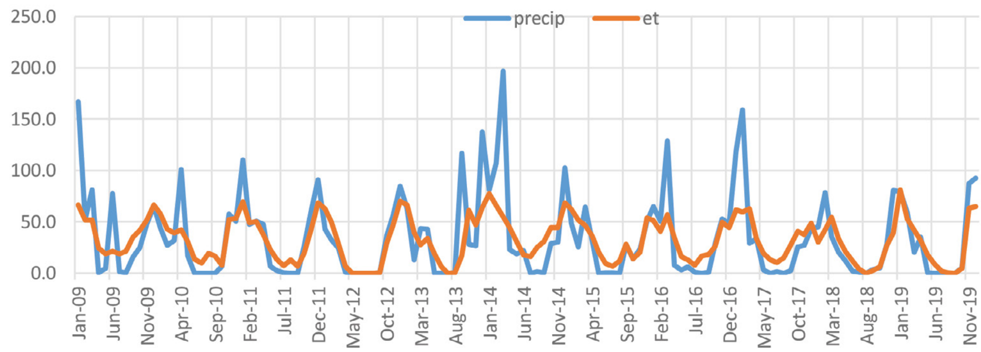


Figure 12. Precipitation and Evaporation in the Bonwapitse and Serorome Catchment Area

4. Discussion

The findings from this research based on the hydrological and soil properties indicate that, Palla Road wellfields have a significant potential in Managed Aquifer Recharge implementation. This serves as an opportunity to mitigate the adverse effects of low and unreliable rainfall thus translating to low natural groundwater recharge rates due to the semi-arid climate.

There has been no review of MAR in Palla Road wellfields however, MAR suitability mapping has been carried out by Ebrahim et al. (2017) for Ramotswa transboundary aquifer located in the south-eastern part of Botswana. Therefore, the limitations of the project were data availability and the lack of previous studies on MAR in Botswana. However, MAR has been used in all parts of the world, in Europe it has been used for over a century with a trial and error method and has continued to develop, Sprenger et al. (2017). Furthermore, it has been noted that the benefits of MAR could develop to it being top priority in ensuring water sustainability. As a result, it has been considered to alleviate the constant effects of climate change, salinization, and increased weather variability. Yaraghi et al. (2019), elucidated that MAR helps provide a stable and increased groundwater supply which has improved the socio-economic lives of semi-arid region inhabitants.

Modelling and assessing water resources with lack of data can be addressed by using geo-spatial data which can provide the required information. Although, when modelling groundwater resources there are minimal tools to provide the required data. Despite the limitations incurred when carrying out the project the main objective of identifying the potential of MAR in Palla Road wellfields has been achieved.

The soil and water balance showed a variance in groundwater recharge over the years with the 3 output files represented on figures 3.1, 3.2 and 3.3 although the central part represents higher recharge rates. The QSWAT + model has shown that the northern part of the catchment area has high precipitation rates but also has high evaporation. The southern side of the catchment has low precipitation and low evaporation rates. These are represented by the figures 3.5 and 3.7 respectively. Therefore, according to representations from the results section it can be seen that both models; the water balance model and the QSWAT + model suggest that the center region is most suitable for MAR. Also, it is evident from figure 3.9 which shows the annual water balance that most of the precipitation that most of the precipitation is lost through evaporation in the area. Also, the percentage evaporation ratio is 98% which classifies the climate as Arid Steppe using the Koeppen Climate classification. This communicates that MAR could be implemented so that the water losses due to evaporation are minimized by the deliberate input of water to the ground. Moreover, the figures 3.4 and 3.8 show the groundwater recharge. Figure 3.4 shows how the precipitation and percolation are co-related and it elucidates that during the months of February and March is when most of the percolation occurs. In addition to that, figure 3.8 is more precise and specific to the regions where more percolation occurs.

5. Conclusion

The world is gradually recognizing the value of groundwater, the United Nations World Water Day theme for the year 2022, "Groundwater: Making the Invincible Visible". Groundwater is a non-renewable resource that should be managed effectively. In this research, the soil water balance model was used in order to determine MAR suitability in Palla Road wellfields and to further improve the groundwater resource management in the area. To conclude, water is life and plays an essential role in sustainable development. Thus, groundwater management in Botswana is imperative as this resource provides water for most parts of the country. Therefore, MAR serves as a basis to ensure sufficient supply of water for the future growth of the population.

Botswana having a semi-arid climate, has never favored the country characterizing it with little or no rainfall annually therefore MAR implementation serves as a solution to diversify its available water resources. In addition to that, it increases the estimated natural recharge rate in wellfields. With regard to the knowledge, tools and techniques used in this research I recommend the launch and implementation of MAR in Palla Road wellfields. This has been proven to be a substantial investment that improves and contributes positively to the water security of countries that are already practicing different MAR technologies for example, Namibia were some of the wellfields were completely replenished and also encourages an integrated approach of water management. Furthermore, extensive research based on the hydrogeological characteristics to access the potential of managed aquifer recharge in Palla Road wellfields is needed.

Acknowledgements

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References

Akter, A., Uddin, A. M. H., Wahid, K. Ben, & Ahmed, S. (2020). Predicting groundwater recharge potential zones using geospatial technique. *Sustainable Water Resources Management, 6(2)*. https://doi.org/10.1007/s40899-020-00384-w

Caroline, R., & Modisha, O. (2017). Investigation of the Ramotswa Transboundary Aquifer Area, groundwater flow and pollution Reshoketswe Caroline Oudi Modisha GEOL 7028 – Research report In partial fulfillment for Master of Science in Hydrogeology School of Geosciences University of the Witwatersrand. June.

Conti, K. I., Velis, M., Antoniou, A., & Nijsten, G. (2016). Groundwater in the Context of the Sustainable Development Goals: Fundamental Policy Considerations. Brief for GSDR, 5.

Crawford, A. (2016). Review of Current and Planned Adaptation Action in Botswana.

Ebrahim, G. Y., Sajad, F., Lautze, J., Ansems, N., Villholth, K., Nijsten, Gj., Magombeyi, M., Mndaweni, S., Kenabatho, P., Moehadu, M., Keetile, K., Gomo, M., Somolekae, B., Nkile, C. (2017). Review of Managed Aquifer Recharge (MAR) Experience in Africa and MAR Suitability Mapping for Ramotswa Transboundary Aquifer Area.

Global Water Partnership. (2011). Limpopo basin. https://www.gwp.org/en/WACDEP/IMPLEMENTATION/Where/Limpopo/

Hassan, M. F., & Hammuda, M. (2018). A novel observer-based tracking controller for nonholonomic wheeled mobile robots. *ACM International Conference Proceeding Series,* 2018-February, 62–66. https://doi.org/10.1145/3185066.3185074

Igor S. Zektser, L. G. E. (2004). Resources of the World and Their Use.

Lindhe, A., Ros, L., Johansson, P., & Norberg, T. (2020). *Dynamic Water Balance Modelling for Risk Assessment and Decision Support on MAR Potential in Botswana.*

Luo, T., Young, R., & Reig., P. (2015). *Aqueduct Projected Water Stress Country Rankings. Technical Note. Washington, D.C.: World Resources Institute. August, 1–16.*

Maliva, R. G. (2020). Introduction to Anthropogenic Aquifer Recharge. Tsur 1990, 1–20. https://doi.org/10.1007/978-3-030-11084-0_1

NGWA The Groundwater Association. Available online: https://www.ngwa.org/what-is-groundwater/About-groundwater/groundwater-facts (accessed on May 5, 2020)

Nijsten, G. J., Christelis, G., Villholth, K. G., Braune, E., & Gaye, C. B. (2018). Transboundary aquifers of Africa: Review of the current state of knowledge and progress towards sustainable development and management. Journal of Hydrology: Regional Studies, 20(October 2017), 21–34. https://doi.org/10.1016/j.ejrh.2018.03.004

Rashid, J. A., Glenn, H., & Lange, M. (2003). *Groundwater and Water Accounting in Southern Africa within the Perspective of Global Climate Change. August, 1–112.* https://www.car.org.bw/wp-content/uploads/2016/06/Groundwater-and-water-accounts-in-southern-Africa.pdf

Singh, A., Panda, S. N., Uzokwe, V. N. E., & Krause, P. (2019). Groundwater for Sustainable Development An assessment of groundwater recharge estimation techniques for sustainable resource management. Groundwater for Sustainable Development, 9 (April), 100218. https://doi.org/10.1016/j.gsd.2019.100218

Sprenger, C., Hartog, N., Hernández, M., Vilanova, E., Grützmacher, G., Scheibler, F., & Hannappel, S. (2017). Inventaire des sites de gestion des aquifères par recharge en Europe: développement historique, situation actuelle et perspectives. *Hydrogeology Journal, 25(6),* 1909–1922. https://doi.org/10.1007/s10040-017-1554-8

Yaraghi, N., Ronkanen, A., Darabi, H., Kløve, B., & Torabi, A. (2019). *Science of the Total Environment Impact of managed aquifer recharge structure on river fl ow regimes in arid and semi-arid climates.* 675, 429–438. https://doi.org/10.1016/j.scitotenv.2019.04.253

C. ADDRESSING WATER SCARCITY AND QUALITY

Assessment of Innovative Water Solutions as a Response to Water Scarcity in Africa: A Review

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Abstract

Today, 40 percent of the African population is living in cities, and that percentage is projected to grow to 50 percent by 2030. Besides the growing population, the groundwater over exploitation, water pollution risks in Agriculture and both observable and potential effects of climate change on water resources in Africa led to water scarcity as well as certain challenges like ensuring the basic water supply and sanitation, food security, and economic development. In order to feed the growing population and contribute to water quality and quantity in Africa there is a need for sustainable and innovative solutions. The three methods that have been proposed to address the issue of water scarcity in Africa are, open access of remotely sensed derived data portal (WaPOR), designing and implementing an innovative agriculture system for producing food in urban areas (Vertical Farming) and implementing Integrated Water Resources Management (IWRM). Results showed that vertical farming is the practice of growing crops in vertically inclined surfaces with use of less water and no soil. WAPOR uses remote sensing technologies to monitor and report on agricultural water productivity over Africa and IWRM as the Global Water Partnership defined, is the process of promoting the coordinated development and management of water, land, and related resources, to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. This paper is an attempt to review the best practices of the three chosen methods to improve water quality and quantity in Africa. It's also a critical review of different resources that guides to provide a set of recommendations and lessons that can benefit young people to replicate them in Africa.

Keywords: Africa, water resources, water scarcity, innovative solution, planetary boundaries.

1. Introduction

Water scarcity is one of the major challenges of the 21st Century. There is unprecedented pressure and competition for water resources due to several factors (FAO, 2017). It has been predicted that by 2050, at least, one in four people is likely to live in a country with shortage of freshwater. Consequently, ensuring availability and sustainable management of water has been adopted as part of the United Nations Sustainable Development Goals, Transforming Our World: the 2030 Agenda for Sustainable Development. In fact, water should not be a problem in Africa considering her abundant natural resources (World Bank, 2003). However, the groundwater overexploitation, water pollution risks in agriculture and both observable and potential effects of climate change on water resources in Africa led to water scarcity as well as certain challenges like ensuring the basic water supply and sanitation, food security, and economic development (Douglasa and al, 2006). The planetary boundaries framework provides such an approach which can be conducted by youth engagement and water security which are important features of the SDGs and Agenda 2063 (UN-Water, 2013). Therefore, to ensure sustainable water for future generations at adequate in quantity and quality, it is necessary to invest more in technology and innovation that young African people are leading with adequate attention to planetary freshwater boundaries (UNEP, 2014).

Water use has been identified as one of the nine planetary boundaries (Gleeson and al, 2020). The Freshwater Boundary is defined as the maximum additional consumptive blue water use in the world beyond the pre-industrial situation and set at 4000–6000 km^3 years (UNEP, 2010). Moreover, water is at the heart of sustainable development and Agenda 2063, and it is one of the cornerstones of every nation's economic growth. Young people are the water users of the future (United Nations, 2015). According to Agenda 2063: Africa would be a fully water-secure continent by 2030. Therefore, practices and new technologies would be in place to ensure the efficient use of water resources and develop new sources. About 90% of domestic wastewater would be recycled to supplement water for agricultural and industrial use (Scott and Thapa, 2015). Furthermore, water use for irrigation can be lowered by increasing conveyance efficiency (taking water from the source to the farm), distribution efficiency (farm to the field), and application to crops.

Best practices can be promoted by better access to finance for many small and medium-sized farmers. This would be through public-private partnerships, public funds to support an innovative public sector, with the right experience and the knowledge to make changes in the water sector. In addition, to sharing economy such as the spread of cheap Android smart phones to support African farmer's access to water resources, etc. Furthermore, African farmers need more knowledge together with policy reforms in water regulation and purification. Therefore, to ensure a sustainable water for future generations and adequate in quantity and quality, it is necessary to invest more in technology and innovation that young African people are leading with adequate attention to planetary freshwater boundaries. From this perspective, there is a call for change: in order to navigate pathways towards resilience and global sustainability, governance should encourage learning and innovation, be flexible to uncertainty, encompass indicators, and review mechanisms for the complex global processes that Earth system science now illuminates.

Water resources management requires a clear understanding of the ongoing challenges and innovative approaches. There is a need to focus more on the water sector challenges and find sustainable solutions. The concept of water security emerged to address the lack of a clear goal for water management (Bakker, 2012). This requires behavioral adjustment, technological innovation, policy reform, water management, governance, infrastructure investment, and global cooperation (Zekri, 2020). This paper focuses on the dissemination of knowledge and best practices of innovative technologies to monitor and improve water quality and quantity in Africa. It also provides a set of recommendations and lessons that can benefit young people to replicate them in Africa. Thus, to overcome the challenges that are fundamental to the management of water resources, cutting-edge knowledge, innovative approaches and an in-depth understanding of the underlying scientific, economic, social and environmental issues is imperative. This will foster resilience and contribute to achieving the 2030 Agenda for Sustainable Development.

2. Materials and methods

Water constitutes the bloodstream of the biosphere and a vital ingredient of development and human security. A bottom-up participatory approach needs to be followed up. This approach is to involve young people and encourage them to come up with innovative and lateral thinking on water-resources problems. In fact, most of the solutions cannot be implemented successfully without data of adequate water quantity and quality in Africa. Fortunately, the World Meteorological Organization (WMO) and other international bodies have come up with a seemingly sustainable initiative of viable real-time data and information technology. The paper proceeds as follows. First, the key solutions by their contribution to water quality and/or water quantity are presented. Second, Data are collected from international resources such as FAO AQUASTAT and World Bank database. This study, is focused especially on these initiatives:

- Water productivity through open access of remotely sensed derived data portal (WaPOR);
- Vertical farming (VF);
- Implementing Integrated Water Resources Management (IWRM).

Then, an example of a region in Tunisia was taken in order to collect water samples and to evaluate the efficiency of these innovative solutions on this region in terms of quality and quantity. Technologies cited in this paper used to eradicate water scarcity across Africa, build healthy food systems and drive the 2030 and 2063 agendas success across the region. In this introduction, three methods with compared case studies are presented followed by selections.

2.1. Vertical farming

2.1.1 Introduction to vertical farming: An innovative agriculture system for producing food in urban areas

Today food demand is increasing due to the growing population and which is one of the greatest challenges in Africa. To be able to feed the additional population, it's required to have more additional arable land which is simply not available. On the other hand, Africa has two abundant resources: its youth and agriculture sector (UNESCO, 2004). However, the agricultural sector has the lowest productivity in the world. This contributes to food insecurity and malnutrition on the continent. The population projections show that today 54 % of the world's population lives in urban areas, and by 2050, the ratio is expected to reach 66 % (United Nations, 2014).In addition, much of urbanization growth is likely to take place in Asia and Africa (Ibid 2014).

Indoor Vertical farming is one of the innovative agricultural systems for producing food in urban areas and which can keep the youth involved in agriculture. Also, it's one of the main avenues for achieving the three most important goals for economic growth and ensuring water security in Africa: new employment opportunities, food security and inclusive economic expansion. Vertical farming creates an alternate source of sustainable food production units for today's urban needs and future generation. It leads to the creation of a sustainable urban environment such as fewer abandoned lots and buildings, cleaner air, safe use of municipal liquid waste, and an abundant supply of safe drinking water.

The food production is just the start. These vertical farms will recycle grey water and black water, generate power from the incineration of plant waste (think plasma arc gasification) which will reduce waste to its constituent molecules, and harvest water from dehumidification (Rashmi and Pavithra, 2018). The patented vertical farming system can be considered a "climate-smart" solution for sustainable food production in land scarce urban areas.

Table 1. Principal advantages of the Vertical Farming method(Dickson, 2015)

Advantages
1. Less deforestation and land use. This means less erosion and less flooding, 2. Abandoned or unused properties will be used productively, 3. Crops will be protected from harsh weather conditions like floods, droughts and Snow, 4. Reduction in vehicular transport as the crops produced is easily consumed, 5. Less CO2 emission and pollution by decreasing reliance on coal burning product, 6. Overall wellness as city wastes will be channelized directly into farm buildings, 7. Water is used more effectively, 8. No chemicals or pesticides, 9. Reduction of food spoilage as crops would be sold and consumed within moments after harvesting, 10. Year-round crop production 11. Eliminates agricultural runoff 12. Significantly reduces use of fossil fuels (farm machines and transport of crops) 13. No weather related crop failures 14. Offers the possibility of sustainability for urban centers 15. Converts black and gray water to drinking water 16. Adds energy back to the grid via methane generation 17. Reduces the risk of infection from agents transmitted at the agricultural interface 18. Returns farmland to nature, helping to restore ecosystem functions and services 19. Controls vermin by using restaurant waste for methane generation.

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2.1.2 Methods employed in Vertical Farming (VF)

In this part of the paper, authors demonstrate the application of lean manufacturing implementation in the context of Vertical Farming in a practical manner. It is a process improvement methodology that is useful in a Vertical Farming context. It emphasizes reduction of waste of all kinds. In fact, single cell operations or those with limited product variety, which currently represents most VF operations, should aim to adopt lean principles.

Table 2: Vertical Farming cultivation methods

	Roots	Nutrient source
Hydroponic	Media such as soil, rock wool, peat or gravel	Mineral nutrient solvent
Aquaponic	Media such as soil, rock wool, peat or gravel	Fish waste
Aeroponic	Air	Mineral nutrient solvent mist

2.2. Open access of remotely sensed derived data portal (WAPOR)

2.2.1. Introduction to WaPOR

WaPOR is presented by (Peiser, 2020) as a tool to help countries assess the impacts of conflicts and climate extremes on food and water security, during one of the five sessions of the "Earth Observation for Agriculture under Pressure. In fact, the portal provides open access to the water productivity database and allows for direct data queries, time series analyses, area statistics and data download of key variables associated to water and land productivity. The portal provides information on variables such as water productivity, land productivity, above ground biomass production, crop calendars, harvest Index and precipitation, among others (FAO, 2017).

In-depth water accounting and auditing assessments are being carried out using WaPOR in several locations, providing an overview of availability and use of water resources by different sectors, and insight into the scope and possible impacts of water productivity increase. Assessments have been completed for the Litany River Basin and are ongoing for the Jordan River, Nile River, Niger River and Awash River basins. In Mali, Ethiopia and Lebanon, WaPOR data has been coupled with land cover and crop maps to determine productivity and identify potential gaps for irrigation schemes and smaller watersheds. This will help irrigation managers, extension workers and others follow up with water users, close existing gaps and generate "more crop per drop".

Table 3. Principal advantages of WaPOR method

Advantages
1. Open-access of Remotely sensed derived data 2. Assisting countries in monitoring water productivity, 3. Identifying water productivity gaps, 4. Proposing solutions to reduce these gaps and contributing to a sustainable increase of agricultural production. 5. Taking into account ecosystems and the equitable use of water resources 6. Overall reduction of water stress. 7. Providing near real time pixel information, 8. Assisting farmers in obtaining more reliable yields and improving their livelihoods, 9. Giving irrigation authorities the access to information to modernize their irrigation schemes.

2.2.2. Methods employed WaPOR

WaPOR sifts through satellite data and uses Google Earth Engine computing power to produce maps that show how much biomass and yield is produced per cubic meter of water consumed. The portal also allows direct data queries, time series analyses, area statistics and data download of key variables associated with water and land productivity assessments, from a catalogue of more than 6 000 data layers, with direct access through application programming interfaces (APIs). Maps are available for all of Africa and the Near East and can be rendered at resolutions of as low as 30 to 250 meters, and updated every one to ten days. Capacity development activities are being carried out to explain the concepts and methodology behind WaPOR and to train people on using the database (FAO, 2018).

2.3. Integrated Water Resources Management (IWRM)

2.3.1. Introduction to IWRM

IWRM, as the Global Water Partnership defined, is the process of promoting the coordinated development and management of water, land, and related resources, to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems. In an effort to encourage a move toward more sustainable approaches to water development and management, the World Summit on Sustainable Development (WSSD) in 2002 called for all countries to develop IWRM and water efficiency plans by 2005.

IWRM aims to support countries in their efforts to tackle specific water challenges, e.g., water scarcity, waterborne diseases, floods, droughts, and access to water and sanitation, and thus sustain their development to achieve the goals such as poverty alleviation, food security, economic growth, and ecological conservation (ESCWA, 2006). However, IWRM is not just about managing physical resources; it also requires and promotes the positive changes in water governance regarding the enabling environment, institutional roles, and management instruments (Benson et al, 2015). Table 4 shows the major steps and tasks of developing an IWRM strategy. Although the IWRM strategy is shown in a logical sequence in the table, it is by no means a one-shot and linear process but a long-term and iterative one. IWRM systems should, therefore, not only be responsive to changes among its development process, for example, between projected goals and decision-makers' willingness, but also be capable of adapting to new economic, social, and environmental conditions and to changing human values over a long-term implementation (Sun, 2011).

2.3.2. Methods employed by IWRM

In the following table, is presented the principal steps of the process of developing an IWRM strategy.

Table 4. Process of developing an IWRM strategy

Steps	Tasks
Establish status and overall goals	Water resource issues
	Goals and progress toward IWRM framework
	Recent international developments
Build commitment to reform process	Multi stakeholder dialogue
	Awareness
Analyze gaps	Water resource management functions required
	Management potentials and constraints
Prepare strategy and action plan	Enabling environment
	Institutional roles
	Management instruments
	Links to national policies
Build commitment to actions	Political adoption
	Stakeholder acceptance
	Identify financing
Implement frameworks	IWRM framework
	Framework for water infrastructure development
	Build capacity
Monitor and evaluate progress	Indicators of progress toward IWRM and water infrastructure development framework

3. Results

The situation of water scarcity and quality is even more dismal than before in Africa. New, integrated approaches are essential to couple water productivity and allocation, with resilience and landscape configuration in ecosystem services and socio-economic systems. A key challenge will be to invest in integrated land–water strategies that simultaneously meet social and economic needs, reduce pressures on finite water resources through productivity and efficiency improvements, adapt to unavoidable changes in water supply and reduce the risk of abrupt changes in the hydrological cycle. Political economy and ecology must be integrated. Getting water stewardship on to policy agendas is a large political challenge, accentuated by the fact that much of the blue water used by society is handled in a market system.

Another important challenge is transboundary water management. In shared basins, it is imperative to put in place regional integration and collaboration through treaties and multinational agreements. Such a package should include integrated management plans, establishment of appropriate legal and institutional frameworks (including monitoring systems) and the exchange of data, information and technology together with research (Godinho and Barco, 2015).

4. Discussion

Research shows that as a closed system, vertical farming consumes less water, CO2 and fertilizers compared to conventional cultivation systems. On the other hand, performing photosynthesis with artificial light increases the energy consumption. However, IWRM must deliver more tangible progress at a faster and larger scale than previously achieved. To achieve SDG 6, there is a need for increased focus on the mechanisms for implementing and using IWRM, including sustainable financing and pragmatic problem solving.

5. Conclusions

This study proved the efficiency of these solutions, especially IWRM. This technology approach is used to increase water supply through the construction of dams, aquifer recharge, desalination and reuse of treated wastewater, and management of water use by improving irrigation techniques and crop productivity. Furthermore, the results highlighted the importance of awareness and capacity development to knowledge diffusion, follow-up of farmers, decentralized and community-managed groundwater systems. A bottom-up participatory approach needs to be followed up. This approach is to involve young people and encourage them to come up with innovative and lateral thinking on water-resources problems. From this perspective, Africa needs to build more capacities in terms of data collection and build youth's capacity in this sense. The new knowledge will further the capacity of African countries to better understand the value of the seas, lakes, rivers and floodplains in order to inform the management and exploitation of the blue economy. In order to maintain a global environment that is conductive for human development and well-being, which must define and respect planetary boundaries that delineate a "safe operating space" for humanity.

African young people can start their own start-up dedicated to water security. It is true that the start-up costs are high, but with further innovation and economy of scale, the three methods (WAPOR, Vertical Farming and IWRM) may be part of a solution to feed Africa and save water. This can provide high agricultural yields, good quality food with high adaptability to the growing media and environment while minimizing the use of natural resources.

Abbreviations & Acronyms

FAO:	Food and Agriculture Organization of the United Nations
IWRM:	Integrated Water Resources Management
WAPOR:	Water Productivity through Open access of remotely sensed derived data
WMO:	World Meteorological Organization

References

Bakker K. (2012). Water security: research challenges and opportunities. Science, 337:914-915.

Benson D, Gain AK, Rouillard J. (2015). Water governance in a comparative perspective: From IWRM to a "nexus" approach? *Water Alternatives,* 8:756-773.

Dickson D. (2015), the vertical farm feeding the world in the 21st century, Advantages of Vertical Farming, Advantages of vertical farming, from: http://verticalfarm.com

Douglasa E. M., Githuib F. W., Mtafyac A. R., Greend P. A., Gliddena S .J., and Vörösmartya C. J. (2006) Characterizing water scarcity in Africa at different scales, *Journal of Environmental Management.*

ESCWA (2006). Guidelines for Legislative and Institutional Reforms Needed for the Implementation of IWRM at National Level in ESCWA Region.

FAO (2017), Water Productivity through Open access of remotely sensed derived data (WaPOR) beta version portal.

FAO (2018), working together for Zero Hunger through digital innovation, FAO digital services portfolio.

Godinho F. M. and Barco C. F. (2015), "A framework for choosing among different lean-based improvement programs," *International Journal of Advanced Manufacturing Technology,* vol. 81, no. 1–4, pp. 183–197.

Peiser L. (2020), WaPOR for the assessment of the impacts of conflicts and climate extremes on food and water security, FAO organization.

Rashmi M.R and Pavithra M.P (2018), Vertical Farming: A concept, *International Journal of Engineering and Techniques* -Volume 4 Issue 3, page 500.

Scott C.A. and Thapa B. (2015), Environmental security. In Oxford Bibliographies in Environmental Science. Oxford University Press.

Shahin, M (2002), Hydrology and water resources of Africa, *Water Science and Technology Library*, Volume 41, Kluwer Academics Publishers, Dordrecht, The Netherlands.

Sun F. (2011), In Encyclopedia of Environmental Health.

UNEP, (2010). "Afrique: Atlas de l'Eau". Division of Early Warning and Assessment (DEWA). United Nations Environment Programme (UNEP). Nairobi, Kenya.

UNEP (2014), United Nations Department of Economic and Social Affairs, revision of the World Urbanization Prospects.

UNESCO (2004),The UN world water development report Water for People, Water for Life, United Nations Educational, Scientific and Cultural Organization World Water Assessment Programme, Paris, France.

Tom Gleeson, Lan Wang Erlandsson, Samuel C. Zipper, Miina Porkka, Fernando Jaramillo, Dieter Gerten, Ingo Fetzer, Sarah E. Cornell, Luigi Piemontese , Line Gordon , Johan Rockström, Taikan Oki , Murugesu Sivapalan, Yoshihide Wada, Kate A Brauman, Martina Flörke, Marc F.P. Bierkens, Bernhard Lehner, Patrick Keys, Matti Kummu, Thorsten Wagener, Simon Dadson, Tara J. Troy , Will Steffen, Malin Falkenmark, James S. Famiglietti, The water planetary boundary: interrogation and revision, The relevance of a water planetary boundary for water management and environmental 104 governance, and our understanding of socio-hydrologic systems across scale, 2020, 3, file:///C:/Users/LENOVO/Downloads/gleeson_waterpb_oneearth_2oct19%20(3).pdf

UN-Water (2013), Water Security and the Global Water Agenda: A UN-water Analytical Brief. UN University.

United Nations (2015), General Assembly (UNGA): Draft outcome of the United Nations summit for the adoption of the post-2015 development agenda. Sixty-ninth session.

World Bank (2003), World Development Report 2003. Sustainable Development in a Dynamic World. Transforming Institutions, Growth, and Quality of Life. World Bank, Washington DC.

Zekri S. (2020), *Water Policies in MENA Countries*, Global Issues in Water Policy 23, https://doi.org/10.1007/978-3-030-29274-4_8

Water Scarcity and Water Security in Africa, a Scientometric Analysis of 20 Years of Research

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Abstract

Through the scientometric analysis of 20 years of literature, the article aims to identify the trends and emerging research areas of water security and water scarcity in Africa. This geographical connotation is very relevant in offering a decisive contribution regarding the current scientific research issues in fragile areas, considering that water scarcity affects 1 in 3 people in African countries. The analysis shows that researchers' interest has grown considerably over time, especially following the adoption of three international agreements, namely the 2030 Agenda, the Paris Agreement and the Sendai Framework for Disaster Risk Reduction. The analysis results suggest strengthening international scientific collaboration, triggering mechanisms for sharing knowledge, and focusing on the leading themes of irrigation, groundwater, and water management.

Keywords: Africa, water scarcity, water security, climate change, SDGs

1. Introduction

This paper aims to perform a scientometric analysis of the literature on water scarcity and water security in Africa for the last twenty years, from 2000 to 2019, to identify this research area's trends. The research questions to be answered are as follows:

a) How is scientific production distributed over time?
b) What are the leading journals that publish the research?
c) Which are the most influential and most cited papers in the twenty years?
d) Which are the most prolific authors?
e) To which organisations are the scholars of the subject affiliated?
f) Which agencies finance research?
g) How is research evolving?

2. Literature review

There is a growing interest in water scarcity and water security issues in Africa across the global research community. One of the pioneering studies on the subject is undoubtedly from Rijsberman (2006) which offers a review of the indicators used to identify whether water is scarce concerning supply or demand. Naik (2017) pointed out that although water problems persist in Africa, these are mainly economic and organisational and not natural. Although Hallowes et al. (2008) focused on the need to improve water management from both operational and planning perspectives, on the other hand, only a few studies have focused on the role of water education. Amahmid et al. (2019) suggest that water education programs at school should go beyond theory and focus instead of developing skills and behaviour. Hove and Osunkun (2020) recommend strengthening social media from municipalities to empower, educate, and boost civic participation for water conservation. The bibliometric analysis allows us to identify new trends, such as associating water-related research with climate change. As indicated in the United Nations Education and Organization (2020) report, water and climate change are also intergenerational challenges, as well as complex and interconnected, whose interest has grown due to an increasing number of academic programs and scientific publications.

3. Method

The scientometric analysis is conducted based on the indications of Zupic and Čater (2014), helpful in building an appropriate and rigorous scientific mapping workflow based on five steps:

1. Research design, phase in which the research questions are defined;
2. Collection of bibliometric data, through:
   a) The selection of the most appropriate data source;
   b) Definition of search criteria, filters, data export and construction of the dataset.
3. Analysis, choosing the appropriate bibliometric software or combining them, carrying out data cleaning and identifying any anomalies.
4. Visualisation, using information visualisation software
5. Descriptive interpretation of the results.

Bibliographic research is influenced by the strategy used for the query phase. The information on papers was retrieved from the Web of Science (WoS) Clarivate's repository and adopted the following research strategy as described in figure 1.

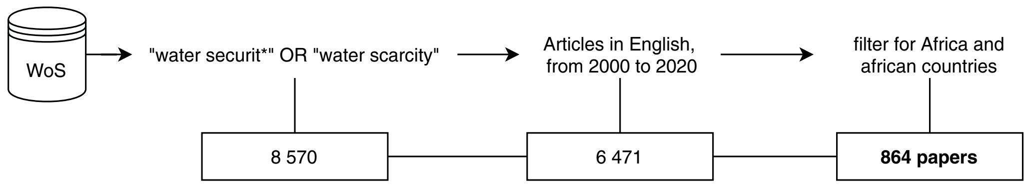

Figure 1. Research strategy

Firstly, the query *"water secur*"* OR "water scarcity" has been searched in the topic section (which includes Title, Abstract and Keywords). The wildcard "*" was used to detect words having identical root and different declinations (in the specific case *"security"* or *"securitisation"*). In doing so, 8570 results were identified. Subsequently, the search was limited to three parameters:

a) only articles (excluding book chapters, conference papers, etc.)
b) written in English and
c) published from 2000 to 2020 (data extracted on 18 August 2020).

The results thus obtained are 6471 papers. Finally, to restrict the sample only with documents having a clear geographical connotation related to Africa, it was looked in the title, abstract and keywords for the word "afric*", including the wild card to include words like "Africans", and the names of each of the 54 fully recognised by the UN country of Africa. The papers identified are 864 from 327 sources. The strategy of including the names of each state has the advantage of identifying papers that have a more geographically granular connotation, such as (Hajjaj and Hashim 2013) or (Wekesa et al. 2020) as well as those addressed to Africa in general, such as (Sanchez et al. 2020) or (Calow et al. 2010). Otherwise, filtering only by the word "Afric*" would have obtained 489 papers.

4. Results

4.1. Descriptive statistics

In the last 20 years considered (2000-2019), the scientific production on water security and water scarcity in Africa has grown considerably (*Figure 2*). The average annual scientific production from 2000 to 2019 is 22.55%, as calculated by the equation (1.1) of the Annual Growth Rate (AGR)

$$AGR = \left(\frac{FY}{IY}\right)^{\frac{1}{n}} - 1 \qquad (1.1)$$

where FY the value corresponding to the paper published in the final year, IY the number of articles published in the initial year, n the number of years between the two periods. Up to 2008, there was erratic growth, from 3 papers in 2000 to 22 in 2008. Between 2009 and 2013, 175 articles were published (20.25 % of the total), while from 2015 until 18 August 2020 there was the most flourishing period of scientific production with 573 papers published, accounting 66% of the total. It is interesting to note that in the year of adoption of the Sustainable Development Goals (2015) from Agenda 2030, the Paris Agreement and the Sendai Framework for Disaster Risk Reduction, there was a significant increase in scientific production (+ 51 % compared to 2014 and + 68 % between 2015 and 2016.

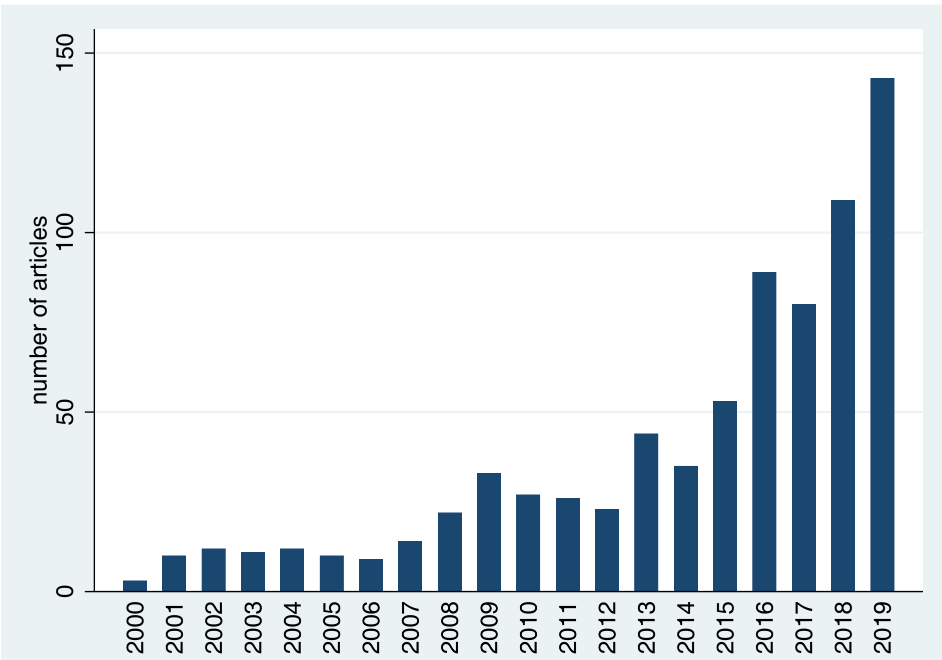

Figure 2. Annual scientific publication

The top ten journals (*Table 1*) accounts for 27 % of the total, with 236 papers published out of 864. “Water” published 39 papers, followed by “Physics and Chemistry of the Earth” (37), “Science of the total environment” (26), “Desalination and water treatment” (25), “Agricultural Water Management” (22), “Water SA” (20), while the others have published between 16 and 19 papers over the 2000-2020 period.

Table 1. Top 10 journals per number of published papers in the field

Journal	Papers	% of 864
Water	39	5%
Physics and chemistry of the earth	37	4%
Science of the total environment	26	3%
Desalination and water treatment	25	3%
Agricultural water management	22	3%
Water sa	20	2%
International journal of water resources development	19	2%
Sustainability	16	2%
Water policy	16	2%
Water resources management	16	2%

Table 2. Top 12 journals per number of total citations

Journal	NP	TC	CY
Agricultural water management	22	1204	16
Physics and chemistry of the earth	37	774	18
Global environmental change-human and policy dimensions	11	771	15
Environmental research letters	9	546	11
Water resources research	9	533	13
Water international	15	458	19
Science of the total environment	26	368	9
Desalination	12	359	19
Hydrology and earth system sciences	8	345	11
Journal of environmental management	7	325	19
Water resources management	16	312	13

Source: Authors' elaboration; NP = number of publications, TC= total citations; CY=citable years

Table 2 shows the top 12 journals by the number of total citations received (considering the journals with at least 300 citations). In addition to those in the ranking of the most prolific journals, the journal "Global Environmental Change" emerges with 771 citations from 11 papers and the highest share of average citations per article equal to 70. Other top-cited journals include "Environmental Research Letters" (546 citations from 9 papers), as well as "Journal of Environmental Management" (46 average citations per article). Among the ten papers with the highest number of total citations (Table 4) emerge studies published within 4 or 6 years from the observation period as Smakhtin, et al. (2004) and Rijsberman (2006), but also more recent studies such as Gleick (2014), Feng and Fu (2013) and Chen Zhan-Ming and Chen (2013).

4.2. Regression analysis

To estimate whether the time-factor and the number of articles published in a journal impacts the citations received, the following regression models have been specified. The first (equation 1.2) is estimated through an OLS (Ordinary Least Squares) linear regression model with TCi the total citations received by the i-th journal, NPi represents the number of articles published in the i-th journal, and Cy represents the number of years between 2019 (reference year) is the year of publication of the first water-related contribution appeared in the i-th journal, and the error term ε. The second equation (1.3) is a log-linear model, with the same regressors as the first model but with the natural logarithm of the number of total citations (logTCi).

$$TC_i = \beta_0 + \beta_1 NP_i + \beta_2 Cy + \varepsilon \quad (1.2)$$

$$logTC_i = \beta_0 + \beta_1 NP_i + \beta_2 Cy + \varepsilon \quad (1.3)$$

Table 3 reports the regression results, and both the number of published papers and the citable years are positive and statistically significant at 99%. Based on the results of model (1), one year after publication, other things being equal, a journal in the sample receives on average 5.7 additional citations (standard error (se) 1.131). The publication of an additional paper in the journal is associated, *ceteris paribus*, with an increase of 14 citations (se 3.833). The model thus defined explains 45.8% of the data. In the second model (2) the number of observations decreases from 323 to 275, due to the conversion of the dependent variable

Table 3. Regression table

	Model (1)	Model (2)
VARIABLES	Total citations	Total citations (log)
Publication (NP)	13.81***	0.119***
	(3.833)	(0.0186)
Citable years (CY)	5.708***	0.170***
	(1.131)	(0.0140)
Constant	-21.51***	1.180***
	(6.528)	(0.0964)
Observations	323	275
R-squared	0.458	0.526

Robust standard errors in parentheses
**** p<0.01, ** p<0.05, * p<0.1*

Table 4. Top 10 of the most cited papers

Title	Author	Journal	Citations	Yearly cit.
Water scarcity: Fact or fiction?	Rijsberman, (2006)	Agricultural Water Management	573	38,2
The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique	Hahn et al. (2009)	Global Environmental Change-Human and Policy Dimensions	398	33,17
Expansion of global drylands under a warming climate	Feng, et al. (2013)	Atmospheric Chemistry and Physics	292	36,5
Water, Drought, Climate Change, and Conflict in Syria	Gleick, (2014)	Weather Climate And Society	244	34,86
A pilot global assessment of environmental water requirements and scarcity	Smakhtin, et al. (2004)	Water International	231	13,59

Title	Author	Journal	Citations	Yearly cit.
Modeling blue and green water availability in Africa	Schuol, et al. (2008)	Water Resources Research	230	17,69
Vulnerability to the impact of climate change on renewable groundwater resources: a global-scale assessment	Doll (2009)	Environmental Research Letters	205	17,08
Quantitative maps of groundwater resources in Africa	MacDonald et al. (2012)	Environmental Research Letters	201	22,33
Preparing for a Warmer World: Towards a Global Governance System to Protect Climate Refugees	Biermann and Boas, (2010)	Global Environmental Politics	182	16,55
Virtual water accounting for the globalised world economy: National water footprint and international virtual water trade	Chen and Chen (2013)	Ecological Indicators	180	22,5

in the logarithmic[2] form. In this case, an additional publication, all other things being equal, is associated with an increase in the number of citations of approximately 12% (11.9%). In comparison, the effect of an additional citable year is associated with a 17% increase in the total of the journal's citations.

4.3. Productivity and collaboration networks

The most prolific authors, who have published at least 4 papers in the sample, are in Table 5, while the organisations to which researchers are affiliated are listed in Table 6.

Table 5. More prolific authors

Author	Papers
Hoekstra Ay	10
Frija A	7
Hope R	7
Speelman S	7
Rockstrom J	6
Ben Rouina B	5
Blignaut J	5
Fader M	5
Jordaan H	5
Kipkorir Ec	5
Macdonald Am	5
Mekonnen Mm	5
Owusu-Sekyere E	5
Stoler J	5
Susnik J	5
Yang H	5

2 Therefore the observations that report 0 citations are excluded, as ln (x) is defined only for x > 0).

As each paper may have multiple authors affiliated to different organisations, beneficiaries of one or more grants from many organisations. It is useful to emphasise the nature of "records" in the following tables, to be read as an occurrence counter, as information that does not necessarily belong to a single paper. Therefore, table 6 contains the ranking of organisations with which researchers are affiliated, can be easily interpreted: 28 scholars belong to the University of KwaZulu-Natal, 23 to the University of Carthage, 21 to the University of Oxford, and so on.

Table 6. Main organisation enhanced, by scholars' affiliation

Organisation enhanced	Scholars
University of Kwazulu-Natal (Ukzn)	28
Universite de Carthage	23
University of Oxford	23
International Water Management Institute Iwmi	22
University pf London	22
University pf Cape Town	21
Ihe Delft Institute for Water Education	20
Wageningen University Research	18
Centre de Coopération Internationale en Recherche Agronomique pour le Développement	17
Stellenbosch University	17

Similarly, if one considers the leading funding agencies that have provided grants to researchers (Table 7), emerge that the European Union is the prominent supporter of water-related studies in Africa 30 times, followed by the National Science Foundation (21 times) up to the United States Department of Health Human Services (9 times).

Table 7. Main funding agency

Funding Agency	Records
European Union	30
National Science Foundation	21
Economic Social Research Council	17
United States Agency for International Development	16
Natural Environment Research Council	15
National Natural Science Foundation of China	11
Federal Ministry of Education Research	9
National Institutes of Health Nih Usa	9
United States Department of Health Human Services	9

The qualitative bibliometric analysis was performed through the package Bibliometrix (Aria and Cuccurullo, 2017) written in language R. Looking at the graph of the yearly word growth (Figure 3), based on the authors' keywords, it emerges that since 2014 "*Climate Change*" is growing exponentially and new words such as "*Groundwater*" "*Irrigation*" and "*Food security*" are flourishing.

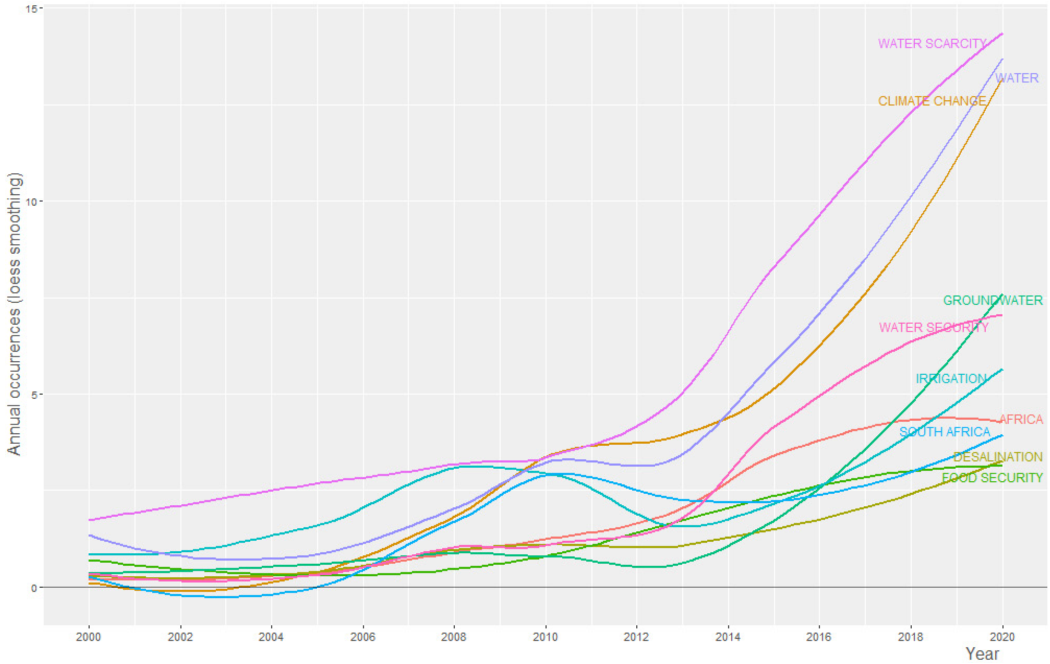

Figure 3. Annual world growth

From a different point of view, considering the annual trend topics based on the logarithm of the frequencies of the keywords (Figure 4), at least two exciting results emerge. Firstly, while "*water demand*" is a trending topic in 2010 together with "*water rights*", in 2018, the trend shifts towards "*water supply*" "*water security*" and "*water quality*". Secondly, among the words emerging over time, "*irrigation*" and "*water management*" occurred in 2014 while "*food security*" and "*desalination*" since 2016, "*groundwater*" in 2018 and "*resilience*" in 2019.

The world map is displayed in figure 5, showing the collaboration among countries (minimum two edges) and the intensity of publication in a specific country (dark blue means high intensity while light blue is a lower intensity, and a grey area are not covered). The greater frequency in collaboration between scholars from different areas occurs between the USA and the United Kingdom (15 joint papers), between the USA and Germany (14 joint papers), between South Africa and the United Kingdom (13) and between South Africa and the USA (12). The affiliation of the co-authors of the papers has a remarkable intensity in the USA (307 records), South Africa (282) and United Kingdom (193). At the same time, there are no papers published by scholars affiliated with universities in many central African countries.

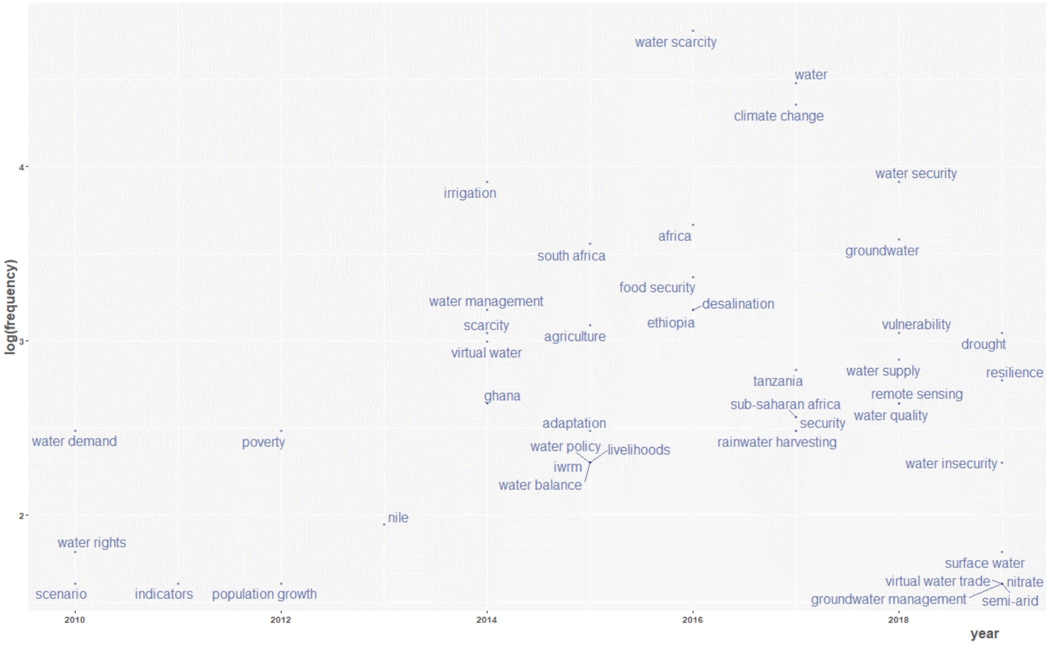

Figure 4. Trend topics (2010-2020)

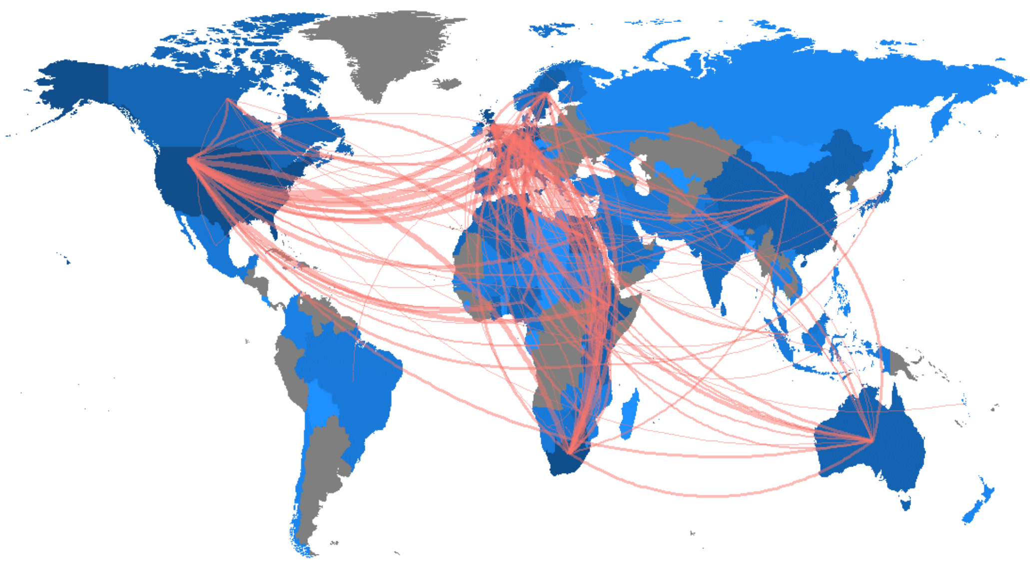

Figure 5. Country collaboration map

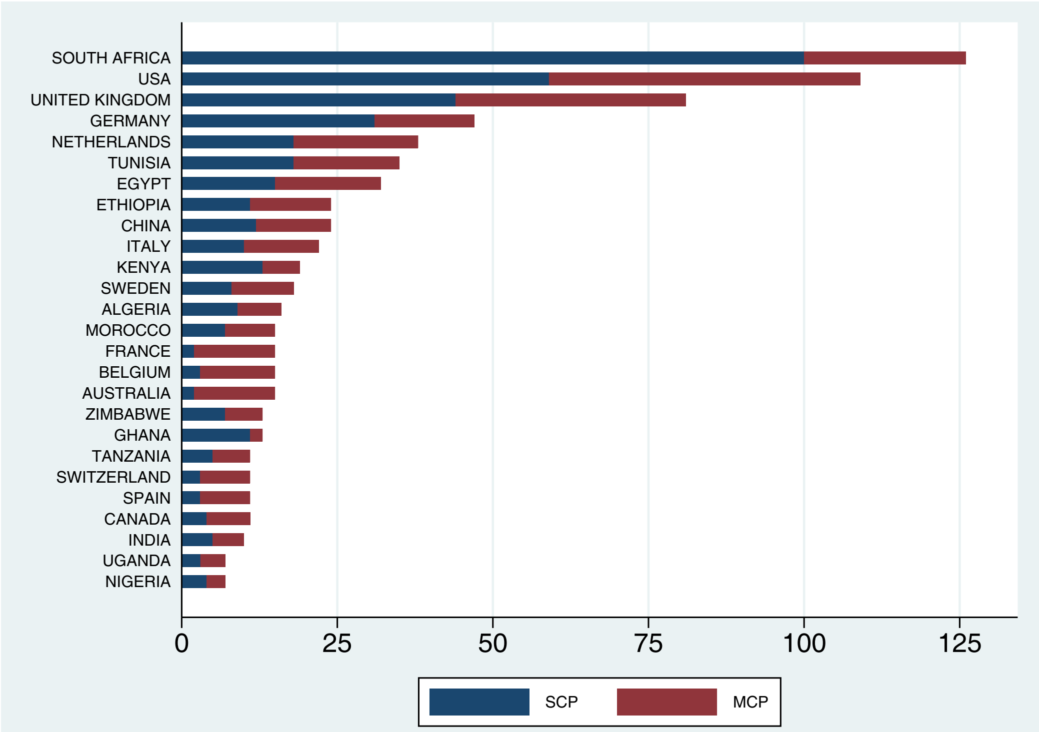

Figure 6. Country collaboration

The productivity by the corresponding author's country is in Fig.6, indicates whether the paper is published within a single country or in at least two countries, respectively associated with the colour red (Multiple Countries Publication, MCP) and green (Single Country Publication, SCP). The ration between MCP and SCP is heterogenous country-by-country varying from a minimum of 0.15 of Ghana (only two over 13 papers are published by authors affiliated to different country institutions) to a maximum of 0.86 observed for France (13 MCPs out of 15). The most prolific authors are affiliated with the Universities of South Africa and record 126 articles, or about 15% of the total. Of these, 100 are published within the South African scientific community, while 26 are written in collaboration with scholars from universities affiliated with multiple countries. Scholars affiliated with US universities have published 109 articles (about 13% of the total), 50 of which were published together with authors from non-US universities. This is the highest absolute value among the Multiple Country Publications.

4.4. Thematic analysis

From the analysis of the keywords used by the authors in the papers, it is also possible to develop a thematic map, to be used for the evaluation of research trends. The graphical representation is presented in the form of strategic diagrams (Cobo et al., 2011) based on two variables: centrality and density (Cd). The first, for a given cluster, takes into account the intensity of the connections with other external clusters, i.e. the degree of interaction of a network with others, and it is possible to interpret this value as a measure of the importance of a theme in the development of entire research field analysed. The second, on the other hand, measures the strength of the links within the network and can be interpreted as a measure of the development of the theme. The graphic visualisation of the strategic diagram allows defining four typologies of themes (Cahlik, 2000) according to the quadrant in which they appear.

- The themes in quadrant I (top right) are called *motor themes* and are characterised by high centrality and high density, therefore they are developed and important for the entire research area.
- The themes in the II quadrant (bottom right) are called *basic themes*, characterised by a high centrality and low density, therefore they are considered transversal, important for the development of a research field but not sufficiently developed internally
- The themes in quadrant III (bottom left) are *emerging or declining themes* and have both low density and low centrality. They are both weakly developed and marginal to the research field, mainly representing emerging or declining themes.
- The themes of the fourth quadrant (top left), *highly developed and isolated theme*, have well-developed internal ties but unimportant external ties. They are of only marginal importance for the field due to their high specialisation or their peripheral nature.

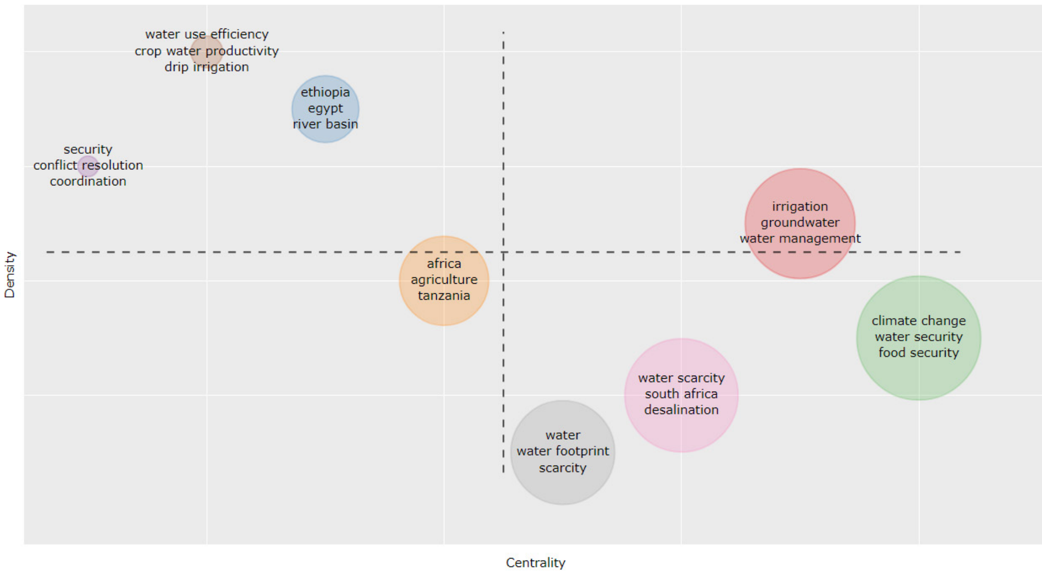

Figure 7. Thematic map

Figure 7 shows the thematic map, in which at least three clusters are considered basic and transversal themes and the most frequent words included in the respective clusters are "water", "water scarcity" and "climate change". In the first two, which is obvious to find in the basic themes, there are associated keywords such as "water footprint", "scarcity and "water scarcity", "South Africa" and "desalination" respectively. On the other hand, it is interesting that the theme of "climate change" is already considered not an emerging theme but a basic theme for research on water in Africa. The climate change cluster also includes "water security", "food security" and "resilience". The themes with greater density and less centrality, on the other hand, include different clusters including "water use efficiency", "river basin", "conflict resolution". However, among the emerging themes, the word "agriculture" is becoming more and more central within the "Africa" cluster. This is confirmed by the trend topics analysis that places the respective keywords among the most influential words of the year 2014. Despite the general interest in agriculture, the themes that lead the literature of water security and water scarcity in Africa are in the cluster accounting the keywords "irrigation", "groundwater" and "water management" and other words such as "remote sensing" and "biodiversity".

5. Discussion

This study used data from Web of Knowledge collection, which contains over 21,100 peer-reviewed, scholarly journals published worldwide in over 250 sciences disciplines, to identify the evolution of the water scarcity and water security literature in Africa. If very often the importance of scientific studies can transcend the geographical context, sometimes, and this is the case, researchers may be interested in a specific geographical area. Specifically, the research strategy employed, unlike (Molatudi et al., 2009), favoured papers that had an apparent reference to Africa or African countries in their content. This strategy has made it possible to include in the database both papers carried out inside and outside Africa, but which are focused in at least an African country, which otherwise would not have been detected. The territorial dimension becomes as relevant as granular is the availability of primary data or research results that can, on the one hand, better orient policymakers and help international organisations to monitor the progress of development policies, on the other. This can be the case of monitoring the indicators of the Sendai Framework for disaster risk reduction (Mizutori 2020), the targets of the 2030 Agenda (Xue et al., 2017) or the Millennium Development Goals (Brault et al., 2020). The "missing data" problem in Africa, however, emerged both in science (Wetsman, 2017; Wubetie, 2017; Kinyondo and Pelizzo, 2018) and in media (DW 2020; Financial Times, 2019; The Economist, 2014). Based on the information published on the Sendai monitor (UNDRR) portal, for example, it emerges that for the target named *"disaster risk reduction strategies"* from 2015 to 2019, there are no data relating to about two-thirds of African countries. Therefore, it happens that researchers try to compensate for the lack of data by conducting place-based experiments (Kumpel et al. 2015) or by using satellite sources and digital earth technologies to facilitate decision-making or policy monitoring (Al-Khudhairy, 2010; Lehmann et al. 2020; Thomas et al., 2009). Similarly, this research can represent a significant contribution to provide evidence and data on the crucial issue of water scarcity and water security in Africa, also with the ambition of offering a starting point for further studies. From the analysis of the thematic mapping, for example, the word "Tanzania" is associated with emerging or declining themes. As the country is experiencing severe weather extremes due to climate change and half of the population does not have access to clean drinking water, researchers should continue to focus on water security in Tanzania, associating it with one of the motor themes (de Bont et al., 2019; Richards, 2019). Furthermore, at least two other relevant elements emerged among the research results. Firstly, unlike the high dynamism among South African researchers, several regions of Africa have a limited share (and in some cases, there are no published in peer-reviewed journals) of research on water scarcity and water security. Secondly, the analysis of the agencies that fund the research confirms the pioneering role of the European Union in a similar way to what happens for Official Development Assistance. On the latter two aspects, a possible extension of the research could evaluate whether publicly funded research boosts bibliometric performance or patenting.

6. Conclusions

Scientific interest in water scarcity and water security in Africa is growing considerably over time. Since 2015 there has been a significant increase in published papers, especially following the release of the Sustainable Development Goals, whose SDG 6 is "*Clean water and sanitation*", the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNISDR 2015) and the Paris Agreement (UN 2015). Scholars are linking the phenomenon of water security in association with climate change, which has become a trending topic and currently represents a fundamental theme in the field of water research in Africa. This is particularly relevant as the impact of climate variability on Africa's water resources is already acute (United Nations Educational and Organization 2020), and the water-related effects of climate change on human health could exacerbate the current vulnerabilities, including the risks of food insecurity, access to safe drinking water, sanitation and hygiene. Furthermore, from the thematic mapping of the scientific literature, it emerged that irrigation, groundwater and water management are the macro-topics that are on the frontier. Although several international funding agencies are supporting researchers to study water scarcity and security in Africa, the degree of international collaboration between scholars is still limited and, instead, it could trigger the knowledge-sharing between different geographical area through a multidisciplinary approach. Finally, one of the frequent findings of the analyses also of international organisations (UN 2018) remains the availability of data. On the one hand, this does not allow measuring progress towards the Sustainable Development Goals or other international agreements, and on the other, it could compromise the possibility of carrying out evidence-based policy interventions.

References

Al-Khudhairy, D. H. A. (2010). Geo-spatial information and technologies in support of EU crisis management. *International Journal of Digital Earth*, *3*(1), 16–30.

Amahmid, O., El Guamri, Y., Yazidi, M., Razoki, B., Rassou, K. K., Rakibi, Y., Knini, G., and El Ouardi, T. (2019). Water education in school curricula: Impact on children knowledge, attitudes and behaviours towards water use. In *International Research in Geographical and Environmental Education* (Vol. 28, (3),178–193).

Aria, M., and Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, *11*(4), 959–975.

Biermann, F., and Boas, I. (2010). Preparing for a Warmer World: Towards a Global Governance System to Protect Climate Refugees. In *Global Environmental Politics* (Vol. 10, 1).

Brault, M. A., Mwinga, K., Kipp, A. M., Kennedy, S. B., Maimbolwa, M., Moyo, P., Ngure, K., Haley, C. A., and Vermund, S. H. (2020). Measuring child survival for the Millennium Development Goals in Africa: What have we learned and what more is needed to evaluate the Sustainable Development Goals? *Global Health Action*, *13*(1), 1732668.

Cahlik, T. (2000). Comparison of the Maps of Science. *Scientometrics*, *49*(3), 373–387.

Callon, M., Courtial, J. P., and Laville, F. (1991). Co-word analysis as a tool for describing the network of interactions between basic and technological research: The case of polymer chemsitry. *Scientometrics*, *22*(1), 155–205.

Calow, R. C., MacDonald, A. M., Nicol, A. L., and Robins, N. S. (2010). Ground Water Security and Drought in Africa: Linking Availability, Access, and Demand. *Groundwater*, *48*(2), 246–256.

Cobo, M. J., López-Herrera, A. G., Herrera-Viedma, E., and Herrera, F. (2011). An approach for detecting, quantifying, and visualizing the evolution of a research field: A practical application to the Fuzzy Sets Theory field. *Journal of Informetrics*, *5*(1), 146–166.

de Bont, C., Komakech, H. C., and Veldwisch, G. J. (2019). Neither modern nor traditional: Farmer-led irrigation development in Kilimanjaro Region, Tanzania. *World Development*, *116*, 15–27.

Doell, P. (2009). Vulnerability to the impact of climate change on renewable groundwater resources: A global-scale assessment. *Environmental Research Letters* (Vol. 4, Numero 3).

DW. (2020). *Wanted: Reliable data on Africa*. DW.COM. https://www.dw.com/en/wanted-reliable-data-on-africa/a-51934942

Ekumah, B., Armah, F. A., Yawson, D. O., Quansah, R., Nyieku, F. E., Owusu, S. A., Odoi, J. O., and Afitiri, A.-R. (2020). Disparate on-site access to water, sanitation, and food storage heighten the risk of COVID-19 spread in Sub-Saharan Africa. *Environmental Research*, *189*, 109936.

Feng, S., and Fu, Q. (2013). Expansion of global drylands under a warming climate. *Atmospheric Chemistry and Physics*, *13*(19), 10081–10094.

Financial Times. (2019). *African countries are missing the data needed to drive development*. https://www.ft.com/content/4686e022-f58b-11e9-b018-3ef8794b17c6

Gleick, P. H. (2014). Water, Drought, Climate Change, and Conflict in Syria. In *Weather Climate and Society* (Vol. 6, 3, 331–340).

Hahn, M. B., Riederer, A. M., and Foster, S. O. (2009). The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change-A case study in Mozambique. In Global Environmental Change-Human and Policy Dimensions (Vol. 19, 1, 74–88).

Hajjaj, M. E., and Hashim, A. H. (2013). Water security and stability in the Kingdom of Bahrain. Desalination and Water Treatment (Vol. 51, 67–74).

Hallowes, J. S., Pott, A. J., and Döckel, M. (2008). Managing Water Scarcity to Encourage Sustainable Economic Growth and Social Development in South Africa. International Journal of Water Resources Development, 24(3), 357–369. Hove, C., and Osunkun, O. O. (2020). Social Media Use for Water Conservation Education in South Africa: Perceptions of Raymond Mhlaba Local Municipality's Residents. In J*ournal of Asian and African Studies* (Vol. 55, Numero 3, pagg. 351–369).

Kinyondo, A., and Pelizzo, R. (2018). Poor Quality of Data in Africa: What Are the Issues? *Politics & Policy,* 46(6), 851–877.

Kumpel, E., Peletz, R., Bonham, M., Fay, A., Cock-Esteb, A., and Khush, R. (2015). When Are Mobile Phones Useful for Water Quality Data Collection? An Analysis of Data Flows and ICT Applications among Regulated Monitoring Institutions in Sub-Saharan Africa. *International Journal of Environmental Research and Public Health,* 12(9), 10846–10860.

Lehmann, A., Nativi, S., Mazzetti, P., Maso, J., Serral, I., Spengler, D., Niamir, A., McCallum, I., Lacroix, P., Patias, P., Rodila, D., Ray, N., and Giuliani, G. (2020). GEO Essential – mainstreaming workflows from data sources to environment policy indicators with essential variables. *International Journal of Digital Earth,* 13(2), 322–338.

MacDonald, A. M., Bonsor, H. C., Dochartaigh, B. E. O., and Taylor, R. G. (2012). Quantitative maps of groundwater resources in Africa. In *Environmental Research Letters* (Vol. 7, 2).

Mizutori, M. (2020). Reflections on the Sendai Framework for Disaster Risk Reduction: Five Years Since Its Adoption. *International Journal of Disaster Risk Science,* 11(2), 147–151.

Molatudi, M., Molotja, N., and Pouris, A. (2009). A bibliometric study of bioinformatics research in South Africa. *Scientometrics,* 81(1), 47.

Naik, P. K. (2017). Water crisis in Africa: Myth or reality? *International Journal of Water Resources Development*, 33(2), 326–339

Parikh, P., Diep, L., Gupte, J., and Lakhanpaul, M. (2020). COVID-19 challenges and WASH in informal settlements: Integrated action supported by the sustainable development goals. Cities, 107, 102871.

Richards, N. (2019). Water Users Associations in Tanzania: Local Governance for Whom? Water, 11(10), 2178.

Rijsberman, F. (2006). Water scarcity: Fact or fiction? In *Agricultural Water Management* (Vol. 80, 1–3, 5–22).

Sanchez, R. G., Seliger, R., Fahl, F., Felice, L. D., Ouarda, T. B. M. J., and Farinosi, F. (2020). Freshwater use of the energy sector in Africa. Applied Energy, 270, 115171.

Schuol, J., Abbaspour, K. C., Yang, H., Srinivasan, R., and Zehnder, A. J. B. (2008). Modeling blue and green water availability in Africa. *Water Resources Research* (Vol. 44, 7).

Smakhtin, V., Revenga, C., and Doll, P. (2004). A pilot global assessment of environmental water requirements and scarcity. Water International (Vol. 29, 3, 307–317).

The Economist. (2014). Off the map. The Economist. https://www.economist.com/international/2014/11/13/off-the-map

Thomas, B. C., Kuriakose, S. L., and Jayadev, S. K. (2009). A method for groundwater prospect zonation in data poor areas using remote sensing and GIS: A case study in Kalikavu Panchayath of Malappuram district, Kerala, India. *International Journal of Digital Earth,* 2(2), 155–170.

United Nations. (2018). SDG 6 S*ynthesis Report 2018 on Water and Sanitation.*

United Nations Educational (2020). T*he United Nations World Water Development Report 2020.*

United Nations International Strategy for Disaster Reduction. (2015a). *Sendai framework for disaster risk reduction 2015–2030.*

United Nations International Strategy for Disaster Reduction. (2015b). The Paris Agreement.

Wekesa, S. S., Stigter, T. Y., Olang, L. O., Oloo, F., Fouchy, K., and McClain, M. E. (2020). Water Flow Behavior and Storage Potential of the Semi-Arid Ephemeral River System in the Mara Basin of Kenya. *Frontiers in Environmental Science,* 8, 95

Wetsman, N. (2017). The missing pieces: Lack of Zika data from Africa complicates search for answers. Nature Medicine, 23(8), 904–906.

Wubetie, H. T. (2017). Missing data management and statistical measurement of socio-economic status: Application of big data. Journal of Big Data, 4(1), 47.

Xue, L., Liu, G., Parfitt, J., Liu, X., Van Herpen, E., Stenmarck, Å., O'Connor, C., Östergren, K., and Cheng, S. (2017). Missing Food, Missing Data? A Critical Review of Global Food Losses and Food Waste Data. *Environmental Science and Technology,* 51(12), 6618–6633.

Zhan-Ming, C., and Chen, G. Q. (2013). Virtual water accounting for the globalized world economy: National water footprint and international virtual water trade. In Ecological Indicators (Vol. 28, Numero SI, pagg. 142–149).

Zupic, I., and Čater, T. (2014). Bibliometric Methods in Management and Organization: Organizational *Research Methods.*

The Solution to Pollution: Effective Lead Removal Via Algal Biosorption

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Abstract

Lead pollution from lead acid battery (LAB) recycling is the worst form of chemical pollution in developing countries and degrades both human health and the environment. A cost-effective and renewable method of lead removal is bioremediation by Chlorella vulgaris. Its bioremediation ability is improved by HCl pretreatment which is expensive and time-consuming. Previous studies regarding the benefit of treatment, have only been conducted on low concentrations of lead and have produced poor results. These studies have not considered the high concentration of lead pollution that is caused by unregulated LAB recycling pollution in developing countries. This study tests out the effectiveness of pre-treated Chlorella vulgaris to remove high concentrations of lead pollution that originates from unregulated LAB recycling. Chlorella vulgaris biomass was mixed with different lead nitrate solutions and measured for lead concentration post bioremediation. Chlorella vulgaris present in the lead solution was centrifuged out, and this solution was tested for pH and conductivity and used in lettuce seed bioassays. The difference in removal efficiency between pre-treated and untreated algae for 20mg/L was 14%, while the 40mg/L trials had a difference of 44% and the 60mg/L trials had a difference of 36%. The findings indicate that treatment for algal bioremediation is not necessary in regions with 20mg/L lead pollution like parts of Zambezi River but is needed in areas in Kenya which have lead pollution near 40mg/L or above. This principle can be applied to determine an effective lead pollution removal strategy with algal bioremediation.

Keywords: lead pollution, bioremediation, algae, water pollution reduction

1. Introduction

1.1 Importance of lead pollution analyses

790 million people in the world, or 11% of the world's population, lacks access to safe drinking water (CDC, 2021). The water quality in these regions is affected by the chemical pollutants present in the water. More than 80% of untreated wastewater is returned back into the environment. Heavy metal toxins are dangerous in low concentrations. They are not biodegradable, so they persist in the environment. Lead is one of the deadliest heavy metals. It is a neurotoxin that causes a variety of human health problems including lead encephalopathy, behavioral disturbances, concentration difficulties, confusion, prolonged reaction times, and memory loss. In the environment, lead contaminated water inhibits plant growth by reducing ATP production, lipid peroxidation, and chlorophyll production (Li et al., 1970). The effect of lead pollution intensifies within the communities of an ecosystem through the process of biomagnification. Lead pollution in water can be sourced from water pipelines, cathode ray tubes, cell phone coatings, tire wear, bullets, bearing water, lubricating grease, solder, cables, and batteries. However, the deadliest, most pervasive form of lead pollution is sourced from unregulated lead acid batteries (LABs), which are used in automobiles. Almost 100% of LABs are recycled, yet although more lead is produced through recycling than mining this way, the process of LAB recycling is often unregulated and releases the lead back into the environment

and water bodies, initiating a contamination cycle (Association of Battery Recyclers, 2017). With the rise of the automobile industry, LAB recycling pollution is only increasing in recent years, and LAB recycling contributes to 85% of global lead pollution (Lin et al., 2011). LAB recycling is especially unmanaged in developing countries, as LAB recycling is done by unregulated small family businesses instead of large, controlled factories. LAB recycling is the number one source of chemical pollution in developing countries (Worstpolluted, n.d.) and it is much more common in such countries.

Because lead is tasteless, colorless, and odorless in water and there are few available lead testing kits, the local inhabitants of these developing countries are unaware of the high lead concentration in their drinking water. Since the high concentrations go undetected, the locals of such a country are found to have up to 613.9 micrograms of lead in a deciliter of blood (613.9 μg/dL), which is roughly 60 times greater than the safe 10 μg/dL limit (Mitra et al., 2009). Common methods of lead removal such as carbon filtration or reverse osmosis are expensive and meant for individual usage. However, bioremediation is an eco-friendly and relatively inexpensive pollution remediation process. Bioremediation removes toxic chemicals, like lead, from the environment through biological agents that naturally extract the toxin. A biological agent used in bioremediation is algae. Algae performs bioremediation in two different methods: bioaccumulation and biosorption (Bilal et al., 2018). Bioaccumulation is when the algae absorbs the pollutant at a more rapid rate than the pollutant is lost through catabolism, while biosorption is when the algae binds the pollutant to its cellular structure. Live algae can simultaneously bioaccumulate and biosorp, while dead algae is only capable of biosorption. However, dead algae can remove more lead than live algae. This is because dead algal cell walls contain sulfated ester polysaccharides and polyuronides, which are rich with carboxylic functional groups capable of metal uptake, and they have a large surface area/ volume ratios for optimal metal uptake (Velasquez, 2018). Dead algae is also more practical in real world applications because there is no possibility of eutrophication, it is reusable, dead algae is much easier to remove from the water bodies, and it does not become a part of the marine food chain. The toxicity of the lead also does not impact the dead algal biomass itself. The most common algal species used for algae bioremediation is *C. vulgaris* due to its unique cell wall structure that allows the free passage of ions in liquid solutions and more availability of binding sites (Lim et al., 2010).

The dead algal cell walls function as a magnet, attracting the ions present in the water to its cell walls. Lead mainly uses ion exchange to bind to the algal cell wall. The combination of biosorption techniques causes lead to be the most attracted to the algae when compared to other metals. Multiple protic acid treatments could be applied to the dead *C. vulgaris* to further increase their performance, as these chemical treatments rearrange the cell wall structure. The most common and effective method of pretreatment is the HCl pretreatment (Brar et al., 2017). However, HCl pretreatment increases the cost, time, and effort needed for the bioremediation process, which acts as constraints especially because the lead acid battery disposal areas are almost always developing, low income areas. The HCl pretreatment requires an increase in the amount of additional steps and materials needed (Flouty & Georgette, 2012).

1.2. Purpose of this study

In previous studies, the difference in removal efficiency between pretreated and untreated algae ranges from 15-20%, so the difference does not seem to be high enough for additional investment.The lead concentrations tested out are usually below 20 mg/L, which is considered to be incredibly high in developed countries. LAB recycling pollution occurs in lead concentrations at or above this concentration in developing countries. This study aims to find the optimal method of cleaning groundwater contaminated with very high concentrations of lead by analyzing the difference in biosorption capacity between pre-treated and untreated dead algae. The results from this study will indicate if there is a need for acid pretreatment of algal biomass in the bioremediation of water contaminated with very high concentrations of lead. The experimental design is organized in Figure 1.

1.3. Lead concentrations chosen

In the countries Morocco and Senegal as well as along the Zambezi River, lead concentrations of water reach 20 mg/L. In Nigeria and Kenya, lead concentrations of water are as high as 60 mg/L. Another concentration tested in between these two concentrations is 40 mg/L, which has been observed in parts of Sudan. Although the above concentrations are more common, the lead concentrations do reach upto 690 mg/L, which is 690,000 times the safety limit set by WHO. To put the deadliness of LAB recycling pollution in perspective, the Flint Water Crisis of 2014 resulted in water with the highest lead concentration of 13.2 mg/L.

Experimental Question	• What is the effect of different lead concentrations on the effectiveness of biosorption via pre treated and untreated dead *C.vulgaris* biomass?
Independent Variable	• Treatment type (HCl or none) • Lead concentration (20 mg/L, 40 mg/L, 60 mg/L) • 12 trials for each concentration (6 trials for both treatments) • 36 total experimental trials
Dependent Variable	• Removal efficiency percent, pH, conductivity, and metal ion uptake (mg/g) of the pretreated and non pretreated algae for each concentration • Root length of lettuce seeds post bioassay conduction (mm)
Controlled Variables	• Lead nitrate used as the contaminant • Butter crunch lettuce seeds (Lactuca sativa) • Chlorella vulgar is Algal culturing at optimum conditions (25 ± 1°C, 3900 ± 100 lux,16 hour light + 8 hour dark cycle) • Biosorption at optimum conditions (1.5 g/L biosorbent dosage, 30 ± 1°C, pH of 6, shake at 150 rpm,180 minutes, 3000 ± 100 lux) • Lettuce seed bioassayat optimum conditions (25 ± 1°C, 2 mL of media, 12 hour light and 12 hour dark cycle, 5 seeds per dish)
Control Group	• The trials with lead polluted water that contained no algal biomass (6 trials per concentration: 20 mg/L, 40 mg/L, & 60 mg/L) • 18 total trials • Baseline trial for the lettuce seeds were the lettuce seeds watered with distilled water (6 trials done)

Fig.1: Experiment Design

1.4. Research hypothesis

H_a (alternative hypothesis): If the pretreated algae is used in higher concentrations of lead, then the removal efficiency, root length of lettuce seeds, pH, conductivity, and metal ion uptake will be much higher than the untreated algae.

H_0 (null hypothesis): If the pretreated algae is used in higher concentrations of lead, then the removal efficiency, pH, conductivity, root length of lettuce seeds, and metal ion uptake will not be impacted.

2. Materials and Methods

2.1. Background information

The procedure was conducted in a total of 5 phases. The first part was to make the culturing mechanism and culture the *C. vulgaris* in this device. The second phase was to produce the lead concentrations used in this experiment. In the third phase, the biomass was extracted from the cultured *C. vulgaris* and heat-killed. Half of the biomass was treated with HCl. The fourth phase consisted of combining the lead solutions with the algal biomass. In the fifth phase, the pH, conductivity, and lead concentration of each trial was tested. In the final phase, lettuce seed bioassays were conducted with each lead concentration solution with the algae centrifuged out. All procedures were conducted in controlled, optimum conditions.

2.2. Risk & safety

The following procedures included the use of lead (II) nitrate, HCL, sodium hydroxide, and *C. vulgaris*. Manuals on how to handle live algae were reviewed. The lead (II) nitrate, HCL, and sodium hydroxide SDS sheets were reviewed. Protective goggles, lab coats, safety gloves, and face masks were worn throughout the experiment to prevent exposure. The HCl was diluted with water and poured down the drain. The NaOH was mixed into the lead nitrate solution and disposed of in the same method as the lead (II) nitrate solution. The lead (II) nitrate solutions and the used *C. vulgaris* dead biomass were disposed of by shipping to a hazardous waste disposal site (a certificate of disposal was produced at the end.)

Part 1: Culturing the algae

For making the culturing mechanism, 10 cm of 0.64-cm inside diameter (ID) piping was connected to an air pump. Then, the other end (OE) of the ID piping was joined to 25.4 cm of the 0.64-cm outside diameter (OD) piping and the OE of the 25.4 cm of the OD piping connected to an inline air filter. The OE of the inline air filter connected to another 25.4 cm of the OD piping, and the OE of the 25.4 cm of the OD piping connected to an elbow hose fitting, while the OE of the barbed adaptor was screwed to the back of the 4 port manifold. Four elbow hose fittings were screwed to the front of the 4 port manifold, and a 50.8 cm of the OD piping was attached to each of the four barbed adaptors. 0.64-cm holes were drilled to the caps of 4 soda bottles and pushed the opposite end of the 50.8 cm of the OD piping into the hole for each of the pipings attached to the 4 barbed adaptors on the front of the 4 port manifold. The schematic diagram explaining the above steps is portrayed in Fig. 2.

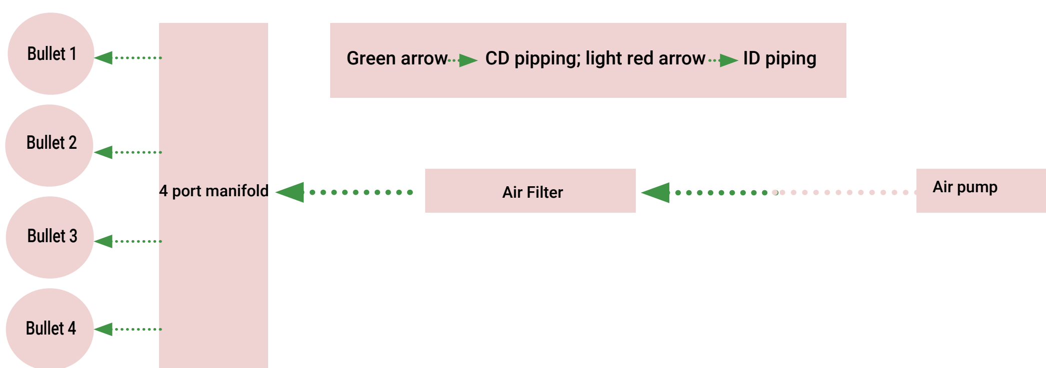

Fig.2: Schematic diagram for the algal culturing device

The Guillard's f/2 solution was mixed with 1.95 L of distilled water. 97.5 mL of *Chlorella vulgaris* algae solution was added to the f/2 media. This was repeated 4 times for each of the four bottles. The caps were closed, and tubing was pushed through the caps. *C. vulgaris* was cultured for 8 days at optimum conditions of 25±1°C, 3900±100 lux, and a 16 hour light 8 hour dark cycle. At the end of 8 days, *C. vulgaris* had a cell density of 1100 cells/mL of medium The initial experimental setup is depicted in Fig. 3.

Fig.3: Initial Experimental Set-up for stage1 © Shreya Chaudhuri

Part 2: Making the lead concentrations

To make the 60 mg/L of lead concentration,
5.8 mL of 0.05 M $Pb(NO_3)_2$ solution was mixed with 1 L of distilled water. The 40 mg/L lead nitrate concentration used 333.3 mL of the 60 mg/L lead nitrate solution and 166.7 mL of distilled water. The 20 mg/L lead nitrate concentration used 166.7 mL of the 60 mg/L lead nitrate solution and 333.3 mL of distilled water.

Part 3: Making the biomass

The cultured algae was centrifuged using a 15-mL centrifuge machine. The supernatant was removed. This centrifugation process was repeated for all of the algae cultured. The algal biomass was washed 3 times with distilled water and left in an incubator set at 90°C for 15 minutes. 2.025 g of the dry algal biomass was made into a power with a mortar and pestle. The algal biomass is depicted in Fig. 4. Then, 1.025 g of the biomass powder was suspended in 10 mL of 0.1 mM HCl and agitated on a shaker for 30 minutes at 30 rpm. After centrifuging, the pellet was thoroughly washed with distilled water. It was left to dry in an incubator set at 32°C for 12-16 hours. The schematic representation of this process is detailed in Fig. 5.

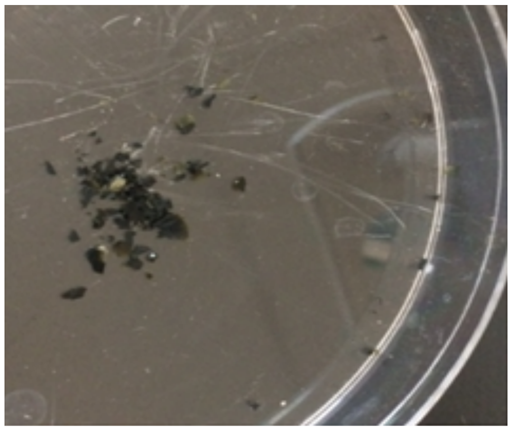

Fig. 4: Algal biomass © Shreya Chaudhuri

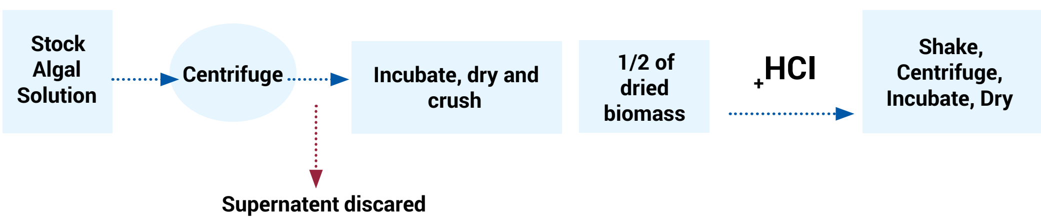

Fig.5: Schematic diagram of making the biomass and treating half of it

Part 4: Making the experimental groups

6 100-mL beakers were labelled as the pretreated algae trials for the 60 mg/L lead (II) nitrate concentration. 25 mL of the 60 mg/L lead (II) nitrate concentration was pipetted into each of the beakers. 0.0375 g of the pretreated algal biomass was mixed into each of the beakers with the lead solutions.

This process was repeated for the 6 100-mL beakers labelled as the nontreated algae trials for the 60 mg/L lead (II) nitrate concentration. 0.0375 g of the pretreated algal biomass was mixed into each of the beakers with the lead solutions. 10 100-mL beakers were labelled as the pretreated algae trials for the 40 mg/L lead (II) nitrate concentration. 25 mL of the 40 mg/L lead (II) nitrate concentration was pipetted into each of the beakers. 0.0375 g of the pretreated algal biomass was mixed into each of the beakers with the lead solutions. This process was repeated for the 10 100-mL beakers labelled as the nontreated algae trials for the 40 mg/L lead (II) nitrate concentration. 0.0375 g of the pretreated algal biomass was mixed into each of the beakers with the lead solutions. 6 100-mL beakers were labelled as the pretreated algae trials for the 20 mg/L lead (II) nitrate concentration. 25 mL of the 20 mg/L lead (II) nitrate concentration was pipetted into each of the beakers. 0.0375 g of the pretreated algal biomass was mixed into each of the beakers with the lead solutions. This process was repeated for the 6 100-mL beakers labelled as the nontreated algae trials for the 20 mg/L lead (II) nitrate concentration. 0.0375 g of the pretreated algal biomass was mixed into each of the beakers with the lead solutions. 6 100-mL beakers were labelled as the control trials for the 20 mg/L lead (II) nitrate concentration. 25 mL of the 20 mg/L lead nitrate concentration solution was poured into each of the beakers. 6 100-mL beakers were labelled as the control trials for the 40 mg/L lead (II) nitrate concentration. 25 mL of the 40 mg/L lead nitrate concentration solution was poured into each of the beakers. 6 100-mL beakers were labelled as the control trials for the 60 mg/L lead (II) nitrate concentration. 25 mL of the 60 mg/L lead nitrate concentration solution was poured into each of the beakers. The pH of each of the trials was adjusted to 6 with sodium hydroxide. The temperature was set to 30±1°C. It was agitated at 150 rpm for 180 minutes.

Part 5: Lead concentration and other tests

The algae was centrifuged out of all of the trials. The supernatant's lead concentration was measured by using the UV-Vis spectrophotometry method at 225 nm after 180 minutes (after reaching theequilibrium concentration). The pH and conductivity levels of all of the trials were also tested out. Only the pH and conductivity was tested because according to the initial research, these qualities are the most impacted by biosorption. Anova, t-test, and standard deviation were calculated to ensure that the values were valid and relevant.

Part 6: Conducting the lettuce seed bioassays

A 10% bleach solution was prepared. *Lactuca sativa* seeds were soaked in this bleach solution for 15-20 minutes and were then washed 4 times with distilled water. 54 petri dishes received a filter paper. Each plate received 2 mL of the appropriate lead concentration. 5 lettuce seeds were placed equal distance apart from each other on each petri dish. After 120 hours, the root length and physical conditions of the lettuce seed was observed and measured.

3. Results

3.1. Lead concentration difference

The UV-Vis spectrophotometry method was employed to find out the lead concentration of each trial. Using Beer's Law, the absorption (AU) was converted to a lead concentration. The removal efficiency for each lead concentration was calculated using Equation (1). In Equation (1), Ci refers to the initial concentration, and Cf represents the final concentration.

Equation (1): Removal Efficiency = $\frac{(C_i - Cf)}{C_i} \cdot 100$

Equation (2): $q = \frac{(C_i - Cf) \cdot V}{m}$

Equation (2) was used to calculate the metal ion uptake level. For the pretreated *C. vulgaris* in the 20mg/L concentration, the average removal efficiency was 98% and the average metal ion uptake level was13.0 mg/g. The untreated *C. vulgaris* in the 20 mg/L concentration had an average removal efficiency of 84% and an average metal ion uptake of 11.3 mg/g. The difference between the treatments is 14% for the removal efficiency and 1.7 mg/g for metal ion uptake level. The difference is heightened in the 40 mg/L trial. The pretreated *C. vulgaris* had an average removal efficiency of 87% and an average metal ion uptake level of 23.1 mg/g, while the untreated *C. vulgaris* had an average removal efficiency of 43% and an average metal ion uptake of 11.4 mg/g. In this concentration, the removal efficiency doubles and the metal ion uptake is nearly halved. This correlation continues in the 60 mg/L trials. The pretreated *C. vulgaris* had an average removal efficiency of 67% and an average metal ion uptake of 26.9 mg/g, but the untreated *C. vulgaris* had an average removal efficiency of 31% and an average metal ion uptake of 12.3 mg/g.

These values strongly differed with the control, which had a removal efficiency of 0% and metal ion uptake of 0 mg/g. The removal efficiency of all trials decreased with the increasing concentrations, and the metal ion uptake increased with the increase of concentrations. This is depicted in Figs. 6 and 8. Although the removal efficiency is not as high in higher concentrations, there is still more lead being absorbed onto the *C. vulgaris* so the metal ion uptake continues to increase. However, in the pretreated algae, the metal ion uptake increase is much more prominent because the removal efficiency is consistently above 50% throughout the experiment, while the untreated algae's removal efficiency decreases dramatically as the concentrations rise.

3.2. pH and conductivity difference

The pH and conductivity of each trial greatly differed and corresponded with the lead concentration left in the solution post bioremediation. The average pH and conductivity level for the 20 mg/L pretreated trials was 0.4 pH units and 60 µS/cm, while the untreated trials had 0.3 pH units and 40 µS/cm respectively. For the 40 mg/L pretreated trials, the average pH and conductivity level was 0.8 pH units and 100 µS/cm, but the untreated trials had an average pH level and conductivity level of 0.5 pH units and 58 µS/cm. Finally, the pretreated trials with the 60 mg/L solution, the average pH level and conductivity level was 1.5 pH units and 135 µS/cm. The untreated trials had an average pH level of 0.9 pH units and a conductivity level of 75 µS/cm. The control trials without any Chlorella vulgaris had a pH of 6.0 pH units and for the 20, 40, and 60 m/L trials, it had a conductivity of 100 µS/cm, 180 µS/cm , and 225 µS/cm, respectively. The pH and conductivity of the solution increased as removal efficiency increased. This is depicted in figs. 7 and 8.

3.3. Lettuce seed bioassays

The root length of lettuce seeds grown in 20 mg/L lead contaminated water that previously contained the pretreated algal biomass was 50 mm, while the untreated equivalent had a root length of 43.2 mm. The lettuce seeds grown in the 40 mg/L lead contaminated solution that was treated with pretreated algae had a root length of 44 mm, but the similar trials with the untreated algae had a root length of 22.9 mm. For the 60 mg/L lead polluted solution that was remediated with pretreated *C. vulgaris*, the root length was 23.8 mm, and the untreated counterpart's root length was 13.8 mm. The difference of the root lengths of lettuce seeds grown in lead contaminated water compared to the root lengths of the baseline value of lettuce seeds grown in distilled water was plotted on the graphs.

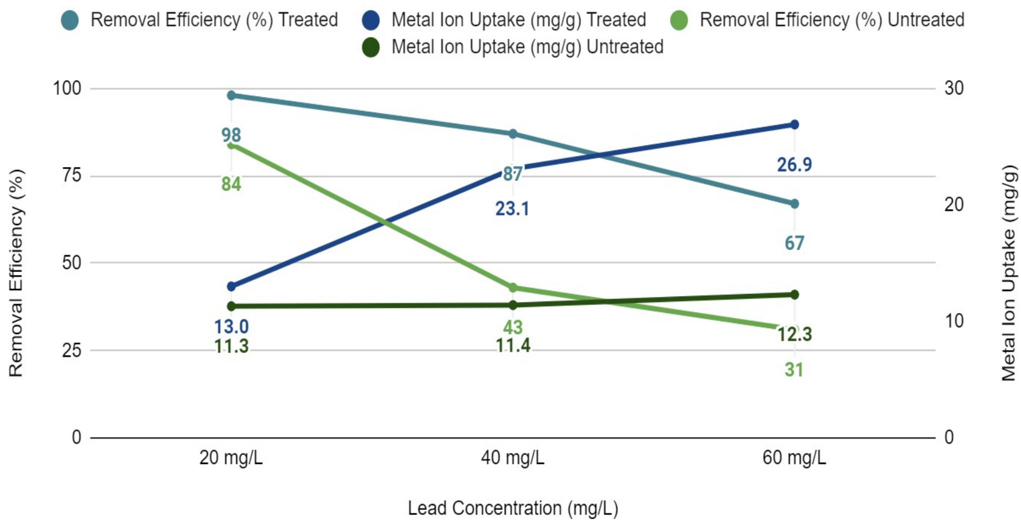

Fig. 6: Effect of Lead Concentration on Removal Efficiency & Metal Ionic Uptake

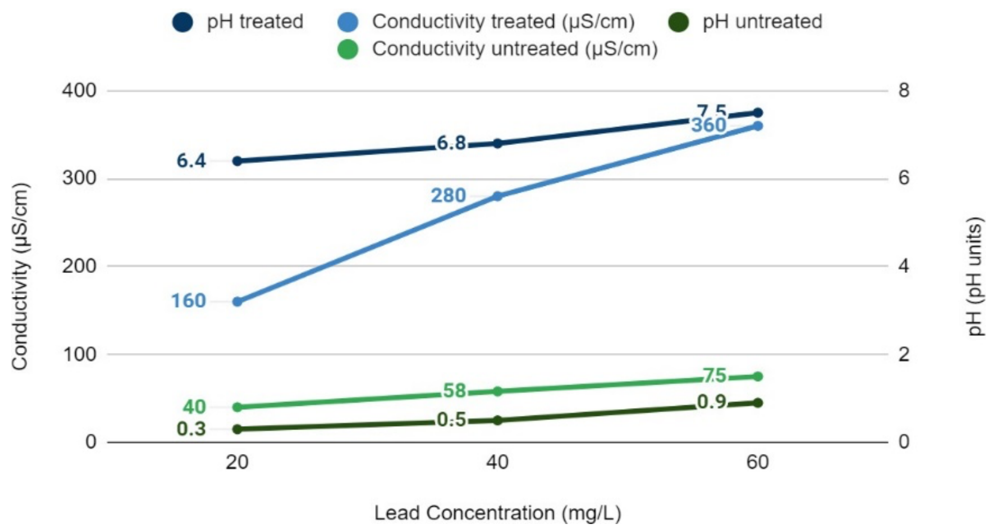

Fig. 7: Effect of Lead Concentration on pH & Conductivity

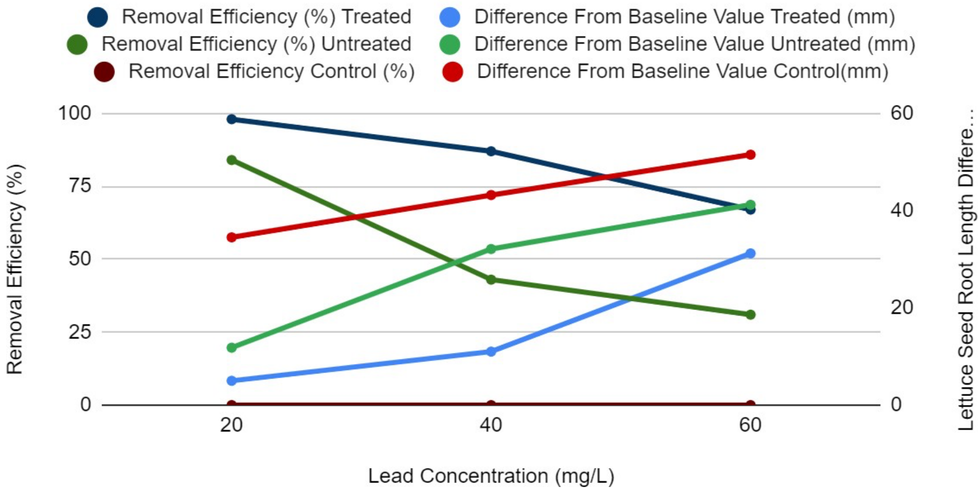

Fig. 8 Effect of Lead Concentration on Removal Efficiency & Lettuce Seed Root Length (difference from baseline trails' average of 55 mm)

Average Lead Concentration Difference for Pretreated Alagae

Concentration	Electrical conductivity (µS/cm)	Removal efficiency (%)	Metal ion uptake (mg/g)	pH in pH units	Root length (mm)	Difference from baseline value
20 mg/L	160	98	13.0	6.4	50	5
40 mg/L	280	87	23.1	6.8	44	11
60 mg/L	360	67	26.9	7.5	23.8	31.2

Average Lead Concentration Difference for Nontreated Alagae

Concentration	Electrical conductivity (µS/cm)	Removal efficiency (%)	Metal ion uptake (mg/g)	pH in pH units	Root length (mm)	Difference from baseline value
20 mg/L	140	84	11.3	6.3	43.2	11.8
40 mg/L	236	43	11.4	6.5	22.9	32.1
60 mg/L	300	31	12.3	6.9	13.8	41.2

Average Lead Concentration Difference for No Alagae (Control Trials)

Concentration	Electrical conductivity (µS/cm)	Removal efficiency (%)	Metal ion uptake (mg/g)	pH in pH units	Root length (mm)	Difference from baseline value
20 mg/L	100	0	0	6.0	20.5	34.5
40 mg/L	180	0	0	6.0	11.8	43.2
60 mg/L	225	0	0	6.0	3.5	51.5

Fig. 9 A verage conductivity, pH, metal ion uptake, removal efficiency, root length, difference from baseline length for pretreated, untreated, and control trials

4. Discussion

4.1. Benefits of pretreatment

Dead *C. vulgaris* has a rigid cell wall with two basic layers - the algenan layer and the polysaccharide layer, which consists of the hemicellulose and the cellulose. Influenced by lead's electronegativity, the polysaccharide layer contains many carboxylic functional groups that the lead binds to through the process of ion exchange (Lesmana et al., 2009). In ion exchange, the ions that were previously bound to the carboxylic functional groups leave the cell and the Pb+ ions from outside the cell bind to the functional group. The HCl pretreatment improves this process because it partially dissolves thehemicellulose, which exposes more binding sites within the cell wall and allows the lead to also bind to the inorganic and organic complexes within the *C. vulgaris.* Essentially, the HCl treatment enables both extracellular and intracellular biosorption to occur.

4.2. Effects on the ph and conductivity

pH and conductivity of the solution increases with the increase of removal efficiency (Sulaymon et al., 2013). This occurs because the light metal ions present on the carboxylic functional groups involved in biosorption on the cell walls are released when the cell wall or the algal biomass comes in contact with the lead bearing solution. The light metals are usually alkaline earth metals, so the increase of their concentration increases the pH, and the increase of metal ions in a solution always raises the conductivity (Zhang et al., 2018). Therefore, as more biosorption occurs, a greater release of the light metal ions will occur, thereby raising the pH and conductivity.

4.3. Effects of the increase of lead concentration on the algae (pretreatment vs regular) and the ability for metal ion uptake

The cell wall contained enough binding sites to support the ion exchange of lead in the lower concentrations, but as the lead concentrations increased, less binding sites were open (Saunders et al., 2012). This led to the decrease of removal efficiency and explains why the initial difference of removal efficiency, metal ion uptake, pH, conductivity, and lettuce seed root length between the pre treated and untreated *C. vulgaris* was less than 15% for the 20 mg/L trials but increased as the lead concentration increased. In the pretreated *C. vulgaris* trials, the HCl exposes more binding sites, so even as the lead concentration increases, the *C. vulgaris* is still able to remove over 60% of the lead. However, in the untreated algae as the lead concentration increases, fewer carboxylic function groups are available for the lead to bind to, as the intracellular biosorption did not occur because of the sturdy cell wall not being dissolved by the HCl.

4.4. Significance of the lettuce seed bioassays

Lead is detrimental towards plant growth, because it inhibits ATP production, lipid peroxidation, seed germination, chlorophyll production, and water protein content (Kumar et al., 2020). This is caused by the obstructed electron transport, distribution of Calvin Cycle enzymes, and CO2 deficiency from the closure of the stomata, among other harmful effects that rise from lead inside of the plant (Silva et al., 2017). As a result, a high lead concentration in the water would decrease the root length and germination time. This correlation was displayed in the results. The lettuce seeds were chosen as the bioassay initially because lettuce seeds are a common bioassay for measuring both soil and water toxicity. Because the LAB pollution originates in the soil and then leaks into the groundwater, impacting the drinking water sources and agricultural water sources. So, this gives an insight on whether the water post-bioremediation is harmful and shows how the lettuce seeds, a living organism, would have reacted to the lead present in water.

4.5. Error analysis & further improvements

The pH of a solution rapidly changes due to carbonic acid forming through the reaction with the distilled water in the lead (II) nitrate solutions, so the pH might be slightly inaccurate (Kulthanan et al., 2013). To avoid inaccuracy, each pH measurement was recorded 5 times and averaged to decide on the pH of each trial; standard deviation was calculated to ensure that each recording was acceptable. To build on this study, in addition to HCl, other common pretreatments like CaCl2 or formaldehyde pretreatments' effectiveness in higher lead concentrations could be analyzed.

4.6. how this study can help water pollution caused by lab recycling pollution

As portrayed in the figure below, Morocco, Senegal, and Zambezi River, areas of Africa that have lead concentrations of 20 mg/L in some groundwater, would not require an HCl pretreatment. The 20mg/L trials with the untreated *C. vulgaris* leaves a concentration of 3.1 mg/L in the water. This amount of lead can be removed using inexpensive organic bio adsorbents. Green coconut shells, cassava peelings, wheat shells, and papaya wood, which can be found in this area, have removal efficiencies of 97% or above (EPI, 2018). If used only once or twice on the water body after bioremediation, the lead concentration level will be within the safe level set by the EPA and WHO. But, in Kenya, Nigeria, and Sudan, pretreatment is necessary for optimal lead reduction. This concept is illustrated in Fig. 10.

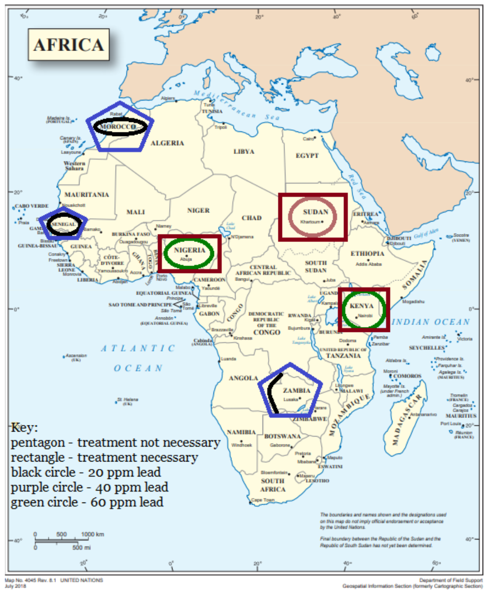

Fig 10. Clean-up Action Plan Details

5. Conclusions

In water bodies with lead concentration around 20 mg/L but less than 40 mg/L, pretreatment is not absolutely necessary as it is only around 15% more efficient than untreated algae.

In water bodies with concentrations around or above 40 mg/L, pretreatment is necessary. The process would take twice as much time, effort, and money, but regardless of this fact, pretreatment improves removal efficiency.

Funding must be allocated to ensure pretreatment in developing countries.

The null hypothesis was rejected, and the alternative hypothesis was accepted. All of the pretreated trials had a higher metal ion uptake, removal efficiency, root length of lettuce seeds, conductivity, and pH. even in higher lead concentrations. The method of lead removal should be tailored to the concentration, instead of employing a generic method for all cases.

The lettuce seeds will still grow in the lead contaminated water that was cleaned with pretreated algae, and it displays fewer physical signs of lead stress. The lettuce seeds that were grown in the lead polluted water that was cleaned with untreated algae, had more lead accumulation at the root tips.

As deduced by the results from the lettuce seed bioassay, any agricultural crop will be damaged when grown using lead polluted water that was cleaned up solely by untreated algae.

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References

2018 epi Results. (2018). Retrieved April 10, 2021, from https://epi.yale.edu/epi-countries

Bilal, M., Rasheed, T., Sosa-Hernández, J. E., Raza, A., Nabeel, F., & Iqbal, H. (2018). Biosorption: An Interplay between Marine Algae and Potentially Toxic Elements-A Review. Marine drugs, 16(2),65. https://doi.org/10.3390/md16020065

Brar, A., Kumar, M., Vivekanand, V., & Pareek, N. (2017). Photoautotrophic microorganisms and bioremediation of industrial effluents: current status and future prospects. 3 Biotech, 7(1), 18. https://doi.org/10.1007/s13205-017-0600-5

Flouty, Roula, and Georgette Estephane. (2012) "Bioaccumulation and Biosorption of Copper and Lead by a Unicellular Algae Chlamydomonas Reinhardtii in Single and Binary Metal Systems: A Comparative Study." Journal of Environmental Management, Academic Press, Volume 111, 30 November 2012, Pages 106-114. https://doi.org/10.1016/j.jenvman.2012.06.042

Global wash fast facts. (2021, April 01). Retrieved April 10, 2021, from http://www.cdc.gov/healthywater/global/wash_statistics.html

J;, Velásquez L;Dussan. (2009) "Biosorption and Bioaccumulation of Heavy Metals on Dead and Living Biomass of Bacillus Sphaericus." Journal of Hazardous Materials, U.S. National Library of Medicine, 167(1-3):713-6. https://doi.org/10.1016/j.jhazmat.2009.01.044

Kulthanan, K., Nuchkull, P., & Varothai, S. (2013). The pH of water from various sources: an overview for recommendation for patients with atopic dermatitis. Asia Pacific allergy, 3(3), 155–160. https://doi.org/10.5415/apallergy.2013.3.3.155

Kumar, A., Kumar, A., M M S, C. P., Chaturvedi, A. K., Shabnam, A. A., Subrahmanyam, G., Mondal, R., Gupta, D. K., Malyan, S. K., S Kumar, S., A Khan, S., & Yadav, K. K. (2020). Lead Toxicity: Health Hazards, Influence on Food Chain, and Sustainable Remediation Approaches. International journal of environmental research and public health, 17(7), 2179. https://doi.org/10.3390/ijerph17072179

Lesmana, Sisca O., et al. (2009) "Studies on Potential Applications of Biomass for the Separation of Heavy Metals from Water and Wastewater." Biochemical Engineering Journal, Elsevier, Volume 44, Issue 1, 15 April 2009, Pages 19-41. https://doi.org/10.1016/j.bej.2008.12.009

Li, Bin, et al. (1970) "Study on the Migration of Heavy Metals Pollution from Soil to Lettuce." ASABE Technical Library :: Abstract, American Society of Agricultural and Biological Engineers. https://doi.org/10.13031/aim.20141913994

Lim, Sing-Lai, et al. (2010) "Use of Chlorella Vulgaris for Bioremediation of Textile Wastewater." Bioresource Technology, Elsevier, Volume 101, Issue 19, October 2010, Pages 7314-7322. https://doi.org/10.1016/j.biortech.2010.04.092

Lin, Sihao, et al. (2011) "Environmental Lead Pollution and Elevated Blood Lead Levels among Children in a Rural Area of China." American Journal of Public Health, American Public Health Association, 101(5): 834–841. https://doi.org/10.2105/AJPH.2010.193656

Mitra, A. K., Haque, A., Islam, M., & Bashar, S. A. (2009). Lead poisoning: an alarming public health problem in Bangladesh. International journal of environmental research and public health, 6(1), 84–95. https://doi.org/10.3390/ijerph6010084

National recycling Rate study. (2017, December 05). Retrieved April 10, 2021, from http://www.associationofbatteryrecyclers.com/national-recycling-rate-study/

Polluting our soils is polluting our future. (2018, February 05). Retrieved April 10, 2021, from http://www.fao.org/fao-stories/article/en/c/1126974/

Saunders RJ, Paul NA, Hu Y, de Nys R (2012) Sustainable Sources of Biomass for Bioremediation of Heavy Metals in Waste Water Derived from Coal-Fired Power Generation. PLOS ONE 7(5): e36470. https://doi.org/10.1371/journal.pone.0036470

Silva, S., Pinto, G. & Santos, C. (2017) Low doses of Pb affected Lactuca sativa photosynthetic performance. Photosynthetica 55, 50–57 (2017). https://doi.org/10.1007/s 11099-016-0220-z

Sulaymon, A. H., Mohammed, A. A., & Al-Musawi, T. J. (2013). Competitive biosorption of lead, cadmium, copper, and arsenic ions using algae. Environmental science and pollution research international, 20(5), 3011–3023. https://doi.org/10.1007/s11356-012-1208-2

United Nations. *Africa.* Scale 1:1000. Map No. 4045 Rev. 8.1, 2018.

Worstpolluted.org : Reports. (n.d.). Retrieved April 10, 2021, from http://www.worstpolluted.org/

Yanhao Zhang, Haohan Zhang, Zhibin Zhang, Chengying Liu, Cuizhen Sun, Wen Zhang, Taha Marhaba, (2018). "pH Effect on Heavy Metal Release from a Polluted Sediment", Journal of Chemistry, vol. 2018, Article ID 7597640, 7 pages, 2018. https://doi.org/10.1155/2018/7597640

Rainfall Variability and Potable Water Supply in Buea, Southwest Region, Cameroon

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Abstract

Endowed with a rich bioclimatic condition, favorable geomorphological configuration and volcanic substratum of high water retention capacity, Buea, paradoxically, suffers from constant water shortages. This research on "Rainfall Variability and Potable Water Supply in Buea, Southwest Region, Cameroon focuses on the impact of rainfall variability on the quantity of potable water supply in Buea and adaptation measures. To attain the aforementioned objectives, quantitative and qualitative approaches and inferential statistical analyses were used. Correlation coefficients, regression and anomalies were used to determine the relation between rainfall variability and water supply. This was intended to understand the impact of rainfall variability on water supply. Questionnaires were randomly administered to four most populated quarters in Buea in order to understand the water consumption dynamics and population perception of the actual water supply dilemma. The results with a standard Precipitation Index of 25.5%, Seasonality Index of 0.69 and a Correlation Coefficient of 0.742, indicate that there have been significant fluctuations in rainfall and water availability over the years. Contrary to popular opinion that water shortages are predominantly due to fluctuating rainfall patterns, the situation has been exacerbated by geology, the non-rehabilitation of the water supply network, mismanagement of resources and urbanization. To adapt, the citadels have turned to streams, springs, rain water harvesting and boreholes but with many constraints. It is therefore imperative that all stakeholders play an active role if Objective 6 of the UN Sustainable Development Goals is to be attained and the challenge of water security combated.

Keywords: Rainfall Variability, Water Supply, Impact, Adaptation, Buea

1. Introduction

Globally, the significance of clean water, health and sanitation to livelihood of people is universally acknowledged. In fact, it is recognized that the accessibility of clean water is often a tool for healthy lives, development and peaceful societies (WaterAid, 2009). It is not surprising then that in Africa, countries actively promote the supply of water to rural and urban communities. Environmental security is therefore, related to the extent to which a region's water resources are being managed with awareness of, and consideration for, the environmental services that water provides (Allan, 1996). As Abate (1994) reiterates, water resource development is vital for the progress of every community.

Parallel to this, the United Nations Sustainable Development Goals 6; clean water and sanitation, clearly highlights how clean, accessible water for all is an essential basic human right and necessary in the world we live in. Although there is sufficient fresh water on the planet to achieve this goal, bad economics and poor infrastructure have resulted in the deaths of millions of people, particularly children every year, from diseases associated with inadequate water supply, sanitation and hygiene (UNESCO, 2015). WaterAid (2009) is in paralysis with this, as it gives how lack of water contributes to about 700,000 child deaths every year due to diarrhea, mainly in developing countries. The United Nations (UN) 2013 report on *water for life*, further elucidates how more than 1.1 billion people globally lack access to clean drinking water. As more people put pressure and with the ever increasing demand on existing water resources, the cost and effort to build or even maintain access to water has been increasing.

Water scarcity, poor water quality and inadequate sanitation negatively impact food security, livelihood choices and educational opportunities for poor families across the world (FAO, 2008). 80 countries of the Third World that support 40% of the world's population suffer from the water shortage problems which have become a daily life fact. These countries suffer from shortage of personal and household needs. Consequently, 1.2 billion people are suffering physically from water shortage while 1.8 billion lack adequate sanitation (Elhance, 1999). More than 2 billion people are living with the risk of reduced access to freshwater resources and it is estimated that by 2050, at least one in four people is likely to live in a country affected by chronic or recurring shortages of fresh water (FAO, 2018). Drought specifically afflicts some of the World's poorest countries, worsening the already existing hunger and malnutrition levels as UNICEF (2015) acknowledges.

Africa has been identified as one of the parts of the world that is most vulnerable to the impacts of climate change (IPCC 2014; Niang et al., 2014). In the Sub-Saharan region, climate change and rainfall variability have been very evident, manifesting through drought and desertification in many countries, if not all. The large decline in many West African river flows is primarily related to the effects of the prolonged drying in the Sahel (late 1950s-late 1980s), with conditions still drier than during the humid 1950s (l'Hôte et al. 2002; Dai et al., 2004). According to Hulme, 1992, there has been a marked downturn in rainfall and river flow in countries of Sub Saharan Africa. This has led to water supply crisis in her urban areas.

Urbanization has increased in Cameroon, so has urban water demand. The Ministry of Water and Energy is in charge of potable water supply in Cameroon cities including Buea (Buea CDU, 2015). There is an urgent need for potable water supply to be augmented and made more efficient. The citadels are chronically vulnerable to insufficient potable water supply from the water authority. The above-stated circumstances prompted this investigation described herein. The objective is to address the impact of Rainfall Variability on potable water supply in Buea and develop measures stakeholders can adopt to prevent recurrent water crisis. Current and previous actions are also accessed. The research also explored the impact of the water crisis at the household level, particularly youths, especially girls who are typically vulnerable due to the unavailability and inaccessibility of water for their menstrual health management, agriculture, domestic uses inter alia. Thus the motivation of this research is to investigate the true cause of water crisis in the region, so that recommendations and solutions can be developed.

1.1. Problem Statement

Potable water supply in Buea has been insufficient from time immemorial and has almost become a norm. This is arising mainly from population growth and consequent increase in water demand. But CAMWATER, the main water supply authority, does not meet the water consumerism need of the public. This deficiency in potable water supply has been blamed on rainfall variability. Fluctuating rainfall patterns lead to a rise and fall in underground and catchment water supply.

Rainfall variability in Buea has had a great toll on the sustainability of water catchments, resulting from a drop in the water table, low stream discharge and catchment drying up during long drought periods. This situation is compounded by catchment sedimentation and pollution.

Despite the above mentioned natural causes of the water crisis, anthropogenic factors have also aggravated to the problem. Therefore it is empirical to seek the roots of the problem and develop solutions and that is the aim of this research.

2. Materials and Methods

This research made use of a number of materials and methods of data collection and analysis geared towards achieving the set objectives.

2.1. The study area

Buea has an estimated population of about 200,000 inhabitants (Buea CDP, 2015). She is the capital of the South West Region of Cameroon, located between latitude 4º 12' and 4º 31' North of the Equator and longitudes 9º 9' to longitude 9º 12' East of the Greenwich Meridian (Lambi, 2009). Buea has an average elevation of 896m and a surface area of 870 square. Average annual rainfall ranges between 3000mm and 5000mm with temperatures between 23°c and 27ºc. Buea has a warm and humid tropical climate and volcanic substratum of high water retention capacity. Rivers like the Ndongo take their rise from the Mount Cameroon (4100m). This area hosts many water catchments like the Small Soppo, German Spring and Mosul catchments. These catchments which are all harnessed for potable water supply.

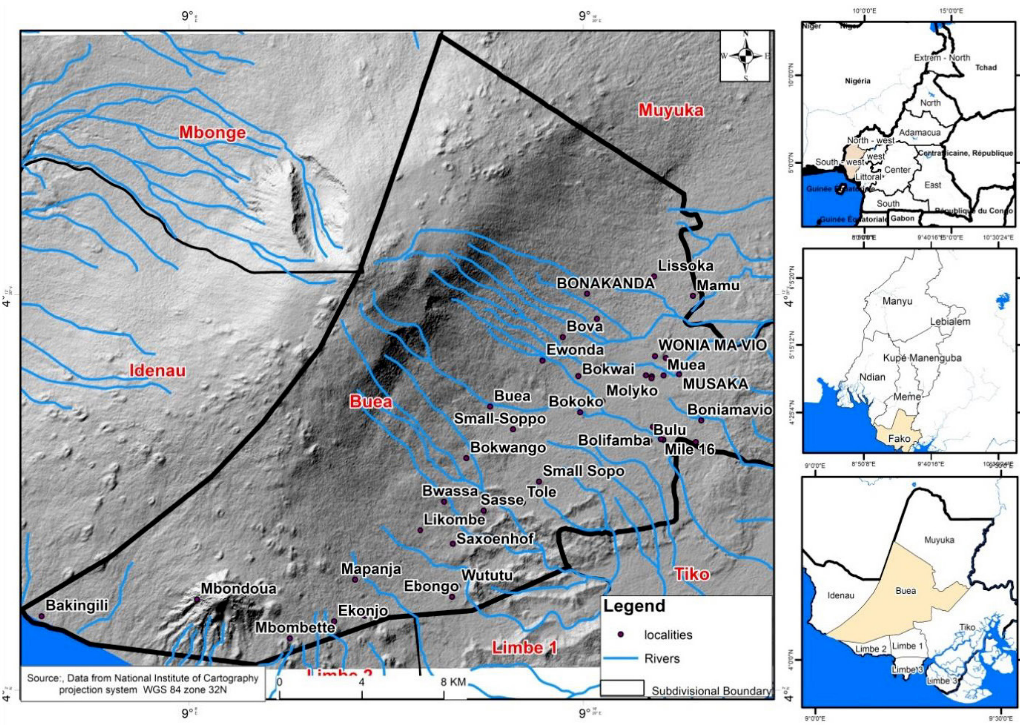

Figure 1. Location of Buea in Fako Division

2.2. Method of data collection

Primary data was generated through the use of questionnaires, interviews and field observations. Secondary data was gotten from books, articles, libraries, the internet and other unpublished scientific works. Field observations were an instrumental tool to collect data. Simple random sampling technique was used to administer questionnaires.

2.3. Method of data analysis

Quantitative and qualitative methods were primordial in data analysis. Inferential statistical analysis included;

2.3.1. Analysis of coefficient of variance

This analysis was done to establish rainfall variation patterns. Decadal, inter-annual, monthly and rainy days variability were established. This was done using the formula;

$$Coefficient\ of\ variation = \frac{\sigma \times 100}{\bar{y}} \text{-- (1)}$$

Where; $\bar{y}$= mean and Ϭ= Standard deviation

2.3.2. Standard precipitation index

The Standardized Precipitation Index (SPI; McKee 1993) is the number of standard deviations that observed cumulative precipitation deviates from the climatological average. To compute the index, a long-term time series of precipitation accumulations over the desired time scale were used to estimate an appropriate probability density function. This was done using the formula;

$$Z\text{-}score = (X\text{-}_{\mu})/\delta \text{ -- (2)}$$

Where: Z-scores = score's distance from the mean, μ= Standard deviation, δ= unit

2.3.3. Regression and product moment correlation (person's correlation)

Simple linear regression is a model that assesses the relationship between a dependent variable and one independent variable. Here it was used to show the relationship between rainfall variability and quantity of potable water supply in Buea. The Z-Scores was used where each variable was determined from their mean and standard deviation. Values closer to zero indicate a weak correlation and values close to one indicate a strong correlation.

Also, the Pearson correlation coefficient (PCC, pronounced), also referred to as Pearson's r, the Pearson product-moment correlation coefficient (PPMCC) or the bivariate correlation, is a measure of the linear correlation between two variables X and Y. According to the Cauchy–Schwarz inequality, it has a value between +1 and −1, where 1 is total positive linear correlation, 0 is no linear correlation, and −1 is total negative linear correlation. It is widely used in the sciences. It was developed by Karl Pearson from a related idea introduced by Francis Galton in the 1880s and for which the mathematical formula was derived and published by Auguste Bravais in 1844. The naming of the coefficient is thus an example of Stigler's Law. The formulas are demonstrated bellow;

$$r = \frac{\sum z_X \; z_Y}{N} \text{-- (3)}$$

Where Z = scores, r = Pearson's correlation coefficient, X = Mean Rainfall and Y=Mean quantity of water supply.

$$Z = \frac{X-\mu}{\sigma} \text{--- (4)}$$

Where X = climatic variable (mean rainfall), Y = mean annual water discharge and N = the number of years.

3. Results

3.1. Rainfall variability in Buea

Rainfall data from 1976 to 2018 was used to establish rainfall variations in Buea This included descriptive analysis of inter-annual and monthly rainfall variations plus their anomalies. Rainfall seasonality index, correlation tests, variability tests and coefficient of determinations were also established. These were in line with the hypotheses stating that rainfall has significantly varied over time and space in the study area. The results are presented in Figure 2, 3 and 4.

Figure 2 presents inter-annual rainfall variability in Buea. The highest amount of rainfall was recorded in 1982 with 5232.16mm and 2007 (3898.28mm). This is opposed to some years that recorded really low annual rainfall amounts like 1991 with 1194.8mm and 1990 with 1612mm. this significant fluctuation in rainfall threatens activities that rely on rain. Example is agriculture.

Buea has two main seasons; the rainy season and the dry season. During the dry season, there is limited or no rainfall. This is during the months of November, December, January and February with rainfall amount of below 140mm. during this period, there is a drop in the water table and discharge from the catchments. The rainy season begins in the month of March and fall till October. August records highest rainfall amounts of about 423mm. August is considered the heart of the rainy season with other months of July (407mm) and September

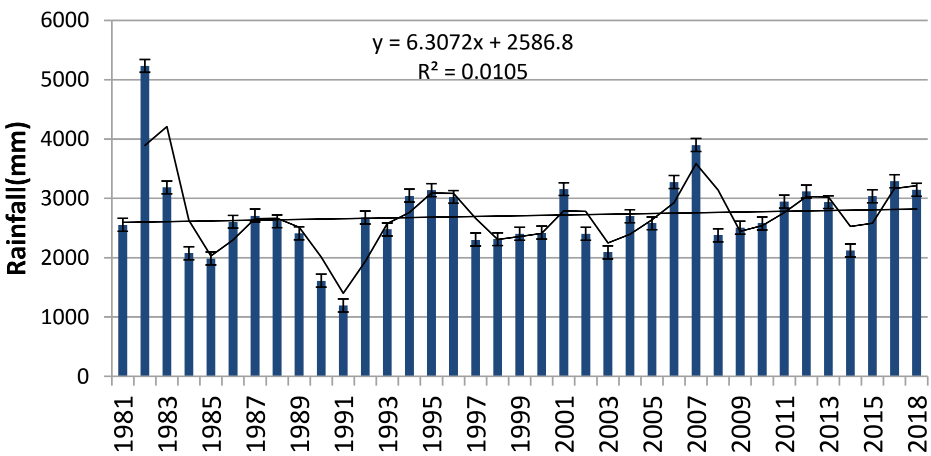

Figure 2. Inter-annual rainfall variability in Buea from 1981-2018(Source: calculated from climatic data from NASA, March 2020)

(379mm) also recording high amounts of rainfall. Inter-annual rainfall variability is illustrated by Figure 3.

As rainfall fluctuates across various months, there are also periods of anomalies both negative and positive. The most significant anomalies were recorded in the months of January with -191.89mm, seconded by December with -184.81mm. There were equally positive anomalies

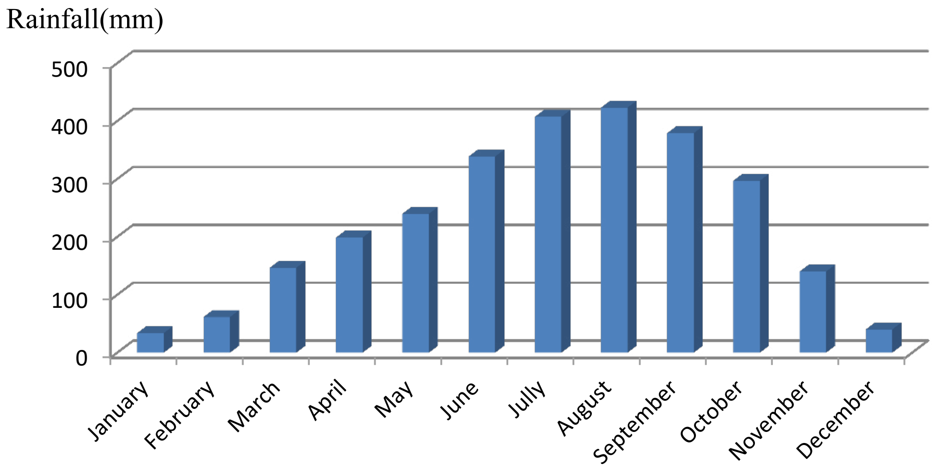

Figure 3. Monthly Rainfall Variability in Buea (Source: Calculated from climatic data from NASA, March 2020)

in months of August (197mm) which is considered as the heart of the rainy season. The positive and negative anomalies all record 50% each showing an equal tendency to have rainfall fluctuations or normal figures with lower rainfall during the dry season and more rainfall amounts during the rainy season.

These anomalies are illustrated by Figure 4.

Figure 5 presents inter-annual rainfall anomalies. There were years with positive anomalies. This means these years recorded rainfall amounts above the normal scenario. Years like 1982, 1992, recorded values of between 3000mm and 5500mm. some years have an insignificant deviation from the normal. They are said to have recorded moderate anomalies. Years with moderate anomalies included 1981, 1989, with figures of between 2000mm and 3000m.

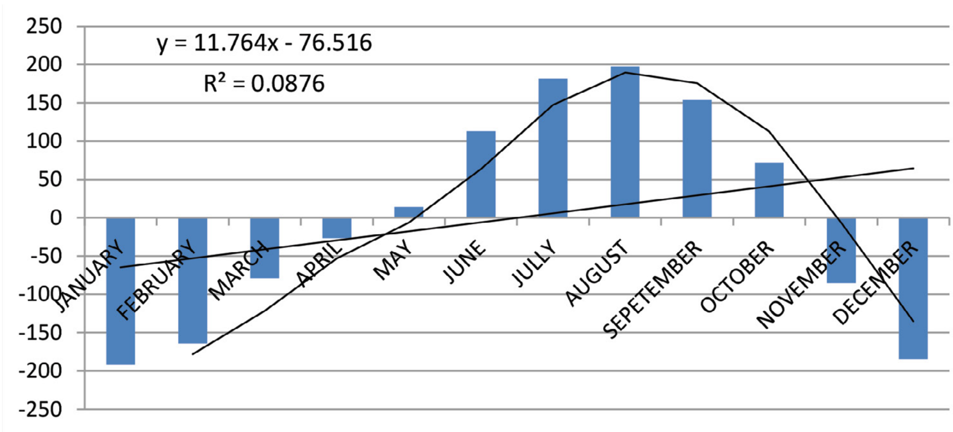

Figure 4: Monthly rainfall anomalies for Buea. (Source: calculated from climatic data from NASA, March 2020)

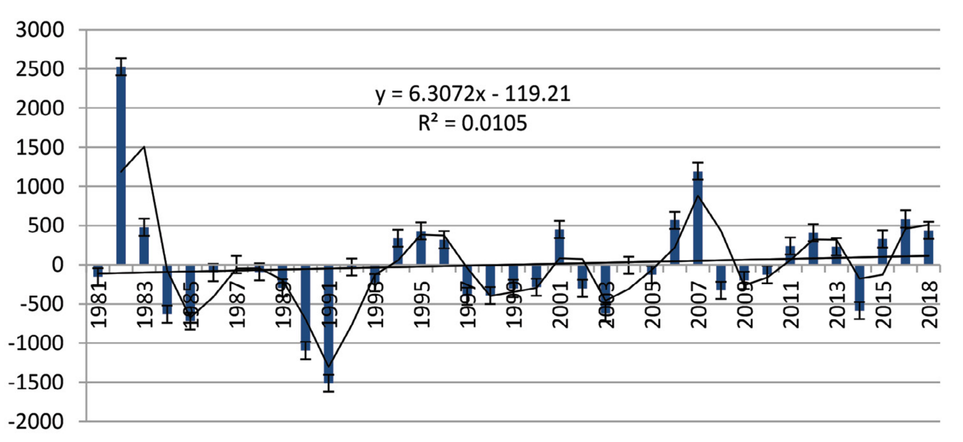

Figure 5. Inter-annual rainfall anomalies in Buea 1981-2018 (Source: calculated from climatic data from NASA, March 2020)

3.2. Water supply network

Potable water supply in Buea is through household/private and public installed stand taps equipped with unit reading meters (only for private taps). Water is harnessed from the main water catchments (Small Soppo, German Springs, Mosul, Bwiteva), pumped using electrical motors through large metal and plastic pipes to the water treatment center in Mosul. From there, this water is supplied to the denizens by water rationing systems with different quarters having different periods of water supply. There are also community water schemes like the Ndongo, Bwiteva and Muea community water, managed by the local elders and quarter heads with support from local and international Non-Governmental organizations like the US embassy and Caritas Cameroon.

Figure 6 gives a pictorial view of public water supply using public stand taps. This water amenity is free of charge to the public and supplied by water rationing. But also deficient in number of water flowing days, some of these taps are left dry for long periods of time.

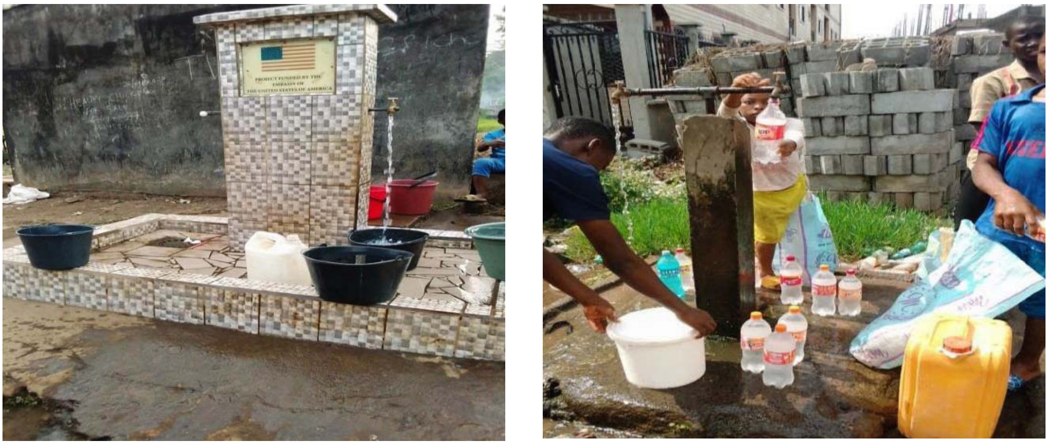

Figure 6. Potable water supply through public stand taps © Bryan Ngala

3.3. Populations perception on the state of potable water supply

Using a 4 point likert scale in the research, the populations' opinion was sort on the state of water supply. The citadels had conflicting views and opinions on the water supply state. Their responses are presented in Figure 7.

As presented in Figure 6, a majority of the population (44.3%) are with the opinion that the situation or potable water supply is poor and 30% perceive the situation is very bad.

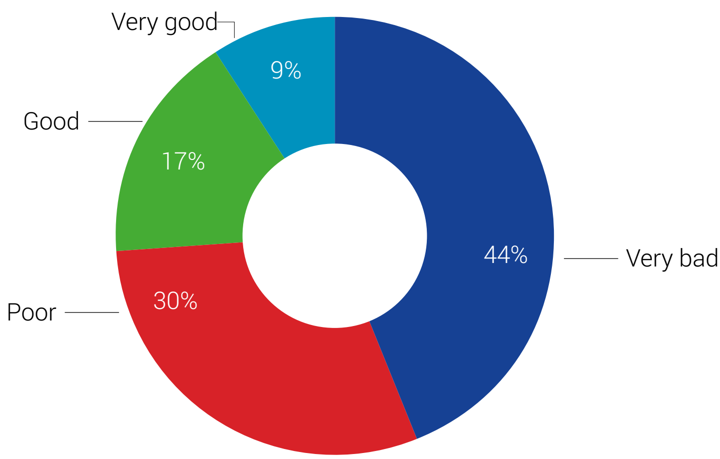

Figure 7. Population's perception on the state of potable water supply (Source: Field Work, March, 2020)

3.4. Impact of rainfall variability on potable water supply

One of the specific objectives of this research was to investigate the impact of rainfall variability on potable water supply. The Pearson's Correlation and regression analysis was done to establish the relation between changes in rainfall and changes in potable water supply and presented in Figure 8.

With a Standard Precipitation index of 25.5%, Seasonality index of 0.69 and a correlation coefficient of 0.742, rainfall variability has a significant impact on water supply (Figure 8).The month with the most rainfall amount has the highest quantity of water supply. This is the month of August with a mean monthly rainfall of 423mm and a water supply of 453,000m³ and the months of January, December and February, with mean monthly rainfall of 33mm, 40mm and 61mm and water supply of 156,000m³, 149,000m³ and 113,000m³ respectively. However during some periods of heavy rainfall, there is sedimentation of the river bed. This is as a result of the deposition of eroded and transported sediments from overland flow. It is made worst by the channels from public drainage systems into the water catchment area. Coupled with the fact that deforestation for agriculture and housing has been intensifying because of the growing population, the catchment is vulnerable to effects from external agents. The trees and grasses that acted as barriers are gradually disappearing. This causes water pollution and reduces stream discharge and in turn, hinders water collection.

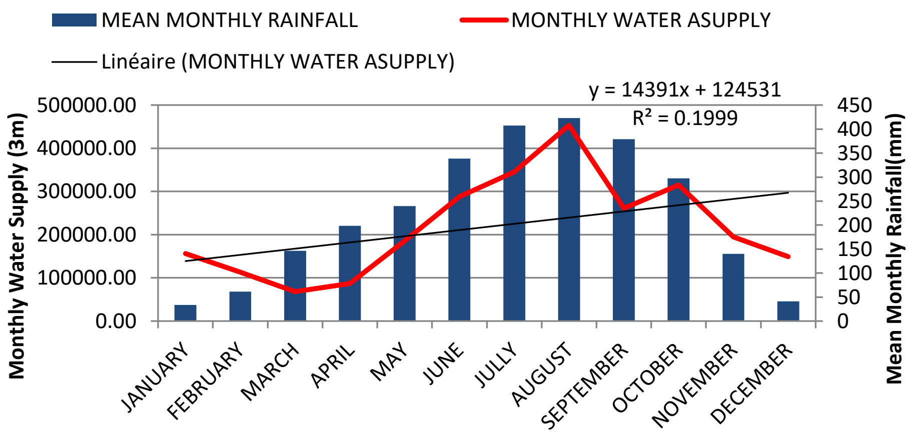

Figure 8. Impact of monthly rainfall variation on potable water supply (Source: calculated from data from Regional Office for Statistics, Buea)

3.5. Other causes of potable water supply crisis

However, with a coefficient of determination of 0.66, rainfall variability is not the sole factor affecting potable water supply. Other factors include the non -rehabilitation of the water supply network over the years, urbanization. Water catchment destruction and poor agricultural activities along catchments, water pollution, and inadequate trained personnel in the water management, insufficient financial and material resources all have a share of the blame.

The population of Buea needs a daily water supply of about 11400m³ but this is not the case. The water supply network constructed since 1984 is still being used today despite the drastic increase in population. This relationship in water supply and population growth is presented in Figure 8

Population growth in Buea has not been accompanied by increase in potable water supply. From Figure 8, we find out that despite the population rising from 63853 in 1987 to 180000 inhabitants in 2012, the water supply still remained at 1970800m³. this situation, as described by some inhabitants is the worst case of service provision to the public.

Because of water crisis, the scramble for available water has led to overcrowding and long waiting hours at public water points. This drives the citadels to harvesting water from unsafe sources. Water harvested from unsafe sources has left the people vulnerable to water borne diseases like typhoid and cholera.

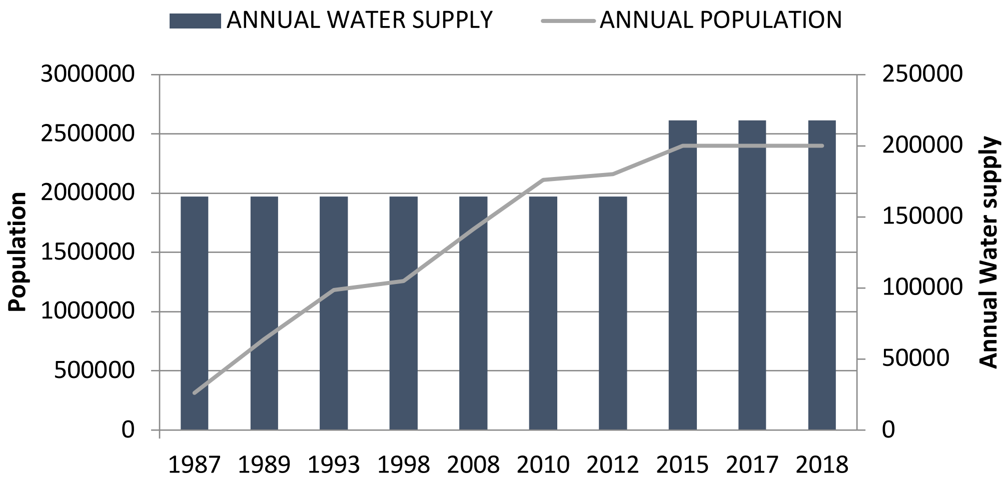

Figure 8. Water Supply and Population Growth in Buea (Source: Calculated from Buea CDP, 2015)

Figure 9. Overcrowding at Public water Points © Bryan Ngala

3.6. Impact on youth and women

In Buea, women have the primary responsibility for the management of household water supply, sanitation and health. Water is necessary not only for drinking, but also for food production and preparation, care of domestic animals, personal hygiene, care of the sick, cleaning, washing and waste disposal. However, the study showed that the water crisis has been disadvantageous especially to women and girls because the need enough water for their specific hygiene needs during menstruation, pregnancy and child rearing.

3.7. Adaptation measures

To remedy this problem of potable water shortages, all stakeholders directly or indirectly related to the wellbeing of the town has been adopting various measures. These stake holders include the Buea Urban Council, Community Water Schemes and other NGOs. They have engaged into various schemes. such as encouraging drilling of boreholes by both private and public entities, fetching water from streams and springs, and the acquisition of many storage containers. This is to store water during periods of plenty and use during periods of shortage. There has also been the encouragement of rain water harvesting and the construction of new public stand taps Other individuals have turned to the commercialization of ground water and this is described by citadels as the most reliable water source .(Figure 11).

Figure 10. Borehole, water storage containers and water marketing © Bryan Ngala

Figure 10, Photo 1 shows borehole drilling using a drilling machine. The drilling is done so deep down the water table, right to the aquifer reserves where a pipe is connected to electric pumps. This water is pumped out to a large container reserve (Photo 2) from where it is supplied to the users. Some individuals are marketing this water to the public by selling in litters. Under normal circumstances, a 20litter of water is sold at 50FCFA. Some households pay for private connections to their residences. This water source is the most reliable in Buea.

Figure 11. Rain Water Harvesting and construction of new stand taps as adaptation measure © Bryan Ngala

4. Discussions

These annual, monthly and inter-annual rainfall variations and anomalies negatively affect potable water supply. Prolonged dry seasons cause a reduction in ground water and catchment discharge. This is corroborated by the work of Mbua, 2019 who says fluctuations in rainfall patter has negatively affected stream discharge and water supply. This is because an increase in rainfall leads to an increase in ground water discharge and other water supply systems like rain water harvesting while a fall in rainfall leads to a drop in the water table and other direct water supply schemes. This result is also in line with the Gausen principle affirming a fluctuation in water availability between dry and humid months.

Furthermore, during the dry season, there is pressure on the limited water resources because of little or no rainfall. This worsens the water crisis with households going for days without a single drop of water flowing from the taps. This is affirmed by the Intergovernmental Panel on Climate Change (IPCC 2017) which says global precipitation and temperature change projections shows anomalies in rainfall patterns on the globe with periods of high and low precipitation. According to this report, water catchments and underground water storage systems will change according to their rainfall regime. Therefore regions with a drop in rainfall will experience shortages in water resources and high consumption towns will face difficulties in supplying water needed by the population. But the limitation to this study came from the fact that the exact quantity of water supplied during the various seasons could not be gotten.

The non-rehabilitation of the water supply network over the years, population growth and urbanization, are also to blame for the water crisis in this region. Despite the large influence of rainfall fluctuations on river flow variability, the response may be influenced other factors such as changes in land use or land cover for Sahel Africa (Mahé et al. 2005; Li et al. 2007; Leblanc et al. 20080) Small water storage tanks and constant pipeline leakages (Mofor S. 2010) cause a 25% water loss during supply periods. Though this research was limited by exact extent of damaged water supply infrastructure and population growth maps, it is in line with research done by Lotsmart et al., 2017 who reiterates climate change and rainfall variability is not the only factor affecting water supply but urbanization and urban sprawl has led to the destruction of water catchments, water shades and over demand of water resources which outweigh the supply.

Rain water harvesting, water management and reuse was identified as some adaptation measures implored by the population to cope with the insufficient potable water supply. This is affirmed by studies of Mark Elliot, et al (2008) who identified that adaptation strategies to rainfall variability include household water treatment and safe storage (HWTS), better water conservation techniques, water reclamation and re-use techniques, increasing use of water efficient fixtures and appliances

Research discovered that water rationing was used as a means to ensure a fair supply of potable water to the denizens. But nevertheless, some residential areas like the Government Residential Areas are always prioritised. Amawa (2015) writes that water rationing can ensure everyone gets water at different times. This measure could take the form of fixed allotment (where industrial, commercial districts or neighbourhoods and households are served with a certain quantity of water based on the number of persons per household) and percentage reduction (where such neighbourhoods are served with water on a reduced percentage of water based on the previous consumption of the neighbourhood).

4.1. Perspective

With the dangers of insufficient water supply, it is recommended that; The rehabilitation of the water supply network will ensure better water supply. Water storage will be increased and pipeline rehabilitation will limit water lost through spillage. Proper management, more financial and human resources will lead to better service provision.

Furthermore the Push for equitable access is recommended. Water rationing is discriminatory as the high class residential areas are prioritized to the poor areas. This negatively affects the activities of the young people of this area.

Additionally, roles and responsibilities of different national institutions to implement the law must be defined properly. Stakeholders must be involved at all the stages of the process to ensure the acceptance of the legislation/regulation by the public. In addition, there must be creation of frameworks for monitoring and enforcing implementation of legislation/ regulation. Environment laws should punish perpetrators of natural resource damage.

Involving the youth; Water-related education and campaigns are most effective when young population and students are involved as beneficiaries. They are agents of behavioral change within their families and their communities. Hygiene and water education that is included in school curricula should be taught conclusively in all schools. Early schools should be the target for anthropogenic factors leading to water crisis, behavior change interventions. Once a child learns about good ways at an early age, that child will grow with the behavior and will be able to influence his/her family members. In the long run, the whole community might easily change.

More so, efficient use of available water will go a long way to ameliorate the water crisis. This is because a huge quantity of water is used unsustainably. The IPCC (2011) proposed more efficient rainwater harvesting, improved water storage and conservation techniques, water re-use, desalination, as possible adaptation strategies to water scarcity. 69% of irrigation farming around the world use fresh water which should be used for domestic purposes. Therefore more efficient strategies should be developed for water uses.

Prioritizing water issues by all stakeholders, led by the government can also help curb the water crisis in Buea. Water issues in Cameroon, particularly Buea are given secondary priority compared to other areas like security and the economic sector of the country. A blind eye has been given on water as a basic and fundamental right as the UN Charter elucidates. Prioritizing water issues is yet also another way the government can facilitate the creation of awareness and public participation in resource sustainability.

5. Conclusion

This research set out with main objective, to investigate the impact of rainfall variability and other anthropogenic factors on potable water supply in Buea. Primary and secondary data was primordial in the research, field observations added more insight to the objectives. Coefficient of variation, Pearson correlations, regression analyses and rainfall anomalies gave statistical interpretation of the data. With a Standard Precipitation index of 25.5%, Seasonality index of 0.69 and a correlation coefficient of 0.742, it was seen that there have been significant fluctuations in rainfall patterns. This was either yearly, monthly or seasonally. There were also years and months of water stress as seen by rainfall anomalies. This has affected potable water supply because of low catchment discharge and little possibility for rain water harvesting and storage.

With a coefficient of determination of 0.66, if was found out that other factors play a role in the water supply crisis. They included geology; the nature of the basalt rocks that makes it difficult to explore the landscape for borehole and wells. Also, the non-rehabilitation of the water supply network, mismanagement of the available resources and the fast demographic growth and urbanization had a part to play.

Therefore to combat water crisis in Buea, there is the need for effective policy implementation and stakeholder involvement. Sustainable and decentralized resource management, effective legal and institutional system will help solve this problem plaguing the ever growing town of Buea.

This research recommends further be carried out to assess the actual impact each variable; water supply network, infrastructure, mismanagement of funds, population misconduct, has on potable water supply shortages. This will pave the way for the adoption of concrete measures to combat this water supply crisis plaguing the Buea community.

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References

Abate, Z. (1994). Water Resources Development in Ethiopia: An Evaluation of Present Experience and Future Planning Concepts. Reading (United Kingdom): Ithaca Press. *Middle East science Policy Series,* 13(12), 385-388.

Allan, J. A., Karshenas, M. (1996). Managing environmental capital: The case of water in Israel, Jordan,the West Bank and Gaza 1947–1995. *In Water, Peace and the Middle East: Negotiating Resources in the Jordan Basin,* 5(31), 68-69.

Amawa, S.G., Kimengsi, N. (2015). Water rationing in the Buea municipality: Patterns, effects and Coping Strategies. *African Journal for Social sciences,* 6(3), 09-12.

Dai, A.D., Lamb, P.J., Trenberth K.E., Hulme M., Jones P.D., Xie, P. (2004): The recent Sahel drought is real. International Journal of Climatology, 24, 1323-1331. https://doi.org/10.1002/joc.1083

Elhance, A.P. (1999). Hydro politics in the Third World: Conflict and Cooperation in International River Basins. US Institute of Peace Press, Washington DC, United States.

FAO. (2008). Water and for the Rural Poor: Interventions for improving livelihoods in sub-Saharan Africa. Rome, Italy.

Fonjong, L., Fokum, V. (2017). Water Crisis and Options for Effective Water Provision in Urban and Peri- Urban Areas in Cameroon. *Society and Natural Resources,* 30(4), 488-505.

Hulme, M. (1996). Climate change within the period of meteorological records: The Physical Geography of Africa, 348(17), 88-102.

Lambi, C., Kometa, S.S. (2009): An Evaluation of Water Resources on the Eastern Slopes of Mount Cameroon, *Journal of Human Ecology,* 28(1), 47-55.

L'Hôte, Y., Mahé, G., Some B., Triboulet, J.P. (2002). Analysis of a Sahelian annual rainfall index updated from 1896 to 2000:The drought continues. *Hydrological Science Journal,* 47(4), 563-572.

Li, K.Y., Coe, M.T., Ramankutty N., De Jong, R. (2007): Modeling the hydrological impact of land-use change in West Africa. Journal of Hydrology, 337(3-4), 258-268.

Lloyd-Hughes, B., Saunders, M.A. (2002). Drought climatology for Europe: Climate in low income countries: Case of Buea municipality – Cameroon international. *Journal of Climatology* 22(13), 1571-1592.

Mahé, G., Paturel, J.E., Servat, E., Conway D., Dezetter, A. (2005). Impact of Land use change on soil water holding capacity and river modeling of Nakambe River in Burkina-Faso. *Journal ofHydrology,* 300(1-4), 33-43.

Mbua, L. (2013). Water Supply in Buea, Cameroon: Analysis and the Possibility for Rainwater Harvesting to Stabilize the Water Demand. Branddenburgischen Technischen, Universitat Cottbus-Senftenberg, Senftenberg, Germany.

Mofor, S. (2010). Buea Municipality and leaking CDE pipes: The RECORDER *Newsline* Saturday, Nov 6,2010. Accessed 21/05/2020.

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., Urquhart, P. (2014). Africa In: Climate change 2014.Iimpacts, adaptation and vulnerability: Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, United States. *American Journal of Climate Change*, 4(4), 1199-1265.

IPCC. (2014). Summary for policymakers In: Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectorial aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate: Cambridge University Press, Cambridge, Unites Kingdom and New York, United States.

IPCC. (2001). Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate: Cambridge University Press, Cambridge, United Kingdom.

UNESCO. (2009). Water in a changing world: The United Nations World Water Development Report 3, Published jointly by UNESCO and Earth scan London, United Kingdom.

WaterAid. (2009). Sustainability and equity aspect of total sanitation programs. A study of recent WaterAid-supported programs in three countries: global synthesis report.

Rainwater Harvesting and Solar Powered Drip Irrigation Design for Ornamental Plants at Lupane State University, Lupane, Zimbabwe.

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Abstract

Climate change and variability have caused water scarcity and shortages in many areas around the world. Methods of water demand management and conservation have been developed worldwide. Design of a rainwater harvesting and solar powered drip irrigation system was performed at Lupane State University (LSU) in Zimbabwe for use in curbing potential water shortages that could hinder sustainable development of the University. Designs were made so that rainwater was collected from the catchment areas for storage in underground reservoirs. The estimated amount of harvestable water at LSU was 9 387 m^3 and the crop water and irrigation requirements for the ornamental plants was 6788m^3. Solar powered drip irrigation with a 2700WP array and 4 l/hr drippers was designed with a conveyance pipeline of 50mm and manifolds of 25 mm. The area to be irrigated is 0.5 ha and the cost of implementing the design is US$143 736.50. The designed project had an internal rate of return of 5%, Net Present Value of -$37 489.00 and B/C Ratio of 1.6 at a discount rate of 20 %. Thus, under the given assumptions, the project is environmentally, socially and financially viable and it is recommended that LSU implement the project and include rainwater harvesting systems in future buildings at the University.

Key words: Rain water harvesting; solar powered irrigation, water scarcity, Zimbabwe.

1. Introduction

El Nino effects and perennial droughts are the talk of the weather forecasters as they have been experienced more often than heavy rainfall in Zimbabwe. Water harvesting is one way of trying to mitigate the scarcity of water. Fenguri (2000) defines rainwater harvesting as the collection and storage of the rainy season precipitation that would have percolated into soil or run off into streams and rivers. Shivakumar (2007) added that rain water harvesting entails the collection of precipitated water in a scientific and controlled manner from rooftops, open areas such as paved ways, parks, roads and fields into lakes and ponds so that it can be stored for future use. Alarm *et al.,* (2011) quotes Evenari (1971) who states that for thousands of years, humans have tried to survive in desert regions. They could only do so by skillfully managing a vital but scarce resource. Water harvesting began before 4000 BC in the Middle East and North Africa (Alarm *et al.,* 2011). Water was gathered from roofs and impervious surfaces and stored in underground tanks and cisterns with masonry walls (Abbas *et al.,* 2011). As the industrial revolution evolved and the modern era drew closer, the development of water sources shifted towards more centralized water storage structures such as dams and lakes (Abbas *et al.,* 2011). Groundwater development through boreholes has been on the rise during the second millennium and these developments have caused rainwater harvesting skills, which were used before industrial revolution, seem like new ideas these days (Abbas *et al.,* 2011).

Due to increase in water scarcity, organizations are turning back to the rainwater harvesting techniques to reduce effects of water scarcity. According to FAO (2007) most parts in Zimbabwe have economic water scarcity, and the regions in the southern part of the country have both economic and physical water scarcity. Lupane State University's water situation can be classified in the economic scarcity group because treated water is reaching the university, and this treated water is expensive for ornamental irrigation.

This study was done at Lupane State University which is in Matabeleland North Province of Zimbabwe. It uses drag hosepipes for ornamental plants irrigation at a low efficiency. This study only considered four buildings and the car park which were already constructed by the time of this research. A drip irrigation system was designed for ornamental plants at the Faculty Building. The study aimed at designing a water harvesting system for the University Main Car Park, Faculty of Agricultural Sciences, Hostel and Dining Hall buildings and to produce an irrigation design for watering ornamental plants around the Faculty Building using the harvested water.

Water scarcity is not a fiction rather a reality in Zimbabwe. The University is located in a semi-arid region with low rainfall. It faces water scarcity. This targeted design is a blueprint towards an integrated strategy to manage and conserve water at the campus. The design would help to green Lupane State University with ornamental plants to increase the aesthetic view of a Faculty Building and residential areas. Increasing the aesthetic view would give a better impression to the visitors about the quality of the university. Currently, the few available plants are being irrigated using potable or treated water. Therefore, watering ornamental crops with harvested water will help reduce the university water bill. The harvested water from the reservoir would also be available for cleaning purposes at the Faculty Building. The design would also act as a pilot project for the harvesting of rainwater from other structures to be constructed at the university.

1.1. Objectives

The aim of the study was to come up with water harvesting system, design, water reticulation and irrigation system for ornamental plants at the University car park, Faculty Building, Hostels and Dining Hall. The first objective was to estimate the amount of water which can be harvested from the university buildings and design the water conveyance and storage tanks. The other objective was to design a solar powered drip irrigation system for the ornamental plants. This included calculating the crop water requirements and coming up with a bill of quantities for the materials needed for the system to be constructed. The cost of implementing the project was used in determining the viability of the project.

2. Materials and methods

2.1. Site description

The study and design were carried out at Lupane State University which is located in Lupane District in Matabeleland North Province of Zimbabwe.

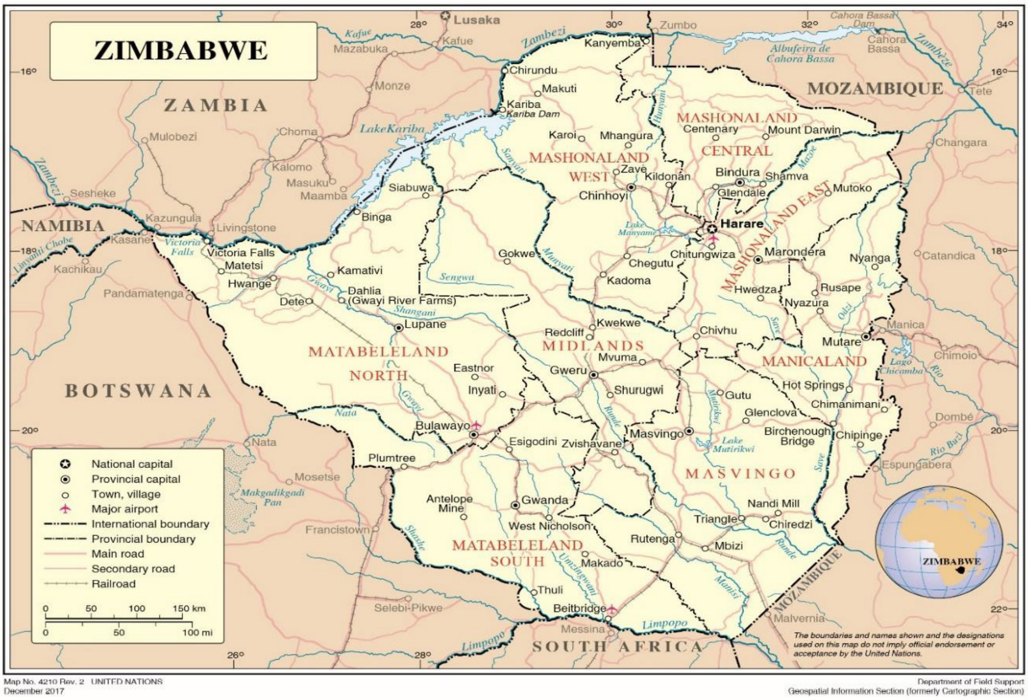

Figure 1. Index map for Zimbabwe showing Lupane in Matabeleland North Province

At Lupane State University the design was done at the Faculty of Agricultural Sciences, Hostels and Dining Hall buildings at coordinates (18° 56’ 46.78”S, 27° 45’ 39.69”E). Lupane State University is in Natural Region IV which receives an average annual rainfall of 550 mm. The rainfall has however, become unreliable and unpredictable as evidenced by recurrent droughts over several years. The rainfall period begins and ends in October/November and March/April respectively. This site was chosen because it has a large area under a roof and car park, and there was need for water to irrigate the ornamental plants since the water at the Faculty Building is potable and cannot be economically used for irrigating ornamental plants.

2.2. Field Operations

Site and ground checks of the possible sites for the reservoir were made as well as checks of the soil characteristics such as structure, texture and stability. The vegetation was also assessed since it acts as an indicator of the soil condition and environment. Soil characterisation was useful in concrete detailing of the proposed reservoir as they help in deducing the type and quantity of reinforcements needed.

2.3. Measurements and data calculation

2.3.1. Calculation of Catchment Area and Harvestable Water

The University Master Plan and Building Plans were used to calculate the catchment area for rain harvesting and siting of the reservoirs. The Master and Building Plans were used for calculating the catchment area and to evaluate possible site for underground reservoirs. Reservoirs had to be located where there would be no building in the future. The design was made in such a way that all the water that falls on the roof and car park would be captured and stored.

The potential of monthly rainwater harvesting from the roof was determined using the method proposed by Aladenola and Adeboye (2010): as equation (1).

$$VR = \frac{R*Ra*Rc}{1000} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where VR is the annual volume of rainwater harvested (m^3), R is the annual rainfall depth (mm) while R is the roof area (m^2) and R_c is the roof coefficient (without units).

The car park area was obtained by calculating the total surface area covered by tarmac and the main driveway. The dimensions of the car park were obtained from the University Master Plan. The volume of annual harvestable water was found substituting the roof area and roof coefficient with the car park area and tarmac surface coefficient in Equation 1.

2.3.2. Soil analysis

Basic literature about the soils was used to determine the available soil moisture and other soil properties. Literature was obtained from Savva and Frenken (2002).

2.3.3. Calculation of crop and irrigation water requirements

The plants to be irrigated are exotic perennial ornamentals, which includes various varieties of *Duranta erecta* (Duranta). The common names of Duranta plants are pigeon berry, golden dew drop and sky flower. The climate data was obtained from FAO, CLIMWAT 2 and it included rainfall, wind speed, humidity, minimum and maximum temperature. Rainfall data was used to estimate the amount of water, which can be received from the car park and rooftops. The crop and irrigation water requirements for the ornamental crops around the campus buildings were calculated using FAO Cropwat 8. Cropwat 8 was used to calculate the reference crop evapotranspiration denoted by ET_o and ET_o is the evapotranspiration from a reference surface not short of water. The reference surface is a hypothetical grass reference crop with specific characteristics. The calculation of the crop water requirements was done as according to FAO Drainage Paper, Number 24.

$$ET_{crop} = ET_o * K_c \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where ET_{crop} is the crop evapotranspiration (mm/day), ET_o is reference crop evapotranspiration (mm/day) and K_c is the crop factor or coefficient.

The values of ET_c and CWR (Crop Water Requirements) are identical, whereby CWR refers to the amount of water that is needed to compensate for the loss. and ET_c refers to the amount of water lost through evapotranspiration. The drip irrigation design considered the worst-case scenario with the highest monthly crop water requirement. Estimated ET_{crop} at peak demand for drip irrigation T_d was determined using Equation 3.

$$T_d = U_d \times [0.1(Pd)\ 0.5] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where Td is the estimated ET_{crop} at peak demand for drip irrigation, U_d is the conventionally estimated peak ET_{crop} and P_d is the Percentage ground cover (%).

The net irrigation requirement was estimated using Equation 4:

$$Ir_n = (ET_{crop} * Kr) - R + LR \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where: Ir_n is the net irrigation requirement, ET_{crop} is the crop evapotranspiration, Kr is the ground cover reduction factor, R is amount of water received by plant from sources other than irrigation (for example rainfall) and LR is amount of water required for the leaching of salts.

The gross irrigation requirement was calculated by multiplying the net irrigation requirement with the application efficiency of the drip irrigation system as in equation 5.

$$d_{gross} = d_{net} * ea \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where d_{gross} is the gross irrigation requirement, d_{net} is the net irrigation requirement and ea is the application efficiency.

Equation 6 was used to establish the duration of time or length of operation.

$$Ta = \frac{IRg}{Np * q} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where Ta is the duration of irrigation per day (hr), IRg is the gross irrigation requirement (mm/day), Np is the number of emitters per plant and q is the emitter discharge (l/hr or lph).

2.3.4. Headwork designing

A drip system was designed for the irrigation of ornamental crops and the pipeline was sized according to the crop water demand. Considering the flexibility and cost, solar powered drip irrigation was recommended and the pump specifications determined depending on the source of energy, water and irrigation requirements and the command area. The solar panel array size was sized using the method postulated by Fraenkel (1986) using the following procedure:

- Calculation of monthly water requirements taking into account the discharge (Q) and head(H).
- Calculation of monthly hydraulic energy requirement.
- Calculation available solar energy for the LSU Campus in Lupane.
- Determination solar panel array, pump and motor specification.

- **Step 1**

The size of the pump depends on the discharge and head of the system. Therefore, a topographical survey was done to calculate the topographical differences between the proposed reservoir sites and the irrigable areas. The discharge required was obtained from the calculation of crop water requirements.

- **Step 2**

The hydraulic energy requirement of the system was found using equation 7.

$$Hf = VH\rho g \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where Hf is the hydraulic energy requirement of the system, V = required discharge per day, H = total dynamic head, ρ = density of water (1000kg/m^3) and g = gravitational constant (9.81m/s^2).

- **Step 3**

The hydraulic requirement is the amount of energy that is needed to lift the desired amount of water from the source considering all the energy loses. In this case it is the energy required to pump the water from the designed underground reservoirs to the irrigation sites. The total dynamic head is a composition of various pressure loses in the pipeline system, pipeline head loses are due to friction between the water and the surface area. Other components that add up to the total dynamic head are operating pressure of the system, suction lift, difference in elevation and the head loss in fittings.

A solar powered system was designed. The parameters needed to calculate this energy are the clearness index, extra-terrestrial radiation and the time factor. The available solar radiation varies with location; therefore, the available energy is a function of season of the year and the weather and location of the design place (Fraenkel, 1986).

$$Ea = ET_{rad} \text{ x } CI \text{ x } T_{factor} \quad \dots\dots (8)$$

Where Ea is the available energy, ET_{rad} is the extra-terrestrial radiation, CI is clearness index and T_{factor} is the factor.

- **Step 4**

The last step is the determination of the solar panel array, pump and motor specification. The specification was found using the equation below.

$$Ep = \frac{Hf}{e} \quad \dots\dots (9)$$

where Ep is the electrical demand for motor and pump, Hf is the hydraulic energy requirement and e is the efficiency.

The solar array area size was calculated using equation 10.

$$Ar = \frac{Ep}{AI} \quad \dots\dots (10)$$

Where A is the solar array area size needed, Ep is the electrical demand for motor and pump and AI is the available irradiation.

2.3.5. Calculation of the bill of quantities

The bill of quantities was compiled for the harvested water conveyance, underground reservoirs, solar pumping system and drip irrigation system. Pricing of the bill of quantities was based on the May 2018 prices on the local market. A financial analysis was carried out to find out if the project was viable.

3. Results

This chapter shows the results of various design calculations of the RWH and drip irrigation system. The chapter also looks at the methods used for calculation of various parameters and variables. The calculations made include the crop water requirements and total harvestable water. The crop water requirements were calculated to determine the amount of water that the RWH system would supply. The compiled BOQ for the design is provided in the appendix.

3.1. Crop water requirements

The water requirements of the cropping pattern were calculated using the modified Penman Montieth method as described in the FAO Irrigation and Drainage Paper, Number 24. The meteorological data of Lupane Station was used as inputs to the Penman equation, from where the reference crop evapotranspiration (ET_o) was derived. The crop coefficients (K_c) were derived using the procedures described in the above reference taking into consideration the crop planting or sowing date, the total growing season and the length of development stages of each crop under the local conditions.

The crop water requirements (ET_{crop}), calculated by multiplying the ET_o with the crop coefficients (K_c), were corrected for the peak months in order to estimate the ET_{crop} to be met at 80% probability. Net irrigation requirement was obtained by subtracting the effective rainfall from ET_{crop}. The gross irrigation requirement was obtained by dividing the net irrigation requirement at irrigation efficiency of 90 %. The project's gross irrigation requirement was later calculated by multiplying the gross irrigation requirement by the area (0.5 hectares) and conversion factor that is 10. The conversion is intended to change the volume of water from millimeters to cubic meters. The result was found to be 6787.8cubic meters of water.

3.2. Preliminary design

Table 1 shows the climate data for Lupane derived from CLIMWAT 2. They were used as input in the calculation of crop and irrigation water requirements.

Table 1: Climate data for Lupane

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sunshine (Hours)	Radiation (MJ/m²/day)	ETo (mm/month)
January	11.4	38.7	70	259	7.1	21.7	206.06
February	7	36.5	72	242	7.2	21.4	171.74
March	8.2	38.9	67	225	8.2	21.6	199.49
April	1.8	36	62	216	8.6	19.8	175.54
May	-2.6	34.3	58	199	9.4	18.3	160.77
June	-7.2	31.6	55	199	9.6	17.2	140.07
July	-5.6	31.4	50	233	9.9	18.1	158.91
August	-7.7	33.4	43	285	10.5	21.1	204.8
September	2	38.2	37	354	10.9	24.5	264.1
October	5.5	41.2	41	372	9.9	25	304.66
November	7.6	41.2	55	328	8	22.9	257.75
December	8.3	38.9	67	285	7	21.6	218.49

Table 2: Crop water and irrigation requirements for Duranta from outputs of Cropwat 8

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
Evapotranspiration of Duranta (mm/month)	28	20	74	105	118	115	139	179	225	239	171	86	1501
Corrected ETcrop (mm/month)	28	20	74	105	117	115	139	179	247	262	170	86	1547
Net irrigation req (mm/month) 100%	0	0	11	84	110	113	139	178	244	239	112	0	1234
Total net irrigation (mm/month/ha) Duranta	0	0	11	84	110	113	139	178	244	239	11	0	1234
Gross irrigation requirement (mm/month/ha)	0	0	12	93	122	124	152	196	268	263	12	0	1357
Project gross irrigation 0.5ha	0	0	62	467	610	623	764	980	134	131	61	0	6787

The design is made for the worst-case scenario where there is highest amount of water required by the plants and according to the above table, it is in September. Therefore, the peak water use is 244.2 mm/month divided by 30 days and thus 8.1mm. The steps followed for calculation of crop water requirements are as suggested in FAO Irrigation Manual Volume 3, Module 9. Designing for the worst-case scenario which is the peak water use during drier months, the crop evapotranspiration was found to be 6.075mm. Gross irrigation requirement and net irrigation requirement were found to be 6.75mm/day and 6.075mm/day respectively. With gross and irrigation requirements above, each and every plant would need 30L of water per every irrigating day. Two emitters with a discharge of 3.5L/hour each would be installed on each plant. The area of the wetted area was found to be 3 m^2.

During the hotter days when there is peak water use by the crop the irrigation frequency would be 3 days. By so doing it allows the irrigation system to replenish the readily available moisture by 90L per tree in every three days. The counted number of trees at the Faculty building and hostels was 750 trees. Therefore, per irrigation cycle 67 500L will have been irrigated. Assuming that we irrigate once in every 3 days then the we have 115 irrigating day per year therefore would need 7 762,5 m^3 per year. A design for a tank to hold 8 000 m^3 was done.

3.3. Calculation of collectable water and sizing reservoirs

Table 3 shows the roof top and car park areas that were calculated using the University Master and Building Plan.

Table 3: Total surface area for structures at the university

Structure	Surface Area (m^2)
Faculty of Agricultural Sciences Building	5 500
Tarmac Car Park	10 300
Male and Female Hostels	2 000
Dining Hall	1 200
Total Surface Area	19 000

Therefore, the total harvestable water using Equation 1 stated above is 9 387 m^3. The 9 387 m^3 is greater than the total crop irrigation requirements (8 000m^3) and this shows that there is enough water to irrigate the proposed plants using rainwater harvesting.

3.4. Designing the water reservoirs

The hostels and dining hall were designed to discharge water in the same reservoir, which was sited near the hostels in order to reduce the running pipeline cost and also to supply the landscape features at the hostels with water supply by so doing a total area of 3 200m^2 was used to calculate the dimensions of the reservoir tanks. Therefore, using Equation 1, the total harvestable water is 1 579.9 m^3. Two tanks will be constructed in order to reduce the size since a large tank is not as stable as a smaller. A large tank would need massive reinforcement, thus increasing the cost. The reservoirs will be circular in shape so as to increase stability as the force is distributed evenly in the whole structure. The dimensions of the tanks were identified using the trial-and-error system for the best dimensions which were of reasonable magnitude and the formulae:

$$r = \sqrt{v/h\pi} \qquad (11)$$

Where r is the radius of the tank, V is the volume of the tank and h is the depth of the tank

Table 4: Dimensions of the Hostels Reservoirs

Capacity	789 000 L
Volume	789 m^3
Radius	8.25 m
Depth	4 m

The soils at the proposed reservoir site are sodic and have slight movement. Therefore, a rectangular reservoir was recommended. Using trial and error a 48m * 48m * 3.5m reservoir was designed. Table 5 below shows the dimensions of the Faculty Building reservoir.

Table 5: Dimensions of the Faculty Building reservoir

Capacity	7 798 000 L
Volume	7 798 m^3
Length	48m
Width	48m
Depth	3.5m

3.4. Water reticulation

During a storm, water will be intercepted by the roof and then directed into the gutters. The gutters direct the water downwards to the underground drainage pipes. The hostels were constructed in such a way that all the water is discharged into two stilling boxes outside the hostels. The Faculty Building was designed in such a way that all the water is directed into the drainage pipes which are 2 m deep with a diameter of 600 mm. The drainage pipes discharge to the earthen drainage, which would discharge the water into the Bubi River.

The size of the outlet pipe from the stilling box would be equal to the stilling box inlet size, which is 90mm PVC size. A paved waterway along the walls will help to collect water on all unconnected gutter which are discharging water outside the hostels. The paved waterway will discharge in a stilling box, which will direct it to the reservoir. A pavement was used rather than pipes to reduce the inconveniences in piping due to connections on the gutters, as it might be difficult to fabricate the connections to the plastic gutters and piping might have complications on connections as they might leak or break easily. The Faculty Building and parking area will use the main drainage system, which runs underground to the bridge along the driveway to the Faculty Building. The water will be collected from that point and directed to reservoir using pipes. The use of the existing discharge system was recommended so as to keep the cost of the designs as low as possible as the discharge pipeline would deliver the water into the reservoir.

3.5. Irrigation method

Drip irrigation was recommended due its high application efficiency and limited wetting area. These features reduce the evapotranspiration. The soils at Lupane State University are loose-textured Kalahari sandy soils with high infiltration rate, therefore the use of drip irrigation would make sure that during irrigation smaller areas are wetted. Emitter selection was done on basis of soils, plant to be grown, slope and area to be covered by each plant. Pressure compensating inline drippers would be used.

Table 6: Irrigation system parameters.

Parameter	Magnitude
Dripper spacing	1m
Dripper discharge	4L/hr.
Dripper type	Inline
Operating pressure	12m
Duration of cycle	1day
Irrigation frequency	3 days

3.6. Energy requirements

Table 7 shows calculated available solar radiation for LSU at different time of the year. The design month was July with available solar radiation of 14.2 MJ/m^2/day which is the lowest and hence the worst case. The water discharge required per day is 34.6m^3/day

Table 7: Calculation of available energy at Lupane Campus

Month	ET_{rad} (MJ)	CI	T_{factor}	Available Energy (MJ)
January	25	0.6	1.54	23.1
February	27	0.6	1.47	23.8
March	30	0.6	1.27	21.0
April	34	0.6	1.05	19.6
May	38	0.5	0.85	16.2
June	39	0.6	0.72	16.8
July	39	0.6	0.66	14.2
August	39	0.5	0.82	16.0
September	38	0.5	0.8	15.2
October	35	0.6	0.98	18.9
November	31	0.6	1.21	20.6
December	27	0.6	1.43	23.2

The hydraulic energy requirement of the system is 12.58 MJ/day. In relation to that during the winter days there is 14.2 MJ/day which is enough to meet the hydraulic energy requirements of the system. The calculated solar array size was a 2200WP.

A bill of quantities for the material and resources needed for the construction of rainwater harvesting system and solar powered drip irrigation system was compiled. The prices were estimated based on 2018 prices by local suppliers in Zimbabwe. Table 8 shows the project's cost estimate.

Table 8: Summary of costs

Description	Cost US $
Reservoir Construction	116 400.80
Solar Pump and Fittings	6 680.02
PVC Piping and Fittings	1 670.90
Trenching and Labor	5 917.80
Subtotal	130 669.50
Add 10% Contingencies	13 066.95

3.7. Project worthiness

The project appraisal was carried out to determine the financial and economic impact of the project on the beneficiaries, which is the university population. The return to labor and capital with the project was compared to without the project situation to appraise the viability. In the financial analysis the point of view of the project is taken, that is evaluating the costs and benefits of the project as such. This includes evaluating the costs and benefit given the priorities of society and the consequence prices that is higher prices on imported goods and lower prices on domestic inputs like unskilled labor. In the analysis, an inflation rate of 1.6% was used. A discount rate of 12 % was used in calculating the net present worthiness of the rainwater harvesting system. Appendix 6 shows the cash flow analysis. The 2018 local prices were used in the appraisal. Costs and benefits were expressed in real terms cleaned for the effects of inflation. For capital, operation and maintenance costs the prices obtainable at the market were used. In order to assess the financial viability, the financial internal rate of return (FIRR), the net present worth (NPW) and the benefit cost ratio (B/C-ratio) have been calculated. The discount rate used was 12 %, based on an assumed inflation rate of 1.6 % and the bank lending rate of 12 %. The internal rate of return was found to be 5% which is greater than 1 while the Benefit/Cost ratio was 1.6 which is greater than 1 again and Net Present Value was found to be - $37 489.00. Thus, using the given assumptions, the project is financially viable.

4. Discussion

4.1. Health and environmental safety

Underground reservoirs were designed and will be covered to prevent a build-up of algae and mosquito breeding. The water in underground reservoirs will be cooled by the soil, thereby reducing chemical reactions in the water. Covering the reservoir reduces evaporative losses. The purpose of the design is to improve the beauty of the environment therefore there is need to keep the natural green environment. The excavated soil would be layered on top of the reservoir and grasses planted on top so that the natural environment is retained. The reservoirs and the solar installations would be fenced off so as to avoid theft and other damages to the structures.

4.2. Water reticulation

The design targets the collection of all harvestable water from the current LSU main campus surfaces. These include the parking area and roof tops. During designing process, the concept of cost of material reduction was utilized through taking of advantage of available water reticulation infrastructure such as drainage pipes and gutters. The gutters discharge water into the drainages that are already on the buildings. In order to harness water that is falling outside the gutters where water does not flow into the main drainage system, a concrete skating, need to be added to direct water to the drainage system. The drainage system will direct water to the underground reservoirs.

The Faculty Building reservoir will be located on coordinates (18°56’39.00”S, 27°45’49.50”E). This site is on the western side of the main University gate. The site was chosen because this is where the installed drainage pipe discharges and the water will flow into the underground reservoir by gravity as it has to be at a lower point than the outlet of the drainage outlet. The site was also chosen because the soils are more stable; the clay soils are more stable than the Kalahari sands, which are the prevailing soils in the area. A rectangular reservoir was designed and since it will be underground, the pressure exerted to the surface walls by the water will be counteracted by the soil thus reducing the probability of bursting.

The hostel reservoir will be located on coordinates (18°56’59.29”S 27°45’42.47”E). Circular reservoirs were designed so that pressure will be distributed to the surface evenly. Dividing tanks was meant to increase stability of the tanks since they are located in sand soils. The presence of reinforcement 8-gauge mesh would also help to increase the stability of the tank. A 25 cm * 25 cm reinforcement steel grid was placed on the base of the tank. The reinforcement is to increase resistance to pressure of water downwards hence pressure increases with depth. The tanks would be underground; this was made so that water gravitates freely into the tanks and as a means to increase the resistance force against the pressure of water. Being underground it also makes the environment natural and more aesthetically pleasing by avoiding too many structures being visible to people.

Water from the reservoirs will be pumped using 2 060 WP solar array panels. Solar energy was chosen because the system has low operating costs and there is abundant availability of solar radiation all year round at Lupane. Solar energy is rather environmentally friendly as there are no waste produced to the environment from solar energy hence utilization of the available natural resource that is solar radiation. PVC pipes are to be used for the mainline because they are cheaper than galvanized iron or HDPE pipes and since the pipes are buried there is no effect of sun on the pipes. The design included on 4 liter/hour point drip emitters rather than on line emitters due to unevenness of tree spacing, online emitters would waste water as there would be irrigating longer distances from the trees inducing weed growth too. Brass gate valves were considered as they tend to be more durable and ball corks were designed for smaller pipes. The design was made for Duranta *(Duranta erecta)* plant which is an exotic drought resistant plant. Some local plants and grasses like *Aloe ferox* and *Acacia caffra* can be used for landscaping as they require little amount of water. Xeriscaping can prove also to be a useful tool to improve the aesthetic view of the university.

According to Gumbo (1998) the cost of implementing RWH in Zimbabwe has not been established, however, there is long paybacks of the system therefore the economic reason to implement the project tends to be trace but an environmental and social reason is objective. Gumbo (1998) goes on to add that realistic volumes of RWH are filled quickly with water during heavy summer rains, but it is ideal to harness all water but the storage volume would seem to be unrealistic. The return period of 11 years was in line with what was found by Sarker *et al.,* (2014) that the range stretch from the 10 to 20 years and it depends on the uses of the water and materials for the system. Giould (2006) added that the cost of constructing RWH in South East Asia is between US $10-$16 per cubic meter. Li *et al.,* (2010) alluded to idea as the RWH designed to hold 920.3 cubic meters cost US $42 569 therefore US$46.50/m^3. Considering Giould's suggestion the cost of implementing the LSU design would be between US $143 370 and US $229 392. Therefore, using the authors above, the estimated cost is within the range they suggested as a total cost of US $143 736.50 was estimated for the design.

The cost may differ due to materials used to construct the storage as using concrete tank is estimated to be thrice as brick tank. The reservoir is the major expense in considering the investment cost and this was supported by Zavala *et al.,* (2018). Campisano *et al.,* (2012) noted that 52-62 % investment cost goes to the reservoir however some literature says 50%-70% of the investment cost goes the reservoir. Considering the design made for LSU the reservoir constitutes 80% of the investment cost. This might be because most of the water drainage infrastructure such as the asbestos cement drainage pipe and gutters has been set in place.

5. Conclusion

The amount of harvestable water at LSU was 9 387 cubic meters and according to the design made the reservoirs will be two sited at (18°56'59.29"S 27°45'42.47"E) and the other one at (18°56'39.00"S, 27°45'49.50"E). The conveyance pipeline drops from 50mm to 25 mm from the reservoir to the last outlet. The water requirement for irrigation was estimated at 6788m^3. Therefore, since the amount of harvestable water is bigger than crop water requirements then there is enough water for irrigation. Solar powered drip irrigation with a 2060WP array, which can supply a discharge of 7.2l/hr on each drip position was designed for the irrigation. The cost of implementing the design is US$ 143 736.50 and the project is socially and environmentally viable.

6. Recommendations

It was recommended that Lupane State University and its funding partners implement this project because it is worth to implement environmentally and socially. Although it might sound uneconomic due to the negative NPV, the design is socially and environmentally feasible. It is recommended that all LSU structures to be constructed should have RWH component so as to harness the rain water and utilize the abundant solar energy.

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References

Abbasi, T. and Abbasi, S.A. (2011). Sources of pollution in rooftop rainwater harvesting systems and their control, Critical reviews in environmental science and technology,41:23, 2097-2167, DOI: 10.1080/10643389.2010.497438.

Aladenola, O. and Adeboye, O.B. (2010). Assessing the potential for rainwater harvesting. Water Resource Management 24. 2129-2137.

Alam, G., Munna, M., Chowdhury, M.S., Sarkar, M. and Ahmed, M. (2012). Feasibility study of rainwater harvesting system in Sylhet City Environmental Monitoring Assessment. 184:573–580 DOI 10.1007/s10661-011-1989-7.

Campisano, A. and Modica, C. (2012). Optimal sizing of storage tanks for domestic rainwater harvesting in Sicily. Resources, Conservation and Recycling. 63. 9-16. 10.1016/j.resconrec.2012.03.007.

Chandela, S., Nagaraju, N.M. and Chandelb. R. (2015). Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies. Science direct Volume 49, 1084-1099.

Chao-Hsien, L. and Yao-Lung, T. (2004). Optimum storage volume of rooftop rainwater harvesting systems for domestic. Journal of the American Water Resource Association.

Drokat, L. and Sergiusz, P. (2015). Drought and water shortages in Asia as a threat and economic problem. Journal of Modern Science. Józefów: 235–250.

FAO, (2012) www.fao.org Coping with water scarcity. An action framework for agriculture and food security FAO report number 38 FAO of United Nations. Rome.

FAO, (2007) www.un.org. Coping with water scarcity. Challenge of the twenty-first century. Rome, Italy.

Fenguri, L., Seth, C., Gordon. T., William, R. and Burch, R. (2000). Rainwater harvesting agriculture. An Integrated System for water management on rain fed land in China's semiarid areas Ambio, Vol. 29, pp. 477-483 Royal Swedish Academy of Sciences.

Fraenkel, P.L. (1986). Water lifting. FAO irrigation and drainage paper 43. Rome, 1986.

Fredrick, S. (2005). Private Water Saves Lives www.cato.org. Financial Times. Retrieved from https://www.cato.org/commentary/private-water-saves-lives Cited 13 June 2018.

Gould, J. (2006). Rainwater harvesting: its time has come. Waterlines, an International Journal of Water, Sanitation and Waste, 24(4), 2–3. Retrieved from http://www.ircwash.org/sites/default/files/Gould-2006-Rainwater.

Lash, D., Ward, S., Kershaw, T., Butler, D. and Eames, D. (2014). Robust rainwater harvesting: probabilistic tank sizing for climate change adaptation. Journal of Water and Climate Change 5 (4) 526-539; DOI: 10.2166/wcc.2014.080.

Li, Z., Boyle, F. and Reynolds, A. Rainwater harvesting and grey water treatment systems for domestic application in Ireland. Desalination 260, 1–8.

Ngigi, S.N. (2003). Rainwater Harvesting for Improved Food Security: Promising Technologies in the Greater Horn of Africa, p. 266, Nairobi, Kenya: Greater Horn of Africa Rainwater Partnership (GHARP), Kenya Rainwater Association (KRA).

Puertas, G.G., Van Beusekom, M., Peréz, A., Van Steenbergen, F. and Kifle, W. (2014) Roads for water: the unused potential. Waterlines Vol. 33 No. 2. Practical Action Publishing, 2014.

Srker, P.C., Islam, N. and Sarker, R.C. (2015). Rainwater harvesting in educational institutions and residential areas. Acase study of University of Asia Pacific in Khada. Paper ID: WRE-012, 900–905.Gazipur Bangladesh.

Shivakumar, A.R. (2007). World's largest rainwater harvesting project in Karnataka. Current Science, Vol. 92, No. 2 pp. 161-163.

Savva. A.P. and Frenken, K. (2001). Irrigation Manual Volume IV Module 9. Localized irrigation systems, planning, design, Operation and Maintenance. FAO SAFR, Harare.

Singh, B. (2005). Techniques and methodologies for rainwater harvesting and its utilization in Pondicherry. Pondicherry (Central) University, India.re1u8.

UNDP (2006) www.undp.org. UN-Water, Human development report. Water scarcity, risk and vulnerability. Rome, Italy.

Van Giessen, E. and Carperter. F. (2009) Georgia rainwater harvesting guidelines. www.dca.ga.gov. cited 13 June 2018.

Zavala, M.Á.L., Prieto, M.J.C. and Rojas, C.A.R. (2018). Rainwater harvesting as an alternative for water supply in regions with high water stress. Water Science and Technology: Water Supply, ws2018018. https://doi.org/10.2166/ws.2018.018.

Appendices

Appendix 1: Sample calculations

Calculation of crop water requirements

The steps followed for calculation of crop water requirements are as suggested in FAO Irrigation Manual Volume 3, Module 9. For the design of drip irrigation systems considering the worst-case scenario

$$ET_{crop\text{-}loc} = (ET_{crop})(Kr)$$

where: $ET_{crop\text{-}loc}$ is the Crop evapotranspiration for localized irrigation, ET_{crop} is the crop evapotranspiration from CROPWAT and Kr is the Crop reduction factor as according to Freeman and Garzolli, Therefore, using Freeman and Garzolli ground cover reduction factor of 0.75

$$ET_{crop\text{-}loc} = 8.1\text{mm/day x } 0.75$$
$$= 6.075 \text{ mm/day}$$
$$IRn = [(ET_{crop\text{-}loc})(Kr) - R + LR]$$

Where IRn is the net irrigation requirement, $ET_{crop\text{-}loc}$ is the crop evapotranspiration for localized irrigation, Kr is the ground cover reduction factor, R is water received by plant from sources other than irrigation and LR is the amount of water required for the leaching of salts. The soils are well drained therefore it is not economic to include the leaching requirement therefore LR = 0. There are no other sources of water expect from irrigation therefore R= 0mm.Therefore IR_n = 6.075mm/day

Gross irrigation requirement (IR_g) is a product of net irrigation requirement and application efficient therefore

$$IR_g = IR_n \div Ea$$

Where IR_g is the gross irrigation requirement and Ea is the field application efficiency. According to Rainbird International (1980) as quoted by Savva and Frenken (2002), an operating efficiency of 90% should be given for dry and hot areas.

$$IR_g = 6.075\text{mm/day} \div (90/100)$$
$$= 6.75\text{mm/day}$$

According to Savva and Frenken (2002), the percentage wetting area is the average horizontal area wetted within the 30cm of the crop root zone depth in relation to total cropped area. In which for low rainfall it is 60%. Rainbird International (1980), recommends A_w (area wetted by one emitter) in sand soil to be 0.5 to 2 m^2 therefore a wetted area of 1.5m^2 was used in the design.

$$EP = \frac{AP \text{ x } Pw}{Aw}$$

Where EP is the number of emitters per plant Pw is the percentage wetted area/100 (%/100) and Aw is the Area wetted by one emitter (m^2)

$$\text{Therefore EP} = \frac{2.5\text{m x2m x 0.6}}{1.5m^2}$$
$$= 2$$

Calculation of volume of water required in a year

$d_{net} = (IRn)(TS)$

where d_{net} is the $_{amount}$ of water needed to replenish amount of water lost or used by the Duranta plant for evapotranspiration, IRn is the net irrigation requirement and (TS) is the tree spacing

$$d_{net} = (6.075/1000)\ (2.5m)\ (2m)$$
$$= 0.03\ m^3 \text{ or } 30\ l/\text{day per tree}$$

Therefore 30 l/day per tree is needed to replenish amount of water lost or used by the Duranta plant for evapotranspiration.

$$A_W = (TS)(Pw)$$

Where AW is the area of wetted soil, TS is the tree spacing and Pw is the percentage wetting area

$$A_W = (2.5m)\ (2m)\ (0.6)$$
$$= 3m^2$$

Available soil moisture per tree (AWC_{tree}) is a product of Available soil moisture (AWC), Area of wetted soil (A_W) and root zone depth (RZD)

$$AWC_{tree} = (AWC)(A_W)(RZP)$$
$$= (120/1000)\ (3\ m^{2)}\ (2m)$$
$$= 0.72\ m^3 \text{or } 720\ l/\text{tree}$$

Readily available moisture for drip system to be replenished by irrigation (RAM_{IRR}) is a product of Available soil moisture per tree (AWC_{tree}) and moisture depletion percentage (P)

$$(RAM_{IRR}) = (AWC_{tree})\ (P)$$
$$= (720)\ (0.2)$$
$$= 144\ \ l/\text{tree}$$
$$IF = AWC_{tree} \div (RAM_{IRR})$$

Where IF is the irrigation frequency, AWC_{tree} is the Available soil moisture per tree and (RAM_{IRR}) is the readily available moisture for drip system to be replenished by irrigation

$$IF = 720\ l/\text{tree} \div 144 l/\text{tree}$$
$$= 3 \text{ days}$$

Since irrigation was done every 3 days, the net amount of water to be applied should be 3 * 30 = 90 liters per tree. At peak water use period, 90 liters will be irrigated per plant and 3 days will be skipped for another irrigation session. Total number of trees to be planted around the Faculty Building and Hostels is 750.

Therefore, the amount of water needed to irrigate all the plants per day (q) is the product of one tree water requirement (qd) and Number of trees irrigated per day(n_{tree})

$$q = (qd)\,(n_{tree})$$
$$q = (90\ \text{liters/tree})\,(750\ \text{trees})$$
$$q = 67\,500\ \text{liters/day}$$

Total amount of water need for the whole project (Q) is a product of Daily water requirements (q) and number of irrigation days per year (n)

$$Q = (q)(n)$$
$$Q = (67\,500\ \text{liters/day})\,(115\ \text{days})$$
$$Q = 7\,762\,500\ \text{liters/ year}$$
$$Q = 7\,762.4\ m^3/\text{year}$$

Therefore, the required volume of reservoir required will be 8 000m^3 reservoir

Energy requirements

The energy requirements were calculated using the formula below:

$$H = Vh\rho gE$$

Where H is the Hydraulic energy requirement, V is required discharge per day, h is total dynamic head, ρ is density of water (1000kg/m^3), g is the gravitational constant (9.81m/s^2) and E which is the subsystem efficiency which is 0.32 in this case

$$H = (34.6m^3)\,(37m)\,(1000kg/m^3)\,(9.81\ m/s^{-2})\,(0.32)$$
$$= 40.1\ \text{MJ/day}$$

Changing from units of energy from MJ/day to KWh/ day a conversion factor of 0.28 was used such that 1 MJ is equal to 0.28 kWh therefore 40.1 MJ/day = 11 kWh/day

The design was done considering the worst-case scenario, which is in July.

$$A_S = (AR)(E)(L),$$

where A_S is the available solar energy, (AR) is the available radiation, E is the conversion efficiency and L is the conversion factor

$$(A_S) = (15.2\ MJ/m^2/\ \text{day})\,(1/0.75)\,(0.28)$$
$$= 5\ kWh/m^2/\text{day}$$

Where A is the array size needed, H is the Electrical demand for motor and pump and A_S is the available solar energy

$$= 11\ kWh\ /\text{day} \div 5kWH//\text{day}$$
$$= 2.2m^2$$

But 1 m^2 is rated at 1000 WP, therefore the array size is rated 2200 WP

Appendix 2: Climate data for Lupane

Table 9. Rainfall data for Lupane

Month	Rain (mm)	Eff rain (mm)
January	152	115
February	127	101.2
March	71	62.9
April	21	20.3
May	7	6.9
June	2	2
July	0	0
August	1	1
September	3	3
October	24	23.1
November	65	58.2
December	144	110.8
Total	617	504.5

Table 10. Climate data for Lupane

Month	Min Temp(°C)	Max Temp (°C)	Humidity (%)	Wind (km/ day)	Sun (Hours)	Rad (MJ/ m^2/day)	ETo (mm/ month)
January	11.4	38.7	70	259	7.1	21.7	206.06
February	7	36.5	72	242	7.2	21.4	171.74
March	8.2	38.9	67	225	8.2	21.6	199.49
April	1.8	36	62	216	8.6	19.8	175.54
May	-2.6	34.3	58	199	9.4	18.3	160.77
June	-7.2	31.6	55	199	9.6	17.2	140.07
July	-5.6	31.4	50	233	9.9	18.1	158.91
August	-7.7	33.4	43	285	10.5	21.1	204.8
September	2	38.2	37	354	10.9	24.5	264.1
October	5.5	41.2	41	372	9.9	25	304.66
November	7.6	41.2	55	328	8	22.9	257.75
December	8.3	38.9	67	285	7	21.6	218.49

APPENDIX 3: Crop and irrigation water requirements

Table 11: Calculation of crop water requirements

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Evapotranspiration of duranta (mm/month)	28.8	20.8	74.2	105.2	117.8	115.3	139.0	179.3	224.7	238.8	170.9	86.3	1501.1
Corrected Et_{crop} (mm/month)	28.8	20.8	74.2	105.2	117.8	115.3	139.0	179.3	247.2	262.7	170.9	86.3	1547.5
Net irrigation req (mm/month) 100%	0.0	0.0	11.3	84.9	110.9	113.3	139.0	178.3	244.2	239.6	112.7	0.0	1234.2
Total net irrigation (mm/month/ha) duranta	0.0	0.0	11.3	84.9	110.9	113.3	139.0	178.3	244.2	239.6	112.7	0.0	1234.2
Gross irrigation requirement (mm/month/ha)	0.0	0.0	12.4	93.4	122.0	124.6	152.9	196.1	268.6	263.5	124.0	0.0	1357.6
Project gross irrigation 0.432ha	0.0	0.0	62.2	467.0	610.0	623.2	764.5	980.7	1342	1317.7	619.9	0.0	6787.8

Table 12: Cost of pumping and labour for electricity powered

Pump Discharge (50L/Hour)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Actual pumping hours per month (20 hrs/day)	280	280	280	280	280	280	280	280	280	280	280	280	3360
Electric motor size (Kw)	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	26.4
Value of Energy $per kwh (communal farms)	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	1.68
Total pumping cost per month (USD)	86.24	86.24	86.24	86.24	86.24	86.24	86.24	86.24	86.24	86.24	86.24	86.24	1034.88
Cost of water per month ($US)	246.34	55.20	295.16	427.00	446.16	425.63	532.38	734.01	1072.2	1153.7	708.92	325.72	6422.40
Labour	400	400	400	400	400	400	400	400	400	400	400	400	4 800
Total costs	732.58	541.44	781.4	913.24	932.4	911.86	1018.62	1220.25	1558.5	1639.9	1195.16	811.96	12257.29

APPENDIX 4: Hydraulics and drawings

Table 13: Calculation of head loss in pipeline of the faculty building system

Pipe Diameter (mm)	Class	Discharge (m^3/hr)	Length (m)	Friction Loss (hl)	Christiansen Factor (F)	HL
50mm	4	4.96	436	0.02	1	8.72
40mm	4	3.91	16	0.03	1	0.48
40mm	4	2.86	285	0.022	0.376	2.35752
25mm	6	1.14	360	0.03	0.356	3.8448
25mm	6	1.05	240	0.03	0.358	2.5776
Head loss						17.9799

Table 14: Calculation of head loss in pipeline of the hostels system

Pipe Diameter (mm)	Class	Discharge (m^3/hr)	Length (m)	Friction Loss (hl)	Christiansen Factor (F)	HL(m)
50mm	4	3	100	0.008	1	0.8
40mm	4	0.72	60	0.025	1	1.5
32mm	6	0.7	50	0.05	0.518	1.295
25mm	6	0.24	480	0.06	0.358	10.3104
Total head loss in pipes						13.9054

Table 15: Calculation of the total dynamic head

Head Loss	Faculty Building	Hostels
Suction Lift	3	3.5
Main Line And Laterals	17.9	13.9
Control Head	2.5	5
Drip Operating Pressure	5	5
Subtotal	28.4	27.4
Fittings 10%	2.84	2.74
Elevation Difference	10	4
Total Dynamic Head (M)	41.24	34.14

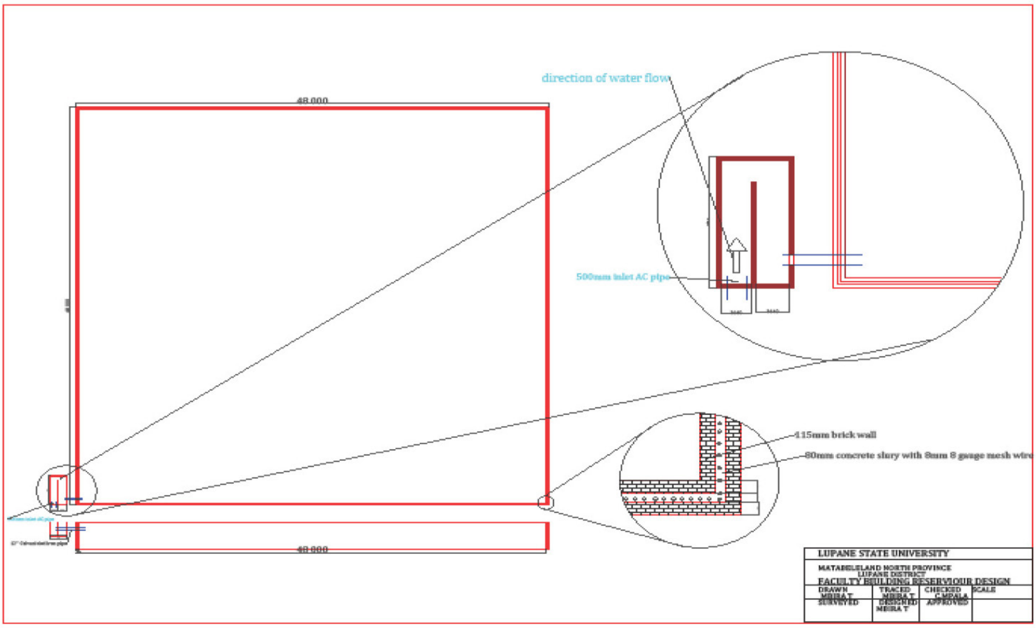

Figure 2: Drawing for the proposed faculty building reservoir

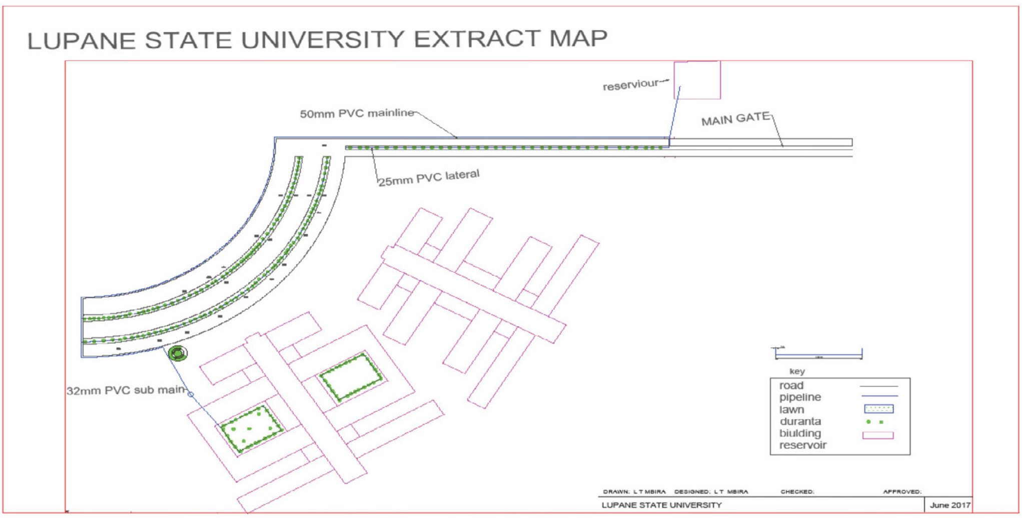

Figure 3: Drawing for the proposed faculty building drip layout

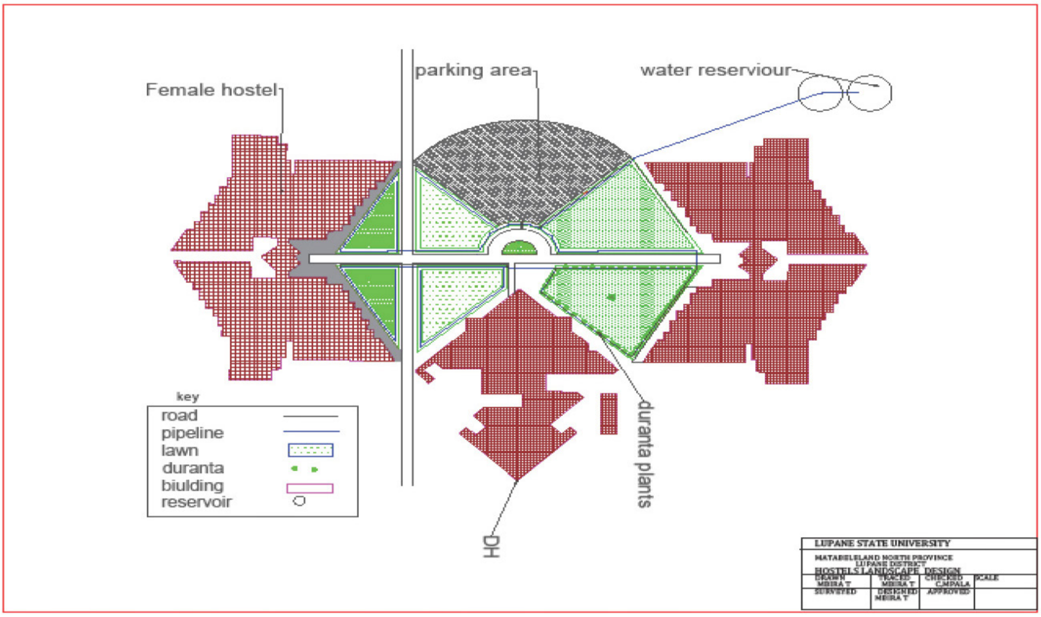

Figure 4: Drawing for the proposed hostel drip irrigation system

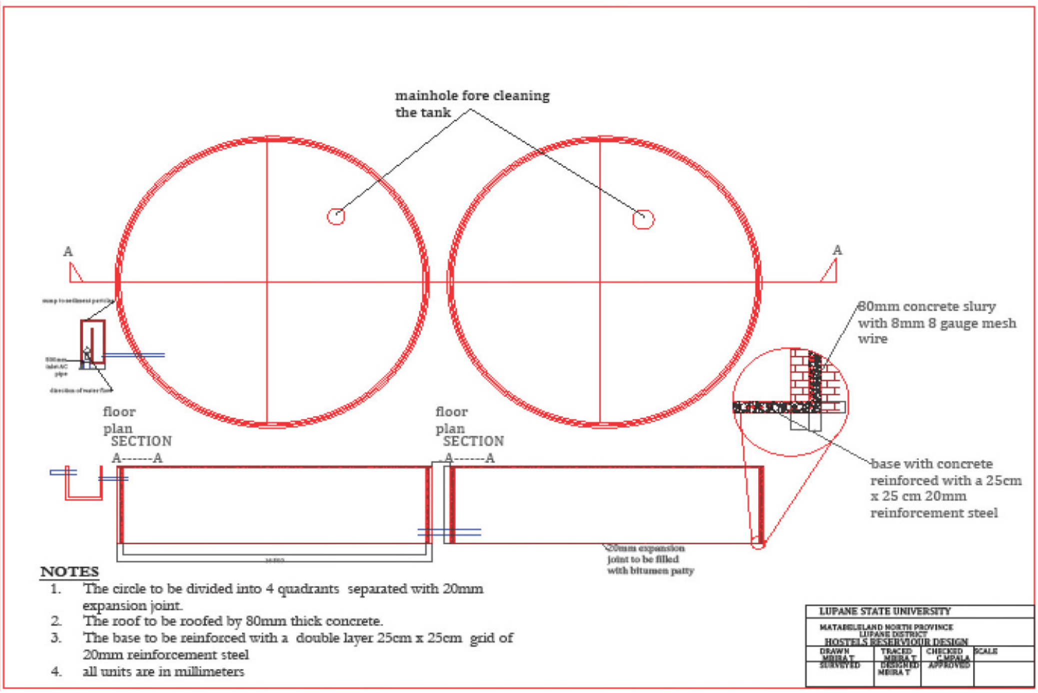

Figure 5: Drawing for the proposed hostel reservoirs

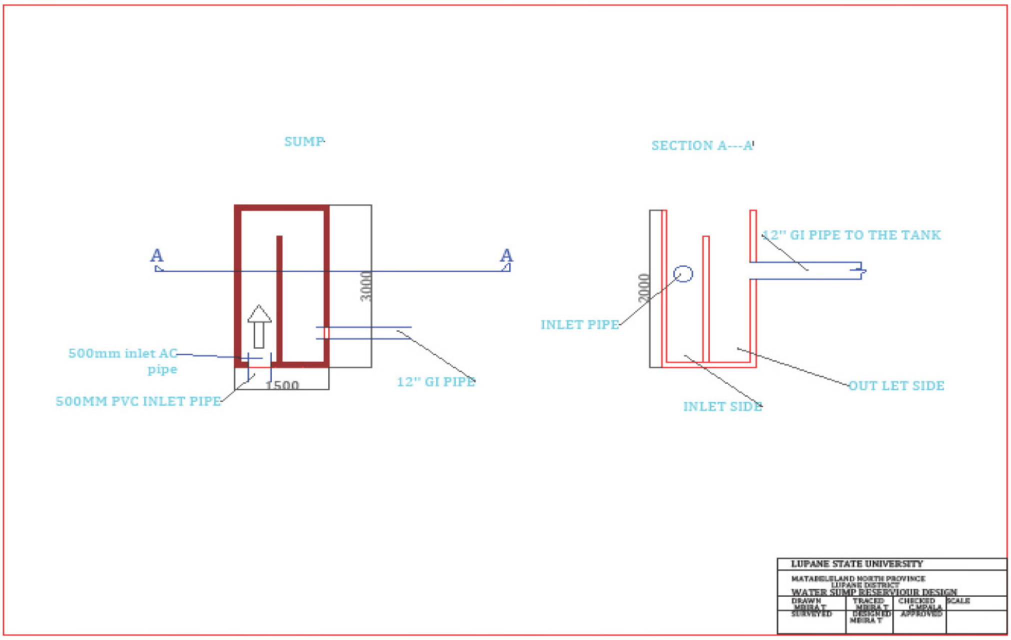

Figure 6: Drawing for the proposed water sump to trap litter into the reservoir

APPENDIX 5: Bill of quantities

Table 16: Bill of quantities for the RWH designed

Item	Description	Quantity	Unit	Unit Cost	Unit Cost
1.water reservoir	1 x 7 798 m^3 + 2 x 789 m^3 brick tanks				
1.1	Cement standard bricks	132612	No	0.15	19891.80
1.2	PMC 32.5 cement	2740	50 kg bag	11.00	30140.00
1.3	River sand	270	m^3	5.00	1350.00
1.4	20 mm quarry stone	300	m^3	5.00	1500.00
1.5	8 mm deformed bars	7120	6 m length	5.40	38448.00
1.6	Binding wire	60	Rolls	4.60	276.00
1.7	115 mm brick force	50	rolls	2.90	145.00
1.8	8 mm x 250 mm x 250 mm x4 m wire mesh	1210	m^2	4.00	4840.00
1.9	Impermo	2000	Kg	0.85	1700.00
1.10	Bitumen patty	50	Kg	5.00	250.00
1.11	Transport to LSU	5000	Lump	1.00	5000.00
1.12	Skilled labour	2500	Lump	1.00	2500.00
1.13	Unskilled labour	1500	Lump	1.00	1500.00
1.14	Excavation	112	machine hours	80.00	8960.00
	Subtotal				116400.80
2. pumps	SOLAR PUMPS AND FITTINGS				

Item	Description	Quantity	Unit	Unit Cost	Unit Cost
2.1	Tying rope	50	M	2.00	100.00
2.2	Solar submersible pump 2.2 KW, Q=50L/min H=40m complete with suitable solar control box, module and accessories	1	Lump	3000.00	3000.00
2.3	Solar submersible pump 2.2 KW, Q=50L/min H=50m complete with its solar control box and module, stand and accessories	1	Lump	3000.00	3000.00
2.4	HDPE pipe 50mm	50	M	2.30	115.00
2.5	Aquavin cable	50	M	5.00	250.00
2.6	50mme equal TEE	3	No	1.57	4.71
2.7	50mm-40mm reducer	2	No	3.70	7.40
2.8	50mm VSP adapter	2	No	0.52	1.04
2.9	50mm compression coupling	1	No	1.87	1.87
2.10	Installation labour	200	Lump	1.00	200.00
2.11	Subtotal				6680.02
3.0 Mainline and laterals	PVC PIPING AND FITTINGS				
3.1	50mm class 6 PVC pipe	92	6 m length	1.69	155.48
3.2	50mm -25mm PVC reducer1	2	No	0.65	1.30
3.3	50-32 mm PVC reducer	2	No	3.68	7.36
3.4	40mm-32mm PVC reducer	1	No	3.25	3.25
3.5	40mm-25mm reducer	8	No	2.75	22.00
3.6	40mm PVC pipe	8	No	1.06	8.48
3.7	40mm PVC equal TEE	2	No	1.20	2.40
3.8	4” brass gate valve	1	No	10.00	10.00
3.9	4” barrenel nipple	2	No	2.45	4.90
3.10	32mm-25mm PVC reducer	2	No	1.40	2.80
3.11	32mm equal PVC tee	2	No	1.12	2.24
3.12	32mm class 6 PVC pipe	21	6m length	0.90	18.90
3.13	25mm VSP adapter	34	No	0.87	29.58
3.14	25mm PVC equal TEE	4	No	0.47	1.88
3.15	25mm PVC endcap	22	No	0.20	4.40
3.16	25mm PVC elbow	32	No	0.30	9.60
3.17	25mm class 6 PVC pipe	187	6m length	0.79	147.73
3.18	1” brass ball valve	18	No	6.70	120.60
3.19	4 L/hr woodpector PC CNL dripper	1 500	No	2.3	920.00
3.20	Transport	200	Lump	1	200.00

Item	Description	Quantity	Unit	Unit Cost	Unit Cost
3.21	Subtotal				1672.90
4	TRENCHING AND BACKFILLING				
4.1	Trenching	2000.00	Lump	1.00	2000.00
4.2	Backfilling	2000.00	Lump	1.00	2000.00
	Subtotal				4000.00
5	Fencing				
5.2	50 mm diamond mesh wire	320.00	M	2.20	704.00
5.3	50mm diameter by 2.1 m steel standard post	32.00	No	21.89	700.48
5.4	W steel droppers	74.00	No	5.60	414.40
5.5	Double leaf gate	2.00	No	35.00	70.00
5.6	Tying wire	5.00	Rolls	5.80	29.00
	Subtotal				**1917.88**
	Total				**130671.60**
	Contingencies				**13067.16**
	Total cost				**143738.76**

Table 17: Summary of the BOQ

Description	Cost US $
Reservoir Construction	116 400.80
Solar Pump and Fittings	6 680.02
PVC Piping and Fittings	1 670.90
Trenching and Labor	5 917.80
Subtotal	130 669.50
Add 10% Contingencies	13 066.95

Table 18: Calculation cash flows

DISCOUNT RATE 12 %									
Year	Net Income	Govt Savings	Total Benefit	Energy, R&M	Capital Costs	Total Costs	Incremental Benefit	Discount Factor	Net Present Value
1			0		143738.76	143738.76	-143738.76	0.8929	-128344
2	12527.30		12527.30	100.00		100.00	12427.30	0.7972	11096.34
3	12527.30	0	12527.30	100.00		100.00	12427.30	0.7118	9907.04
4	12527.30	0	12527.30	100.00		100.00	12427.30	0.6355	8845.75
5	12527.30	0	12527.30	100.00		100.00	12427.30	0.5674	7897.55
6	12527.30	0	12527.30	100.00		100.00	12427.30	0.5066	7051.25
7	12527.30	0	12527.30	100.00		100.00	12427.30	0.4523	6295.67
8	12527.30	0	12527.30	100.00		100.00	12427.30	0.4039	5620.87
9	12527.30	0	12527.30	100.00		100.00	12427.30	0.3606	5019.39
10	12527.30	0	12527.30	100.00	1000.00	1100.00	11427.30	0.3220	4120.68
11	12527.30	0	12527.30	100.00		100.00	12427.30	0.2875	4001.59
12	12527.30	0	12527.30	100.00		100.00	12427.30	0.2567	3572.85
13	12527.30	0	12527.30	100.00		100.00	12427.30	0.2292	3190.09
14	12527.30	0	12527.30	100.00		100.00	12427.30	0.2046	2848.34
15	12527.30	0	12527.30	100.00	1000.00	1100.00	11427.30	0.1827	2338.03
16	12527.30	0	12527.30	100.00		100.00	12427.30	0.1631	2270.47
17	12527.30	0	12527.30	100.00		100.00	12427.30	0.1456	2026.89
18	12527.30	0	12527.30	100.00		100.00	12427.30	0.1300	1809.41
19	12527.30	0	12527.30	100.00		100.00	12427.30	0.1161	1615.55
20	12527.30	0	12527.30	100.00	1000.00	1100.00	11427.30	0.0926	1326.71
	238018.70	0	238018.70	100.00		148638.76	89379.94	7.4583	-37489.88

Table 19: Benefit/Cost Ratio Calculation

Income	Cost	Net Return
	143738.76	-143738.76
12527.30		12527.30
12527.30		12527.30
12527.30	1000.00	11527.30
12527.30		12527.30
12527.30		12527.30
`12527.30		12527.30
12527.30	1000.00	11527.30
12527.30		12527.30
12527.30		12527.30
12527.30		12527.30
12527.30	1000.00	11527.30
12527.30		12527.30
12527.30		12527.30
12527.30	1000.00	11527.30
12527.30		12527.30
12527.30		12527.30
12527.30	1000.00	11527.30
12527.30		12527.30
12527.30		12527.30
238018.70	148738.76	5%

D. WATER AND HUMAN SETTLEMENTS OF THE FUTURE

Reduction of Contamination of Domestic Drinking Water in Slum Neighborhoods of Yaounde, Cameroon

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Abstract

Universal access to drinking water and sanitation is common to several national and international agendas. However, clean water availability data for many communities remain questionable and could be explained by the manipulation of water from the source until the actual consumption, as well as the poor monitoring of post-collection quality. The paradox is more highlighted in cities that benefit from conventional water networks and services. This article examines this issue in the City of Yaounde on typical slum neighborhoods. The analysis is based on in situ observations of supply sources and household's practices, as well as a survey of 369 households selected following a stratified random sampling plan in five neighborhoods. Discussions on priority areas of intervention with institutional health and water personnel made it possible to identify some proposals for improved and sustainable access to drinking water in slums.

The analysis reveals that in poor urban neighborhoods in Yaounde, water supply modes combine pipe networks and alternative unimproved structures. The distance to the supply points as well as the collection and storage practices contribute with handling during withdrawal, to contaminate water. Failure to use or misuse of existing treatment options contributes to increased health risks. Several water-related diseases are thus declared: 326 to 510 cases of typhoid, 109 to 125 cases of gastro enteritis and 4 to 7 cases of bloody diarrhea, monthly. Climate change would make the situation worse with a foreseen reduction of water quantity. Faced with this high health risk, the interventions required for improved health in slum neighborhoods in Yaounde are of a regulatory, institutional, infrastructural educational and financial support nature.

Keywords: drinking water, health risks, slums, Yaounde City, Cameroon.

1. Introduction

More than 800 million people in the world live in slum neighborhoods, and in sub-Saharan Africa, they represent nearly 50% of the urban population (UN HABITAT, 2018). Indeed, cities in developing countries are characterized by exclusion of entire neighborhoods from basic services such as drinking water supply, sanitation and household waste collection. This is how in Cameroon, out of 24 million inhabitants, around 9 million do not have access to a drinking water service (Guepi, 2019). Even though water is available, acceptable quality is not always guaranteed. Prolonged and unexpected interruptions in water supply to households, degradation of water quality in the distribution network, as well as the high cost of water, force households to rely on alternative water sources (undeveloped springs, wells, poorly maintained boreholes): a situation which is not without consequences for the health of consumers. Insufficient access to safe drinking water combined with insufficient sanitation and poor hygiene are the factors that contribute to 1.8 million annual deaths from diarrheal diseases; including 361 000 child deaths, aged under 5 (WHO / UNICEF, 2017). In fact, most of the drinking water supply projects are limited to the supply of water via infrastructures with abandonment of the necessary maintenance of water quality at the time of consumption. This situation negates the purpose of the intervention: "to provide safe drinking water for consumption".

The Abiergué study area is a watershed of the City of Yaounde in Cameroon with 374 555 inhabitants spread over eleven neighborhoods, five of which are slums, with an anarchic distribution of houses, a glaring lack of sanitation, growing use of alternative sources of water and high unemployed or low-income populations (Biembe, 2019). These poor neighborhoods have an urban organization which is characteristic of slums in the entire city: a sprawl that gives rise to spontaneous settling in wetlands, hillsides and summits (Fekoua, 2010). According to Djimani (2016) and Biembe (2019), the efforts made to improve access to drinking water in the area are mostly fruitless due to poor coverage of the drinking water pipe-network, insufficient maintenance of alternative structures, and contamination of water in the process of collection, transport and home storage regardless of the starting source. This article therefore analyzes the causes and proposes some measures that can improve the safety of drinking water at home in slum neighborhoods of Yaounde. This specifically involves analysis of the modes of water supply and the practices of collecting, transporting, conserving, handling and making water potable. Contamination scenarios are analyzed with recommendation of measures to maintain healthy drinking water quality.

2. Materials and methods

The methodology of this article is based on previous studies carried out as part of several works on the Abiergué basin. It comprises field observations, interview surveys, water quality analysis, as well as the use of data and other information from the cameroonian institutional health and drinking water supply system. Specifically, the analysis of the water supply modes was carried out through a survey by directive interview with 369 responding households in five slum neighborhoods of the study area (Messa Carriere, Madagascar, Mokolo, Etetack, Nkolso'o) using a stratified random sampling plan. Observation visits to sources and points of water use in homes were made, as well as interviews with health personnel. Water-borne disease statistics from 15 health centers for the years 2018 and 2019 with the Cameroon Health Districts Information System (DHIS) as a source were collected and analyzed for the health zones covering the studied area (Figure 1).

The performance of the various domestic drinking water treatment practices was assessed after tests performed in the biology laboratories of the University Dschang. Twelve water samples were taken from households (before and after treatment) according to the treatment option. The organoleptic (color, odor, appearance) and bacteriological (*Enterobacteria spp*, total coliforms, *Escherichia coli*, *Streptococcus spp*, *Salmonella spp*, *Shigella spp, Staphylococcus spp*) parameters of major public health importance (WHO, 2000) were thus evaluated. A Strengths Weaknesses Opportunities and Threats (SWOT) analysis of the urban pipe-network water quality monitoring system was carried out based on feedbacks from the household's questionnaires and the interviews conducted with key water sector stakeholders (institutional, private and civil society). All data were organized and processed using EXCEL software.

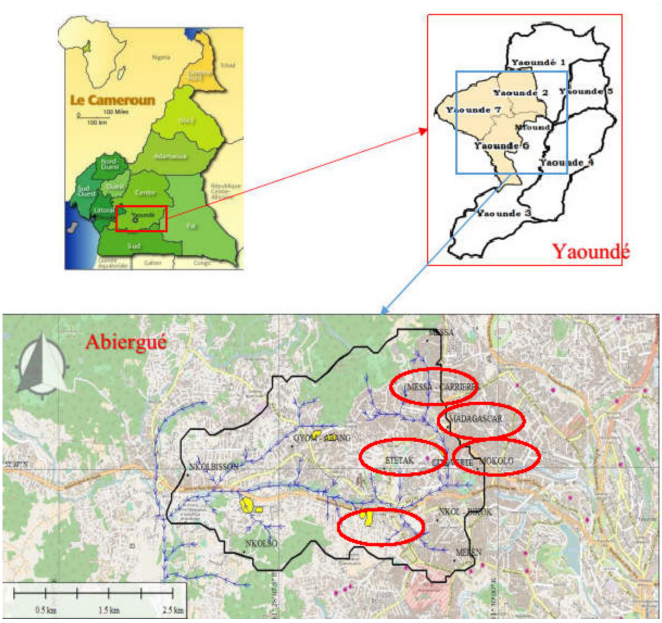

Figure 1: Location of the slum neighborhoods of Abiergué watershed in Yaounde City (Messa Carriere, Madagascar, Mokolo, Etetack, Nkolso'o) Adapted from Ndongo (2016) and Djimani (2016)

3. Results

3.1. Methods of supplying drinking water to slum neighborhoods

The water services of urban and peri-urban poor neighborhoods are dominated by unconventional services (Figure 2), which are restrictive for households. These constraints relate more to the conditions of access to the connection and continuity of service, than the costs of the service (Eloundou, 2010; Lako and Ndongo, 2016). However, vulnerable and insecure households who generally do not have connections to water supply networks suffer disproportionately from insufficient access to paid potable water services (UN, 2019).

Figure 2: Alternative sources of drinking water in slum neighborhoods of Yaounde © Biembe Jules

In fact, according to figure 3, in the urbanized basin of Abiergué the main sources of drinking water for households are developed springs (18%), boreholes (22%), urban water pipe network (57%) and other water sources (3%). Access to these sources is either free or chargeable, and the distances to be covered to the supplies are generally less than 200 meters. Thus, 40% of households are subject to the use of a distant water source of which quality at the source is not "guaranteed". Access to network water is through household taps (57%), resale by neighbors (19%) or supply to standpipes (24%). Also handling of this water exposes it to contamination during collection, transport and storage. This presents a major risk of contamination given that in 30% of the households children under the age of 15 are responsible for collecting water (Biembe, 2019). This proportion in 2007, according to Kuitcha et al. (2008) was already 43% in the north-eastern districts of the city of Yaounde (Tongolo and Ebogo watersheds).

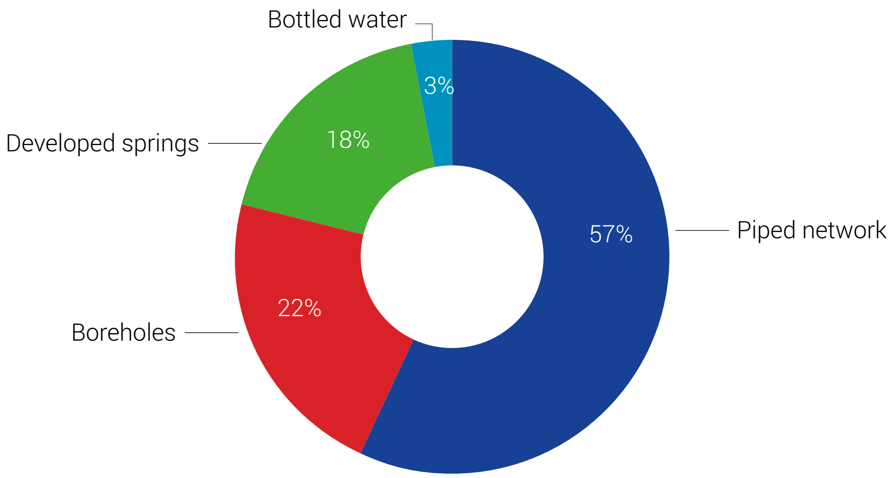

Figure 3: Percentage of households covered by various drinking water sources in slum neighborhoods of Yaounde

3.2. Water collection, transport, storage and handling practices

In the slum neighborhoods of Yaounde, water is collected most often (80% of cases) using cans or covered buckets and transport is done on foot with two-wheel trucks as well as motorcycles. Households store water in containers that are also used for collection. These containers are mostly plastic and vary in volume from 10 to 50 liters (Figure 4). There are three categories of water storage facilities composed of 78.9% of covered cans and buckets, 18.4% bottle water and close to 3% open containers. According to figure 5, households who don't cover their storage container are few and they generally store water for 13 to 24 hours. Besides, covered containers are mainly conserved for 12 to 48 hours. Sealed containers tend to be conserved longer in bottles, gallons and buckets. This situation increases the risk of contamination because according to PSEAU (2017), prolonged storage is often associated with high health risks.

Figure 4: Domestic drinking water transportation and storage material in slum neighborhoods of Yaounde ©Biembe Jules

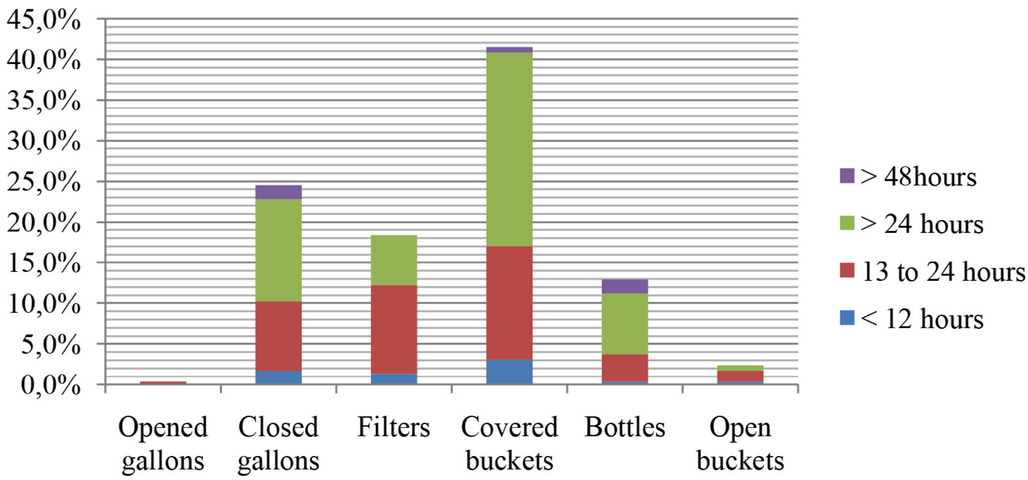

Figure 5: Percentage of household using a storage container and storage duration in slums of Yaounde

In addition, nearly 2/3 of households in that area store their water in containers without service taps and hand washing before handling cups is not common; only 35% of households declare they practice it. This increases the risk of contaminating or re-contaminating their water just before drinking. The people in charge of collecting water are most often the youngest and women. They spend at least thirty minutes a day doing this task and sometimes have to make several trips; extending the duration to two, three or four hours per day. Thus, this chore prevents them from doing other important occupations (UN, 2015). This is why complying with hygiene or safety rules for handling water seems to be an additional burden and waste of time. Trying to save the time dedicated to hygienic water handling could then be a reason, but it is a very risky attitude that requires specific attention in interventions to improve access to safe drinking water for households.

3.3. Existing domestic water purification options for drinking water

Ten options for domestic water purification are used by households in slum neighborhoods of Abiergué watershed, the main ones being filtration (70.2%), chlorination (16.4%) and decanting (11.6%). Three categories of filters are mainly used: mixed filters (mineral granules and ceramic cartridge), ceramic candle filters and membrane filters (Table 1 and Figure 6). The main function of mixed filters is filtration but additional accessory having disinfectant (activated carbon) or mineralizing elements (zeolite bead) are sometimes associated. The ceramic candles are coated with colloidal silver which also allow the elimination of physical and microbiological pollution in water. Indeed, the silver particles reduce the population of Escherichia Coli BL21 after one hour of contact while the activated charcoal completely inhibits bacterial growth (Karnib et al., 2013). Decanting is the least expensive option but presents the highest risk of water contamination, either because of the large amount of water handled, non-compliance with the duration of the treatment, inadequate container or even prolonged storage. Chlorination is done but dosages are not mastered and they are often counted not in milliliters per liter of water but in “caps” per bucket or container. The volume in the cap is thus uncertain and can lead to unsatisfactory disinfectant concentrations.

Table 1: Percentage of households using a stated domestic drinking water treatment option in slums neighborhoods of Yaounde

N°	Domestic drinking water treatment options	Households using the option	Household per category
1	Decanting	9.6	11.6
2	Decanting + Chlorination	1.0	
3	Decanting + Filtration	1.0	
4	Chorination	15.4	16.4
5	Chlorination + boiling	1.0	
6	Solar disinfection	1.9	1.9
7	Coton Layer Filtration	4.8	70.2
8	Membrane filtration	4.8	
9	Ceramic filtration	20.2	
10	Multistage filtration	40.4	

Figure 6: Households water purification options in slum neighborhoods of Yaounde ©Biembe Jules

The multicriteria analysis carried out by Djambou (2020) shows that, multistage filters with a mineralizing cartridge and activated carbon offer better treatment performance at acceptable cost and least chance of water recontamination. This corroborates the conclusions of Banty (2014) and Biembe (2019) regarding the effectiveness of filtration treatment. However, a significant fraction of households does not treat their water; only 29% of the households in this area treat their water before consumption. The reasons being a lack of interest (57%), insufficient financial resources (34%), lack of confidence in domestic drinking water treatment equipments (7%) and insufficient control over the use of existing treatment options (2%). Moreover, although treatment options exist, access and control of their use remain problematic. It is therefore, not enough to offer a reliable source of drinking water at home and a technically sound option for drinking water treatment. It is also important to know how to use it and understand its need to ensure the consumption of potable water at household level.

3.4. Contamination of drinking water at home and associated health risks

In the conventional system, water generally does not present any organoleptic problem. However, samples taken from certain neighborhoods reveal contamination at the pick-up points with an overall coliform level of more than 50 MPN/100 ml (Djambou, 2020). There is also contamination of water related to the use of the option, be it decanting or filtration (Table 2). Decanting leads to contamination with *Escherichia* and *Staphylococcus*, while filtration reduces microbiological contamination in some cases. Chlorination offers the best effectiveness with a 100% removal of pathogens which corroborates the results from WHO (2019).

Table 2: Microbiological indicators of household drinking water from pipe network in slum neighborhoods of Yaounde

Neighborhood	Treatment option	Microbiological parameters (Colony Forming Units/ml)		
		Pathogens	Before treatment	After treatment
MADAGASCAR	Settling 1	*Enterobacteria spp*	00	75
		Escherichia colii	00	40
		Stretptococus spp	00	60
		Salmonella spp	00	25
		Shigella spp	00	00
		Staphillococcus spp	00	150
		Vibrio Spp	00	02
		Coliformes totaux	00	40
	Settling 2	*Enterobacteria spp*	600	400
		Escherichia colii	175	200
		Stretptococus spp	40	50
		Salmonella spp	300	60
		Shigella spp	40	04
		Staphillococcus spp	00	00
		Vibrio Spp	00	00
		Coliformes totaux	180	160

Neighborhood	Treatment option	Microbiological parameters (Colony Forming Units/ml)		
		Pathogens	Before treatment	After treatment
MOKOLO	Multi-stage filter 1	*Enterobacteria spp*	400	06
		Escherichia colii	60	02
		Stretptococus spp	20	00
		Salmonella spp	06	02
		Shigella spp	00	00
		Staphillococcus spp	00	00
		Vibrio Spp	01	00
		Coliformes totaux	50	02
	Multi-stage filter 2	*Enterobacteria spp*	00	25
		Escherichia colii	00	14
		Stretptococus spp	00	05
		Salmonella spp	00	10
		Shigella spp	00	01
		Staphillococcus spp	00	80
		Vibrio Spp	00	00
		Coliformes totaux	00	14
ETETACK	Chlorination with commercial hypochlorite 1	*Enterobacteria spp*	300,	00
		Escherichia colii	150	00
		Stretptococus spp	00	00
		Salmonella spp	200	00
		Shigella spp	10	00
		Staphillococcus spp	100	00
		Vibrio Spp	180	00
		Coliformes totaux	90	00
	Chlorination with commercial hypochlorite 2	*Enterobacteria spp*	120	00
		Escherichia colii	75	00
		Stretptococus spp	00	00
		Salmonella spp	100	00
		Shigella spp	15	00
		Staphillococcus spp	00	00
		Vibrio Spp	00	00
		Coliformes totaux	90	00

The causes of contamination were: the lack of water treatment at home, misuse of treatment equipment, lack of maintenance of existing treatment option, as well as poor compliance with hygiene practices, before and during water handling and storage. These are in line with Dos Santos and Soura (2014) who found that water associated health hazards were relatively worrying in terms of microbial quality with pollution occurring at some sources but more in home reserves. Besides, difficulties in accessing water have a significant impact on the quality of water consumed by populations. Often, suspended materials and pathogens end up in water and pollute it, leading to diseases. As a consequence of water contamination, typhoid (54%), gastroenteritis (35%), and diarrhea (11%) cases are declared by households in the slum neighborhoods of Abiergué. According to figure 7, declared frequencies are higher than diagnosed for gastro enteritis and diarrhea, but underestimated for typhoid. It should be noted that not all cases are reported to hospitals; the reason being that self-medication is common in slum neighborhoods. These are quite alarming, even though lower than figures found in the Tongolo and Ebogo basins in 2007 (Kuitcha *et al.*, 2008). In fact, symptoms may vary and inexpert interpretation may lead to errors in the understanding of the risk. Though, it is advisable to analyze recorded waterborne disease statistics in that location.

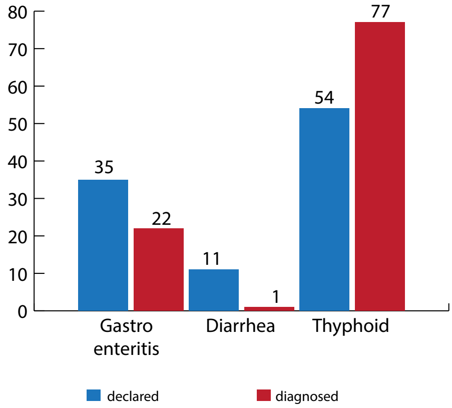

Figure 7: Frequencies of drinking water diseases declared and diagnosed in slum neighborhoods of Yaounde

From health statistics, the most contracted ailments in the area of Abiergué over the period from January 2018 to July 2019 are: typhoid fever (6 110 cases), acute gastroenteritis (1 747 cases) and bloody diarrhea (64 cases). Incidences of these diseases occur continuously throughout the year with peaks in early dry season (May -June and November – December). Recorded monthly cases fluctuate from 326 to 510 cases of Typhoid, 109 to 125 cases of Gastro Enteritis and 4 to 7 cases of bloody Diarrhea (Figure 8). These diseases represent not only a danger to the lives of these people, but also additional treatment costs ranging from 5 000 to 75 000 CFA [2]francs per individual for each episode. Due to inaffordability of treatment to poor households in these neighborhoods, people resort to self-medication, which is not always safe. These statistics underline the need to provide drinking water to safeguard public health. Then, better collaboration of health and water agencies to monitor waterborne diseases and improve water quality monitoring system is essential.

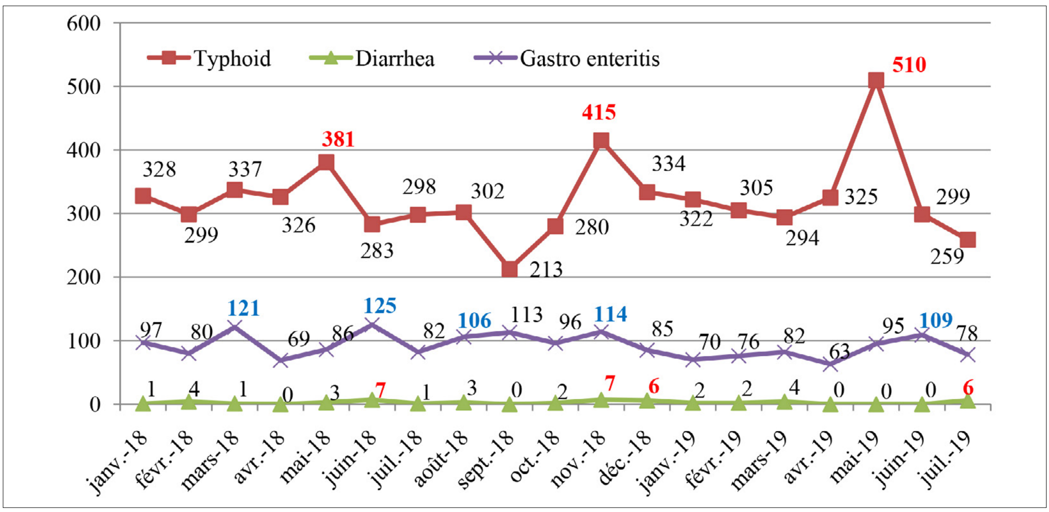

Figure 8: Statistics of reported waterborne disease cases in health centers of slum neighborhoods in Yaoundé between 2018 and 2019

2 Communauté Française d Afrique (1 US $ = 580 CFA franc)

4. Discussion

4.1. Business as usual practices is a programmed health scandal in slum neighborhoods

For many institutions and development agencies, water is a major issue and interventions for sufficient quantity and improved quality are priorities. That's why many investments are made in infrastructure and service development. These are focused on structured spaces and their targeting seems unfavorable to slum neighborhoods in African cities. Under-equipped, remote from improved sources, often indigent, households in poor neighborhoods consume "non-potable" water and are exposed to waterborne diseases with frightening statistics. This is more appealing when considering that less than 20% of households in slum neighborhoods have direct access to a tap. According to Nguendo (2010) this situation exposes those households to a high prevalence of diarrheal diseases with rates of 27 to 41% depending on whether the source is a well or a spring.

In fact, Nguendo et al. (2008) showed, through an epidemiological study on 3 034 children aged 6 to 59 months across 20 neighborhoods of Yaounde, that the average prevalence rate of diarrheal diseases is 14.4% with great variability among neighborhoods. However, on the whole, it is in poorly structured and under-equipped (slum) neighborhoods, that the prevalence rates are highest (17.5 to 23.8 cases per 100 inhabitants) with a higher risk ratio for unimproved sources (wells, springs, streams).

In the context of the Abiergué basin, 60% of water sources are unimproved and the basin undergoes climatic variability that would affect 53% of water sources in all categories (Kuitcha et al., 2008; Djimani, 2016; Djimani, 2018). When we consider that 71% of households in the poor neighborhoods of Abiergué do not treat their drinking water (Djambou, 2020), this raise concerns about drinking water safety in this urban basin. In order to improve access to safe water, policies should therefore focus on encouraging the use of filters, through awareness and subsidy, as well as education on how to use and maintain them properly. This implies a public-private-NGO joint strategy that can address the issue in a community-based approach with the health of the households as its main target.

4.2. The crucial need for evolution in water education and investment philosophy for slum areas

In view of the statistics presented above for slum neighborhoods poor access to improved water sources and low level of service for existing conventional services encourage households to rush towards increasingly unreliable water sources. In addition, uncovered collection containers, unsafe storage practices and water handling constitute other sources of drinking water contamination. Therefore, the presence of drinking water treatment equipment is no longer sufficient on its own to guarantee safe drinking of water. It is necessary to move towards education on safe collection and handling of water, along with hygiene education for all stakeholders. As the households of these areas are generally of very low revenue, such supplementary interventions would require wider external support. The universal access to drinking water sought through agendas 2030 and 2063 will therefore need more than investing in infrastructure and water services. Though, investing more in mindset and attitudes for safe and sustainable water use has to be included in the philosophy of investment in the water sector for Africa.

4.3. Recommended measures to secure potable drinking water in urban slum neighborhoods

WHO (2019) recommends treatment and proper conservation of drinking water at home as effective, accessible, and cost-effective measures to reduce the risks of degradation of drinking water microbiological quality. Besides, it is critical that water must first be of good quality from the source to maintain healthy water quality in households (PSEAU, 2017). And to do so, interventions are needed at four levels: regulatory, infrastructural, institutional and educational.

At the regulatory level, it is important to recognize the provision of drinking water as a public health action and put in place regulatory incentives to ensure that all users can afford quality water for consumption.

At the infrastructural level, it is desirable that alternative structures as well as drinking water distribution networks are improved to provide better quality in sufficient quantity. This may require investments in the extension of existing networks and creation of new networks to adapt to constant urban growth. It is also important to put in place specific water quality control mechanisms on the water system throughout the water chain. However, it is necessary to proceed upstream to the upgrade of the living standard of slums, improvement of service delivery, replacement of degraded pipes, and reduction of remoteness of water sources.

At the institutional level, water services whether conventional or not, should ensure that in terms of collection up to the time of consumption users are provided with advisory support services for household awareness raising and education about the risks associated with the consumption of poor water quality as well as the non-application of good practices throughout the water chain. Indeed, there is common confusion between "*drinking water supply*" and "*drinking water consumption*" because even if the water provided by these networks is safe at the delivery it may not be of satisfactory quality at the time it is consumed by dwellers (PSEAU, 2017). In addition, the "*water peril*" does not change much if the environment remains polluted, more so if individual and collective behaviors are not altered by adequate health education. Such a support service becomes imperative and should also take care of advising on the choice of a treatment equipment, taking into account the household's needs, the composition of the filtering material as well as the cost of the equipment or material.

Djambou (2020) recommends that support for the maintenance of these water treatment equipments should be done twice a year in order to clean and replace worn components. The establishment of such a service would require the mobilization of expertise at a cost to each household that could vary from 34 960 to 41 120 CFA francs per year. This is certainly affordable costs for some households but it is still quite expensive for people living in slum neighborhoods; their average monthly income is less than 115 000 CFA francs per month with families of six to eight individuals. That is why Governments or Non Governmental Organizations subsidies would make the service more accessible to a larger number of households in slums. For reference it is worth mentioning that, the annual cost of home filtration is estimated at 1 685 CFA francs per individual, while chlorination is worth 367 and solar disinfection 350 (WHO, 2013).

At the educational level, it was noted in the Abiergué basin that some households lack information and interest in hygiene in general and specifically water hygiene. Nguendo et al. (2008) indicate that the factors that directly correlate with diarrheal diseases in Yaounde are individual characteristics (standard of living and level of education), sanitation (individual or collective), nature of the site (layout and geographical position) and source of water supply (unimproved). Three out of four explanatory factors are then associated with human behavior and perceptions of environmental risks. Appropriate interventions shall therefore be centered first on changing or improving individual characteristics. COVID 19 pandemic has reminded the whole world of the importance of hygiene in human health and mobilized stakeholders to raise awareness among the populations. However, it is noted by Mausezahl et al. (2009) that sensitization and campaigns to promote hygiene and hand washing in rural areas would have low impact. The sustainability of the changes introduced through this approach would remain problematic according to Sobsey et al. (2008) unless a shift from raising awareness to hygiene education in order to promote good practices by all age groups and targets. Indeed, O'Reilly et al. (2008) shows that behavioral change through education and training of endogenous change agents would produce more lasting effects. This represents a major public health challenge for the achievement of several sustainable development goals on which the actors of communication, environment and education have a key role to play.

5. Conclusion

It emerges from this article that efforts to provide drinking water to households in slum neighborhoods in Yaounde would yield poor dividends without reduction of contamination of water during collection, transport, storage and handling. The use of filters at home, compliance with basic hygiene practices, community education in addition to upgrade of infrastructures and better access to subsidy for acquisition of treatment devices, material and services would make access to safe drinking water possible. This is needed in order to achieve the purpose of all investments made for better access to potable drinking water or improvement of household's health. In fact, water contamination presents serious public health risks and therefore requires additional support alongside improved infrastructures to maintain safe drinking water. If this support is neglected all efforts would be limited to supplying water without or with little safety, leading to water insecurity and higher health risks.

The transdisciplinary and multi-stakeholder response required for this objective would see a very strong contribution from young people beyond research questions. Also, effective financing mechanisms for the establishment of regulatory, infrastructural, institutional, educational and financial support measures for vulnerable groups are essential to achieve the development goals set for universal access to safe drinking water and health for all by 2030, as well as the targets of Agenda 2063 for Africa we want.

The conclusions drawn on the Abiergué watershed may be considered for other slum neighborhoods in Yaounde, but also in developing countries in Asia, Europe and America. The issue of access to safe drinking water in the context of poor neighborhoods in developing countries is subject to many questions on accessibility, availability, quantity, quality, price, management, technologies and even renewal. It is therefore important that this problem is approached by multidisciplinary teams or multi-stakeholder interventions where young people are strongly involved in the quest for adequate and sustainable solutions. One key lever for the implementation of proposed actions is a volunteer program which would make it possible to improve community health, promote local skills and create jobs in such fields like social work, health advice, technical assistance, installation and maintenance of various domestic water purification technologies.

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References

Biembe, J.Y. (2016). Evaluation des performances de quelques dispositifs de traitement d'eau à domicile commercialisés au Cameroun (Performance evaluation of domestic drinking water purification equipments sold in Cameroon). Thesis. University of Dschang, Cameroon. p 96.

Biembe, J.Y. (2019). Risques sanitaires liés à la potabilisation domestique de l'eau dans les quartiers à habitat spontané de Yaoundé : Cas du bassin versant de l'Abiergué (Health risks associated with domestic drinking water purification equipments in slums in Yaounde : Case study of Abiergué Watershed). Thesis. University of Liege, Belgium. p 82.

Banty, E.B. (2014). Traitement de l'eau à domicile : conception et évaluation de l'efficacité des filtres en céramique (domestic drinking water purification : design and evaluation of efficient ceramic filters). Thesis. International Institute of Water and Environmental Engineering. University of Ouagadougou, Burkina Faso. p 64.

Djambou, M.D. (2020). Etude technique de la promotion de l'utilisation des dispositifs de traitement de l'eau à domicile dans les quartiers défavorisés de l'Abiergue à Yaoundé, Cameroun (Technical study of the promotion of the use of domestic drinking water purification devices in slums at Abiergue in Yaounde, Cameroon). Thesis. International Institute of Water and Environmental Engineering. University of Ouagadougou, Burkina Faso. p 87.

Djimani, S. (2016). Contribution des sources alternatives à la satisfaction des besoins en eau domestique à Yaoundé : Cas du bassin urbain de l'Abiergué (Contribution of alternative sources to domestic drinking water needs in Yaounde). Thesis. University of Dschang, Cameroon. p 144.

Djimani, S. (2018). Vulnérabilité des sources alternatives d'approvisionnement en eau domestique à la variabilité climatique dans un bassin versant urbanisé : Cas du bassin versant de l'Abiergué, Yaoundé-Cameroun (Vulnerability of alternative domestic drinking water sources to climate variability in an urbanized watershed : case study of Abiergué Watershed, Yaounde-Cameroon). Thesis. University of Dschang, Cameroon. p 121.

Dos Santos, S. and Soura, A.B. (2014). Climat et accès aux ressources en eau en zones informelles de Ouagadougou (Climate and access to water resources in slums in Ouagadougou) In : Soura, A.B., Dos Santos, S., Ouédraogo, F.D.C., Presses Universitaires, Université de Ouagadougou (ed.) Variabilité climatique et conditions d'accès à l'eau : un défi majeur pour les villes sahéliennes. Ouagadougou, Burkina Faso.

Eloundou, F.B. (2010). Changement climatiques, accès à l'eau potable et santé publique : entre réalités et perspectives en Afrique (Climate change, access to potable water and public health : realities and perspectives in Africa).

Fekoua, D. (2010). Anthropisation et risques environnementaux sur les collines de Yaoundé (Anthropisation and environmental risks on hills of Yaounde). Thesis. Regional Centre for special training in agriculture, forest and wood. University of Dschang, Cameroon. p 85.

Guepi, N. (2019). Cameroun, environ 9 millions de personnes n'ont pas accès à l'eau potable (Cameroon, 9 millions individuals not having access to potable water). Journal du Cameroun.com. https://www.journalducameroun.com/cameroun-environ-9-millions-depersonnes-nont-pas-acces-a-leau-potable/

Karnib, M., Holail, H., Olama, Z., Kabbani, A. and Hines, M. (2013). The antibacterial activity of activated carbon, silver, silver impregnated activated carbon and silica sand nanoparticles against pathogenic E. coli B21. International Journal of Current Microbiology and applied sciences, 2(4), 20 -30. ISSN: 2319-7706

Kouam, K.G. (2013). Vers une gestion rationnelle de l'eau dans une situation complexe d'urbanisation anarchique dans un pays en développement : Cas du bassin versant de l'Abiergué (Yaoundé-Cameroun) (Towards a rational management of water in complex situation of anarchic urbanization in a developing country : case study of Abiergué watershed, Yaounde-Cameroon). Doctoral thesis. University of Liege, Belgium. p.272.

Kuikeu, N.J. (2015). Essai d'une démarche de prévention des inondations et de l'insalubrité dans un contexte d'urbanisation anarchique (Testing of an approach to prevent flooding and insalubrity in a context of anarchic urbanization). Thesis. University of Dschang, Cameroon. p 140.

Kuitcha, D., Kamgang, B.V., Sigha, N.L., Lienou, G. and Ekodeck, G.E. (2008). Water supply sanitation and health risks in Yaounde, Cameroon. African Journal of Environmental Science and Technology, 2(11), 379-386. ISSN 1996-0786.

Lako, S.M. et Ndongo, B. (2016). Défis de la pérennité des services d'eau dans les quartiers précaires : le cas des quartiers péri-urbains de la ville de Yaoundé (Challenges of the sustainability of water services in slum neighborhoods: case study of peri-urban neighborhoods in the city of Yaoundé). European University Editions. p 113.

Mausezahl, D., Christen, A., Gonzalo, G.D., Tellez, F.A., Iriarte, M., Zapata, M.E., Cevallos, M., Hattendorf, J., Cattaneo, M.D., Arnold, B., Smith, T.A., John, M. and Colford, Jr. (2009). Solar Drinking Water Disinfection (SODIS) to Reduce Childhood Diarrhea in Rural Bolivia: A Cluster-Randomized, Controlled Trial. PLoS Med.(ed.)., 6(8) : 1 -13. Doi:10.1371/journal.pmed.1000125.

Ndongo, B. (2016). Gestion intégrée du risque d'inondations urbaines en Afrique subsaharienne : cas de Yaoundé au Cameroun (Integrated urban flood risk management in sub-Saharan Africa: case study of Yaounde in Cameroon). Doctoral Thesis. University of Dschang, Cameroon. p 203.

Ngu, L.J. (2014). Impact of waste management on floods in an urbanized watershed. Master Thesis. University of Dschang, Cameroon. p 127.

Nguendo, H.B.Y. (2010). Suffering for Water, Suffering from Water: Access to Drinking-water and Associated Health Risks in Cameroon. J Health Popul Nutr (5):424-435. ISSN 1606-0997

Nguendo, H.B.Y., Salem, G. and Bruneau, J.C. (2008). Épidémiologie géographique des maladies diarrhéiques à Yaoundé (Cameroun) (Geographical epidemiology of diarrheal diseases in Yaoundé, Cameroon) : M@ppemonde 89 (1). http ://mappemonde.mgm.fr/num17/articles/art08102.html

Ngwe, E., and Banza-Nsungu. (2007). Les déterminants socio-environnementaux de la morbidité diarrhéique des enfants de moins de 5 ans en milieu urbain camerounais : les villes d'Ebolowa et Maroua (Socio-environmental determinants of diarrheal morbidity of children under 5 in cameroonian cities: case study of Ebolowa and Maroua towns). International Research Program on Interactions Between Population, Development and the Environment (PRIPODE) International Committee for Cooperation in National Demographic Research (CICRED).

Onana, I.B. (2015). Etude de faisabilité de l'aménagement d'une source d'eau potable dans le bassin versant de l'Abiergué (Feasibility study for the development of a drinking water spring in the Abiergué watershed). Thesis. University of Dschang, Cameroon. p 94.

OMS. (2019). Results of Round II of the WHO International Scheme to Evaluate Household Water Treatment Technologies. p 80.

OMS. (2000). Directives de qualité pour l'eau de boisson. Deuxième édition, Volume 2 : Critères d'hygiène et documentation à l'appui (Drinking water quality guidelines. Second Edition, Volume 2: Hygiene Criteria and Supporting Documentation). International Program on Chemical Safety. World Health Organization, Geneva. p 353.

OMS/UNICEF. (2017). Progrès en matière d'eau, d'assainissement et d'hygiène : Mise à jour 2017 et évaluation des ODD (Progress on Water, Sanitation and Hygiene: 2017 Update and SDG Assessment). p 116.

ONU. (2015). Rapport mondial des Nations Unies sur la mise en valeur des ressources en eau : L'eau dans un monde durable (United Nations World Water Development Report: Water in a Sustainable World). p 12.

ONU. (2019). Rapport mondial des Nations Unies sur la mise en valeur des ressources en eau : Ne laisser personne pour compte (United Nations World Water Development Report: Leave no one behind). p 214.

ONU HABITAT. (2018). Accès à un logement adéquat et amélioration des bidonvilles (Access to adequate housing and improvement of slums). p 31.

O'Reilly, C.E., Freeman, M.C., Ravani, M., Migele, J., Mwaki, A., Ayalo, M., Ombeki, S. and Hoekstra, R.M. (2008). The Impact of a School-Based Safe Water and Hygiene Program on Knowledge and Practices of Students and Their Parents — Nyanza Province, Western Kenya. Epidemiology and Infection, 136:80–91. Doi:10.1017/S0950268807008060.

PSEAU. (2017). Conservation et traitement de l'eau à domicile. Collection Outils et méthodes. (Domestic water conservation and purification. Tools and Methods). Water Solidarity Program. p 72.

Sobsey, M.D., Stauber, C.E, Casanova, L., Brown, J.M. and Elliott, M. (2008). Point of Use Household Drinking Water Filtration: A Practical, Effective Solution for Providing Sustained Access to Safe Drinking Water in the Developing World. Environmental Science and Technology, 42(12):4261–4267. Doi: 10.1021/es702746n

WHO. (2013). Household water and treatment and safe storage. Manual for participant. p 137.

An Analysis of the Urban Ecosystem Restoration Programs in Nairobi River Basin: An Ecohydrological Perspective

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Abstract

Nairobi River Basin typifies other river basins in Sub-Saharan Africa that are facing natural and anthropogenic challenges. Despite various rehabilitation,conservation and restoration efforts implemented during the past two decades, the water resources remain unfit for drinking owing to the silo-approach inherent in the programs adopted by the Kenyan Government, NGOs and CBOs. Since 2011, UNESCO-IHP endorsed the ecohydrology approach in watersheds to solve social and environmental issues with resounding success in many demonstration sites worldwide. This paper presents an analysis to ascertain the application of ecohydrological principles for the sustainable development of the Nairobi River Basin by examining initiatives adopted to restore/rehabilitate the basin within the past two decades. Effective river basin management is a function of a comprehensive understanding of a river's hydrology, environment, and ecological functions backed by a robust policy, political will, and citizen engagement. These combined efforts will go a long way in ensuring water security and ensuring SDG 6, SDG 11 and SDG14 become less theoretical and a reality.

Keywords: Ecohydrology, Integrated water resource management, Kenya, Nairobi River Basin, Water security

1. Introduction

River basins traverse socio-political or administrative boundaries and are critical planning targets in environmental protection and development planning (Saha and Setegn, 2015). River basins form hydrological units that sustain both aquatic and terrestrial ecosystems as habitats to diverse flora and fauna while delivering a range of ecosystem goods and services. The deterioration in freshwater, namely rivers, lakes, reservoirs, and wetlands and biodiversity, evident in both developed and developing countries, is a testament to the inadequacy of the existing traditional hydro-technical water resources management approaches in achieving sustainable use and management of the global water resources (Wagner et al., 2004).

Population forecasts projects an increase in worlds' urban population from 55% to 68% by 2050 (UN DESA, 2018). The increasing urban population relies on urban ecosystems, both terrestrial and aquatic, that provide essential ecosystem services: clean air, water, carbon storage and sequestration, wildlife habitat, recreational opportunities, and economic stimuli (Mincey et al., 2013). In practice, river basin planning, management and implementation remains characterised by a silo-based approach that springs from institutional inertia and rigid policies that encourage 'closed-loop decision-making (Zhao et al., 2015). Many programs developed for river or lake basins in developing countries remain reactive rather than proactive, as seen by the increase in "restoration and "clean up" program adoption for Lake Victoria, Lake Naivasha and Athi River in Kenya (Gikundi, 2014; Nyika, 2017).

Many urban river basins are facing intense pressure from varied factors such as rapid urbanisation and intensive agricultural practices.While climate change is affecting hydrologic cycles and posing water quantity and quality problems within river basins. These combined factors are contributing to water quality degradation and biodiversity loss in many ecosystems, as exemplified in Sub- Saharan Africa's Nile River and Pangani River (Clancy, 2008; Smit and Parnell, 2012). Although restoration and rehabilitation initiatives in urban ecosystems help improve the quality and quantity of water in urban areas, there is a lack of understanding of the basin's ecosystems processes and hydrologic regime(Wagner and Zalewski, 2009). In response, UNESCO-IHP has since 2011 established ecohydrology global demonstration sites in watersheds at all scales to address social and environmental issues with resounding success (UNESCO, 2015). Ecohydrology programs focus on integrating biological and hydrological processes at a catchment scale to create a scientific basis for a socially acceptable, cost-effective and systemic approach in sustainable management of freshwater resources. The fundamental rationale for ecohydrology is that water is the primary driver of bio-geosphere evolution (IHP, 2016).

There is a growing consensus among scholars that cities should be considered ecological systems in which pertinent ecological processes (such as nutrient dynamics and energy flow) and hydrological processes need to be understood and regulated (Zalewski and Wagner 2005; Wagner and Zalewski, 2009; Gikundi, 2014). Kenya's regarded as a water-stressed country with an estimated 690 cubic meters per capita per annum of water supply against a global benchmark of 1000 cubic meters (Birongo and Le 2005). Furthermore, the population's projected to reach 65.9 million in 2030 .The Nairobi River basin was officially reported as the most polluted in Kenya, while Nairobi Dam is no longer viable as a source of drinking water supply or recreation due to high eutrophication (Kabukuru, 2019;Njuguna et al., 2017). In response, there has been various attempts to redress the river basin with minimal success due to drawbacks inherent in the current river basin planning and management.

A better understanding of any basin's ecosystem processes and the hydrologic regime has the potential to influence the majority of livelihoods positively and sustain the integrity of its natural ecosystems (Polprasert et al., 2015) in line with the Sustainable Development Goals (SDG 6 clean water and sanitation, SDG 11 and SDG 14). This paper assesses the application of ecohydrological principles within the various initiatives adopted and implemented in a bid to restore or rehabilitate the Nairobi River basin over the past two decades. This paper attempts to flag the factors hurdling water security and recommends a holistic and integrated framework of ecohydrological approaches that may help ensure sustainability and inter-generational equity within the Nairobi River basin's rehabilitation and restoration initiatives.

2. Materials and method

2.1. Description of the study area

The Nairobi River basin's has an estimated area of 830km^2 and hosts a number of natural resources. The basin is complex and traverses Kiambu and Nairobi counties' socio-political boundaries. A number of urban, suburban, and rural areas lie within the basin, most notably is the Nairobi City as illustrated in Figure 1. An estimated 4 million people reside in Nairobi City (KNBS, 2019). Nairobi City County also hosts 80% of Kenya's manufacturing companies and holds 50% of Kenya's economy (Nyika, 2017).

The Nairobi River basin (NRB) forms part of the Athi River catchment's headwater, which flows through vast semi-arid lands before emptying into the Indian Ocean. The Athi River drainage basin is the second-largest drainage basin in Kenya after the Tana River (Kithiia, 2007). The

Nairobi River Basin has an altitude ranging from 1,500 to1,800 m. It consists of three main rivers, namely, Nairobi, Mathare and Ngong-Motoine, with catchments found within the Kikuyu and Limuru Hills (Nyika, 2017) as depicted in Figure 2.

The Nairobi River's tributaries include Kamiti River (Gathara-ini), Rui Ruaka, Karura Ruiru, and Kirichwa. The Ngong-Motoine River originates from the Ngong forest, whilst the Kikuyu forest is the Nairobi and Mathare rivers source. These rivers join east of Nairobi County and eventually meet River Athi, which flows to the Indian Ocean. The headwaters of the rivers recharge through rainfall. The Nairobi Aquifer System (NAS) covers 5,880 km^2 and supports 60% of water needs in the basin, which is estimated at 58 million cubic meter per year, via groundwater extraction (Oiro et al., 2020).

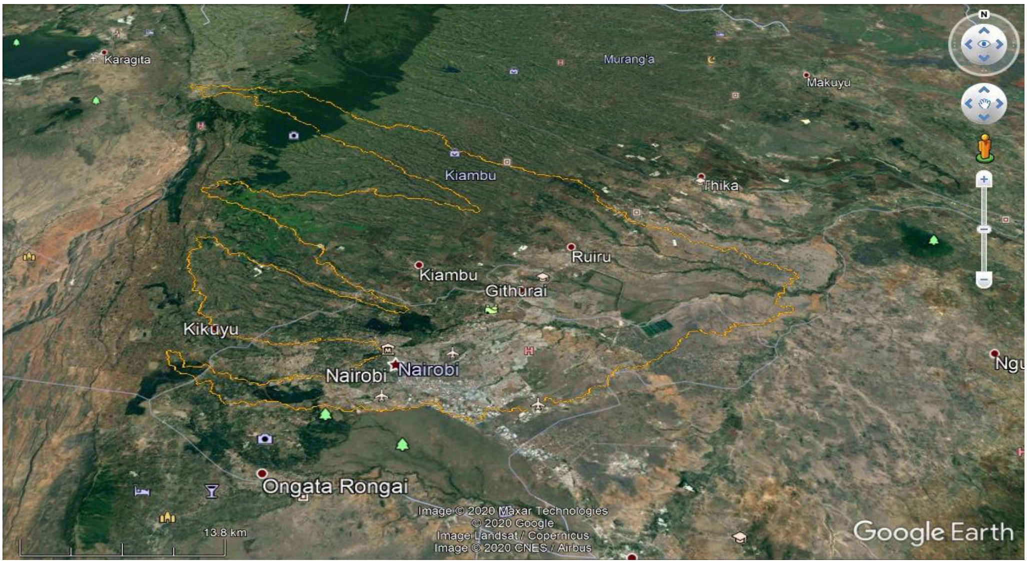

Figure 1. Satellite imagery showing the towns in Nairobi River Basin

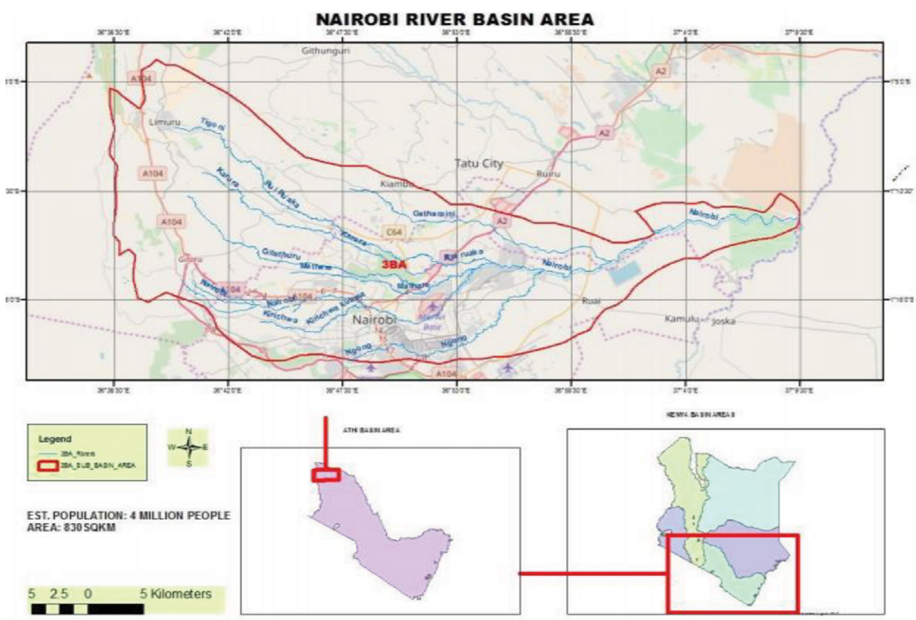

Figure 2. Map showing Nairobi River Basin (adapted from Sobowale, 2019)

The Nairobi River basin is endowed with riverine forests in its headwaters and occupies 37 km^2, which is about 5.7% of the total basin area (Nyika, 2017). The basin has over 1,500 plant species, trees and scrubs, and over twenty mammalian species and birds with aesthetic and economic value. An estimated 60% of the basin's total population resides in informal settlements situated along riverine areas. An approximate area of 280 km^2, which represents 40% of the Nairobi River basin, is under agricultural production, primarily subsistence farming. Ondiri swamp is Kenya's only sizeable quaking bog that forms the basin's headwaters in Kikuyu town. Green spaces and protected areas in the basin such as Nairobi National Park, Karura Forest, Ngong Forest, Ololua Forest, The Nairobi Arboretum, and Nairobi City Park provide cultural services in the form of shady recreation areas with characteristic vegetation for tourists as well as filtering air, and carbon sequestration as illustrated in Table 1 below.

The Dandora, Kayole west plains and Embakasi marshes form transitional habitats in the river's downstream section. However, Nairobi Dam, with an approximate area of 100 acres, is presently an open dumpsite and a sewer for approximately 500,000 inhabitants constituting the Kibera slums and High-rise estates. The catchment's soils are a combination of vertisols and nitisols. In the upper catchment areas, the prevailing soils are friable clay, dark brown, well-drained and deep, while the lower parts have cracked poorly drained clays, dark grey or brown (Sobawale, 2019).

Table 1. Socio-economic and ecological importance of ecosystems in Nairobi River Basin

Ecosystems In Nairobi River Basin and their functions	
Terrestrial	**Aquatic (Freshwater)**
1. Forests Name: Karura Forest, Ngong Forest, Ololua Forest Functions: i. They form recharge areas for the rivers and streams in the basin. ii. Filtration of air. iii. Carbon sequestration iv Wildlife habitat and tourists destination. 2. Grasslands Name: Nairobi National Park Functions: i. It is a habitat for wildlife and a tourist destination. ii. They are biodiversity reserves. iii. Potential carbon sinks.	1. Rivers Name: Ngong-Motoine River, Nairobi River, Mathare River, Ruiru River, Kamiti River, Gathara-ini River, Rui-Ruaka River, Karurua River, Gitathuru River, Kirichwa River Functions: The upper-reaches provide water for irrigation, domestic use, and cottage industries demand. 2. Ponds and Dams Name: Jamhuri Dam, Motoine Dam and Nairobi Dam, Ruai Ponds Functions: i. Storage of water for use in irrigation. ii. Water for recreation purpose. iii. Ruai ponds are used for wastewater treatment. 3. Wetlands, Swamps and Marshes Name: Riu Swamp, Ondiri Swamp Functions: i. Ondiri Swamp is the headwater of the Nairobi River. ii. The marshes and wetlands provide transitional habitats. iii. Filters sediments from flowing water. iv. Habitat for aquatic organisms.

2.2 Drivers and threats to the ecosystems in Nairobi River Basin

For the past three decades, the Nairobi River basin has been under severe pressure from different driving forces of both natural and anthropogenic origin. Rapid population increase coupled with ill-planned urban growth, inadequate urban and industrial waste management, resource-intensive agriculture, deforestation and encroachment has caused severe stress on the Nairobi River basin ecosystems through flow alteration, overexploitation, and pollution (Mwaura et al., 2020; McGill, 2018; Kienja, 2017; Silva, 2016; Njoroge et al., 2014; Orsini et al., 2013; Henry et al., 2006).

Groundwater extraction is rapidly increasing, with an estimated daily average of five new borehole drilling permit applications made at the Water Resources Authority sub-region offices (Oiro et al., 2020). Meanwhile, the alternating flow volume of the rivers in the basin is attributed to the disappearance of wetlands, marshes, riparian and deforestation coupled with the overexploitation and conversion of recharge areas to real estates (Sobowale, 2019). Research conducted by Weru (2012) revealed that an increase in the basin's impervious surfaces also alters the basin's hydrological characteristics by reducing the infiltration rate of rain and increasing surface runoff volume and speed. Increased runoff increases stream discharge and promotes fluvial processes of erosion and sediment transportation within the basin (Weru, 2012).

The rivers in the basin are narrowing due to increased sedimention. Development activities such as roads and settlements within the basin also result in erosion and transport of large quantities of sediments downstream. Kwamboka (2014) study revealed that total suspended solids discharged through the Ngong/Motoine River were approximately 260.058 tons/year. The high total suspended solids percentage was attributed to river erosion and increased built-up areas and roads that rose from 22.78% in 1976 to 50.98% in 2013.

The effects unchecked industrialization and unplanned settlement within Nairobi River basin are evident. The Nairobi River, which was characterised by crystal-clear waters with fish three decades ago, is today a sludgy, heavily polluted canal with murky, brackish green effluence (Kabukuru, 2019). Industrial buildings and informal economic activities such as markets, and "Jua Kali" commercial enterprises have been blamed of discharging their wastes into the rivers. Most of the Nairobi riverbank is also characterised by highly congested informal and middle-class settlements, spilling uncollected garbage; human waste; and over-flowing sewers. The crane bird, which previously flocked all over the metropolis, has not been sighted in Nairobi for decades. In its place is the Marabou stork which scavenges on piles of uncollected municipal waste.

As the Nairobi River flows during its course, it gathers municipal waste, raw sewage, treated and un-treated/partially treated industrial effluent, and stormwater. At the end of the river flow route, Ruai Wastewater Treatment Plant's effluent is added into the river as it flows out into the larger Athi River basin. The 100acre Nairobi Dam is now generally regarded as an open sewer covered with algae or water hyacinth. It has lost its functionality as a reservation for water supply and recreational purposes. Also, the pollution has rendered the water throughout the Athi River basin non-potable (Mbithi, 2013), thereby posing a significant health risk to all users.

However, despite the high level of pollution, farmers along the Nairobi River and its tributaries continue to use polluted water and raw sewage for irrigation. Almost half of the vegetables consumed in the City of Nairobi are grown on the banks of polluted rivers (Tibaijuka, 2007), which also poses hazards to aquatic life. Environmental pollution of the Nairobi River Basin has resulted in more water-borne diseases, loss of livelihoods, reduced number of recreational parks and reduced potential of the rivers as a source of safe drinking water supply for the city. Also, as the Athi River catchment headwaters, the Nairobi River basin's state influences the health and sustainability of the entire Athi River catchment and sea life where the Athi enters the Indian Ocean. Along most of its length, the Nairobi River has lost its assimilation capacity and, therefore, its ecological integrity(Tibaijuka, 2007). The ecosystems ability to provide health-enhancing services such as clean air, water and soil has decreased.

2.3. Ecohydrology concept

Ecohydrology is an integrative science that focuses on the interaction between hydrology and biota (UNESCO-IHP 2016). Ecohydrology is based on quantifying the hydrological and biological processes from the molecular to catchment scale to achieving water quality improvement, biodiversity enhancement, and sustainable development. Ecohydrology helps the resilience of river basins while protecting and achieving sustainability in both ecosystems and human populations (Msuya and Lalika, 2018; Zalewski, 2015). Ecohydrological processes regulate environmental conditions within aquatic systems, maintain energy levels, water quantity and water quality within ranges suitable to native flora and fauna (Wasson et al., 2002).

Ecohydrology is characterised as a sub-discipline of hydrology based on how ecological processes function and occur within the hydrologic cycle. It strives to utilise such techniques for enhancing environmental sustainability. The concept focuses on the regulation of water biota interplay from the top of the river basin up to the bottom of the reservoir and coastal zones, toward slowing down the transfer of water from the sky to the sea, enhancing groundwater resources and maintaining critical habitats for water, energy and nutrients circulation which in turn maintain biodiversity. Also, it is helpful for the reduction of the input and regulation and allocation of excess nutrients and pollutants toward reversing ecosystems degradation and improvement of human well-being.

Three assumptions underpin ecohydrology. First, sustainable water resources management is achievable by reversing degradation and regulating the processes of water, nutrient circulation and energy flow at a catchment scale. Second, ecosystem carrying capacity can be increased in response to human influence by making ecosytems resilient and robust through biodiversity and ecosystem services enhancement. Finally, the interplay of water biota may be used as a water management tool. Thus, ecohydrology is a comprehensive problem solving and cost-efficient tool for integrated water resource management. It informs policies and programmes that need to be implemented on a river basin, thus providing nature-based tools for integrated river basins management (Moss et al., 2014).

The ecohydrology approach proposes a "dual regulation" system that firstly focuses on the hydrological factors that determine the dynamics of natural and human-driven ecosystems. Then secondly focuses on the ecological factors that influence water dynamics and water quality (Zalewski, 2015). This approach quantifies and explains the relationships between hydrological processes and biotic dynamics at a catchment scale and focuses on the ability to restore and maintain evolutionary established water and nutrient circulation and energy flows at the basin scale. The dual management of hydrology and biota is through monitoring multi-dimensional parameters such as water, biodiversity, social ecosystem services, and climate change resilience, as illustrated in Figure 3.

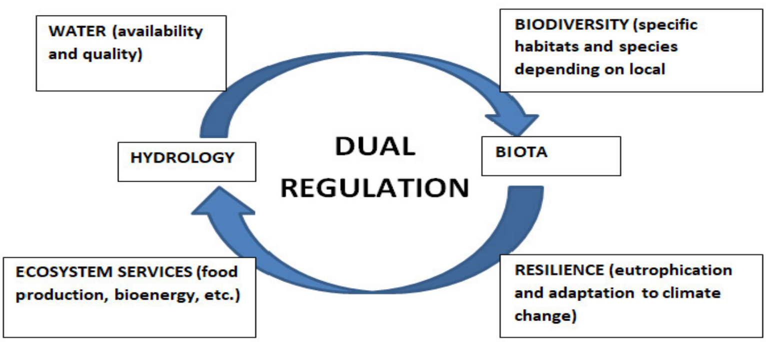

Figure 3. The "dual regulation" nature of the ecohydrology approach in problem-solving (adapted from IHP, 2016)

Ecohydrology integrates ecology and hydrology with the special consideration of geomorphology. The concept is policy-oriented because it encompasses sustainable development components and focuses on reversing biosphere degradation, aligning with Sustainable Development Goals (SDGs). Thus, allows the integration of ecosystem and biodiversity values into local and national planning. The ecohydrology concept also reflects society's priorities such as water quality, food production, flood protection, drought compensation, cultural aesthetic values and tourism in line with SDG 3.3, SDG 14, SDG 11.5, and SDG 13.2.

Ecohydrology rests on three implementation principles, namely the hydrological, ecological and ecological-engineering principle. The hydrological principle focuses on the quantification of the hydrological processes at the catchment scale, vulnerability assessment and mapping of impacts. The quantification of a basin's hydrological cycle's aimed at integrating hydrological and biological processes. It provides a holistic picture of where to reduce the various effects and to what extent. The second principle**,** the ecological principle, identifies potential areas for enhancing sustainability potential or carrying capacity. It entails mapping the biosphere and novel ecosystems *anthropogenically* changed and the use of restoration and rehabilitation or appropriate tools that return them to the original trajectory to increase the entire catchment's sustainability potential.

Lastly, the ecological-engineering principle focuses on the management of biota to control hydrological processes and vice versa. It emphasises the building up of harmony through hybrid systems and integrates them with hydro-technical solutions or eco-hydrological nature-based solutions and translates this to their whole system, thus building synergy between different solutions.

2.4. Ecohydrology principles in practice

Since 2011, UNESCO-IHP endorsed the ecohydrology approach in watersheds to solve social and environmental issues with resounding success in many demonstration sites worldwide. The best practices of ecohydrology are focused on identifying, quantifying, and improvement of the critical inter-relationships among water, biota, and social systems for sustainable water management, in line with ecohydrological principles. IHEP (2016) asserts that the best practices operate at four levels. The first level entails information monitoring by empirical data collection and defining of hydrology-biota-society interactions/feedbacks. The second levels involves defining of patterns that characterize and explain processes in the ecosystems and the basin. The third level is characterized by policy formulation, principles for action and problem-solving approaches based on system solutions, stakeholders involvement, civil education, and implementation. The fourth level relies on the cooperation and collaboration in solving problems through the willingness of different stakeholders to apply the ecohydrology approach in the catchment.

In Poland, inter-disciplinary research has enabled ecohydrological solutions for water resources management in urban water management (Wagner and Breil, 2013) and city planning for human health and sustainable development (Wagner and Zalewski, 2009). There has been the adoption of urban river rehabilitation interventions and the closing of nutrient cycles by reusing sewage sludge to produce green energy. Creating a multi-stakeholder platform has empowered the implementation and upscaling of innovative solutions to city-scale in Sokolowka River Valley, Lodz City, Poland, with resounding success.

The demonstration site in Argentine Lacar Lake focused on reducing soil erosion, mitigation of flooding, and the improvement of ecosystem services in the metropolitan area. This approach helped to address the induced impacts of land transformation on water quality and environmental services in San Martin de Los Andes. The regulation of surface hydrology at the watershed scale, sustainable land use, vegetation cover and phyto-technologies were all proven to improve aquatic ecological processes and ecosystems services (Sarandón et al., 2009).

In the Gumera River basin (one of the Lake Tana sub-basins) located in the north-western area of the Ethiopian highlands, 72% of its area is erodible, and 22 tons of soils are eroded per year (Negussie et al. 2011). Soil loss contributes to the loss of nutrients and water retention and reduces agricultural productivity in the upper catchment. Conversely, flooding and sedimentation are significant problems in downstream catchment. Dejen (2006) reported that the sediment-laden runoff entering the lake reduces the penetration of sunlight into the lake and reduces green algal (microphyte) productivity, resulting in the decline of the fish stocks which feed on these algae.

The government opted for a reforestation and irrigation development project in the Gumera basin, intending to increase crop yields, decrease flooding, and improve people's living standards. However, these interventions were insufficient to achieve future sustainability as the quantity, timing, and quality of the Gumera river flow were determined by the land cover and land use in the whole landscape. Therefore, the following ecohydrological solutions were adopted: soil erosion control using biodegradable geo-fibres; application of shelterbelts for increasing agricultural land productivity through heat and water budget controls; and construction of a sequential bio-filtration system for reducing turbidity, eutrophication and dioxin induced toxicity in Lake Tana.

Sections of Lake Naivasha in Kenya were highly polluted. The water level had also reduced due to unprecedented human-induced factors such as deforestation of the catchment and overgrazing, and over-abstraction of water (Becht, Harper 2002). The lake area shrunk from about 120 km^2 in 2005 to 100 km^2 by 2009. A succession of alien species wreaked havoc on the ecosystem rendering Lake Naivasha's waters not fit for drinking supply. In-depth knowledge of the hydrological conditions and recognition of the Lake Naivasha tropical system's resilience and resistance enabled the adoption of ecohydrological solutions.

Githaiga (2008) indicates that Lake Naivasha's ecohydrological solution depended on creating a barrier across the Gilgil River to re-wet the former swamp area on either side. The answer was more feasible for socio-economic reasons and ecologically sound. The introduction of an attached fee termed Payment for Ecosystem Services (PES) for the European market of flowers from Lake Naivasha in Kenya provided support for wetland ecosystem restoration, community capacity building on sustainable water use, and intervention development methods to achieve 'water-friendly farming in the river basin.

2.5. Linkage of Ecohydrology and Integrated Water Resources Management (IWRM)

Ecohydrology is regarded as a tool for sustainability enhancement as it strives for enhancing environmental sustainability through the reversal of water and ecosystem degradation. Meanwhile, IWRM is considered a tool that can maximise economic and social welfare equitably without compromising vital ecosystems' sustainability through the coordinated development and management of water, land, and related resources. Ecohydrology practices increase a river basin's resilience by managing multi-dimensional parameters such as water, biodiversity, ecosystem services for society, and resilience to climate change to achieve sustainability in ecosystems and the human population (Zalewski, 2015).

A defining characteristic of integrated water resources management (IWRM) is its commitment to balancing water resources' socio-economic development with environmental sustainability. IWRM seeks to involve local communities residing along the river basins to manage the vital ecosystems and natural resources. Therefore, IWRM can be considered a guide to managing, planning, and monitoring water resources and equitable water allocation among competing uses, with stakeholders' involvement in decision-making in both the short term and long term. Ecohydrology offers a framework to mitigate intermediate forms of impact in cases where there has been ecosystem degradation and increase the ecological potential of a water catchment.

Therefore, one of the advantages of the ecohydrology concept to IWRM in river basin management is harmonising human needs with the enhanced ecosystems carrying capacity (Zalecwski, 2010). Ecohydrology calls for understanding that ecosystem characteristics such as the pattern of distribution of biomass in a basin area and its biodiversity play essential roles in shaping the water cycle. It also acknowledges that the surface/groundwater interplay largely determines the biological structure, productivity and related processes in terrestrial and aquatic ecosystems with a broad range of socio-economic consequences.

Berkowitz et al. (2003) assert that the ecohydrology concept can also reduce environmental degradation, provide affordable cost-efficient solutions to water issues, enhance ecosystem resistance against human impact and ensure ecosystem services. On this basis, IWRM is often proposed as the appropriate governance regime for sustainable water resources management because it addresses institutional problems and capacity building for the use, control, preservation and sustainability of water systems. However, in practice, IWRM implementation and success are often challenged by many factors ranging from ecosystem sustainability and economic efficiency to social equity (Sokile, 2005). Thus, ecohydrology's identification of scientific and technical solutions, eco-hydrological-based nature solution, and indigenous solutions puts all aspects of the catchment in balance. The ecohydrology approach incorporation into the IWRM allows for the translation of knowledge to management.

2.6. Methodology

In this study, information from various sources, namely, peer-reviewed journal articles, published reports and databases in the public domain and books, was obtained and reviewed. The study assessed the river basin activities and initiatives implemented by governmental and non-governmental sectors in the study area. The program's technical and operational provisions institutional capacity were assessed. In addittion, this review study builds upon a vast amount of work on the assessment of river basin management approaches by UNESCO and Kenya, which proved to be invaluable sources of data and other information. The study's internet search comprised the search words "Ecohydrology principles" and "ecohydrology in river basins", reduced to only 100 articles. The investigation was then further streamlined based on the problem/issue addressed in the river basin case studies. An assessment of past river programs and initiatives internet search on the Nairobi River basin yielded information on various river restoration and rehabilitation programs. The search results were further filtered and trimmed, noting the activities conducted within the past two decades.

3. Results

There have been numerous efforts by the government and other stakeholders to reverse the extensive environmental degradation and restore the ecosystems of the Nairobi River basin, as discussed below.

3.1. Nairobi River Basin rehabilitation and restoration

The Nairobi River Rehabilitation and Restoration (NRBP) started in 1990 as a three-phase initiative designed through an extensive multi-stakeholder consultative and participatory process. Funded by Various UN agencies (UNEP, UNDP and UN-Habitat) and spearheaded by many governmental ministries, environmental agencies and city municipalities. Its primary goal was centred more on the Nairobi River ecosystem to improve livelihoods, especially for the poor; enhance biodiversity; and provide a sustainable water supply for domestic, industrial, recreational, and emergency uses. For this case, the NRBP identified five key goals to improve the water quality and environment in the Nairobi River Basin namely: the development of environmental management and planning systems; the rehabilitation and restoration of the Nairobi Dam; the development and implementation of water quantity, and quality measuring protocols; the enhancement of service delivery, environmental conservation, and sustainable use of resources; and the maintenance of public awareness, and participation in, ecological issues impacting the Nairobi River Basin.

Phase I of NRBP constituted a situation assessment of water quality, public awareness, community outreach through pilot income generation projects and capacity building. Phase II of the programme (June 2001 - December 2003) was a pilot initiative focused on the Motoine/ Ngong River. It mainly involved pollution monitoring and assessment of 22 km of the Motoine/ Ngong river basin upstream, the dam, and 25 km downstream to the Athi River's confluence. Phase III (October 2004 - September 2008) aimed at implementing strategies that would improve, rehabilitate and restore the Nairobi River Basin.

Phase III ran from October 2004 - September 2008 to implement strategies to improve, rehabilitate and restore the Nairobi River Basin. The third phase differs from past stages as it diversified to include sewage maintenance and extension programs, extended to 2016. The program activities involved raising awareness and assessing social impacts. The riparian reserve was surveyed and delineated, and illegal discharges were stopped. Dredging work on a 2.5km demonstration stretch was completed, as was the relocation and resettlemtn of commercial activities and informal settlements. An integrated solid waste management system was developed and implemented. The Nairobi Dam was rehabilitated as well as the installations and repairs on sewerage and associated infrastructure. The phase program also included the development of a master plan for the economic utilisation of the riparian zone. Finally, riparian area was landscaped and beautified. However, the programme did not utilise any ecosystem approach to analyse and synthesise available data, information, and environmental issues within the project implementation sites (UON, 2005).

3.2. Groundwater protection

Water Resources Authority (WRA) undertook the Kikuyu Spring Conservation study to define and map areas that constitute the recharge zone(s). The study also sought to ascertain whether there is a need to accord the Kikuyu Spring Aquifer a "Special Aquifer" status, quantify mean annual recharge to the recharge zone or zones, and describe parameters likely to lead to natural recharge variations.

According to the study, the primary Kikuyu Springs recharge rock is in Limuru but groundwater infiltrates all the way down into the Karura and Kabete areas. It also revealed that up to 68%

of the annual recharge is abstracted, which should be cause for concern considering the aquifer's lack of a declared Reserve status. Finally, the study found that the abstraction in the northern zone has a greater effect on the system than extraction in the lower zone around Ondiri swamp and Kikuyu springs and should be regulated.

The study recommends an investigation to identify alternative water supply sources for the residents in the main recharge zones of the aquifer. It also recommends protecting the recharge areas against degradation and establishing a reserve volume for the Kikuyu Springs Aquifer to control the amount of water being abstracted. As a result of comprehensive consultations with stakeholders from the proposed Groundwater Conservation Area (GCA), including water users, area Members of Parliament, Members of County Assembly and other institutions, WRA prepared a draft Management Guidelines. The GCA's established in line with Water Act (2002) and the Water Resources Management Rules, 2007 (with amendments in 2012). The GCA establishes a sustainable framework for groundwater usage in the conservation area**.**

The study succeeded in quantifying the groundwater hydrologic cycle component and the vulnerability assessment of ecosystems dependant on the Kikuyu Spring Aquifer, such as Ondiri Swamp. The mapping of anthropogenically changed land areas above the aquifer and the potential acceptance of aquifer legal protection status enhances the aquifer's sustainability potential.

3.3. Urban flood resilience initiatives

Building urban flood resilience by integrating community perspectives in Kibera is an initiative that consists of the Kibera Public Space Project (2006) and consultation under the Building Urban Flood Resilience Program (2014). It is a community-driven, sustainable urban system that functions collectively to mitigate environmental hazards, provide public space amenities, build social networks, and develop small business enterprise. It aimed to transform littered and flooded spaces along the Ngong River and its tributaries into public areas that address macro-challenges that the slums face, such as flood hazards, lack of safe sanitation and recreational areas. The strategic flood risk assessment 'toolkits' produced provides physical evidence on how to plan for flood protection and drainage design solutions by capturing the community perspectives on flood risk using qualitative and quantitative information. It builds on residents' ideas, enhancing them with hydro-technical knowledge, design innovation and connecting them to external resources with the hope of empowering communities to advocate for themselves and address the significant physical, economic, and social challenges they face.

3.4. Wetland Monitoring and Restoration

An example is the National Environment Management Authority: Adopt-a-River Initiative. The youth-led, multi-stakeholder wetlands monitoring and restoration project piloted within the Nairobi River Basin before up-scaling to other parts of the country. The project entails adopting a nearby river by university/college student groups, community youth groups and other interested institutions. The youth groups monitor the adopted river over time, identify its pollution sources, and take local action towards its restoration and conservation (NEMA, 2015).

Through youth groups such as 'Small Axe' on River Gathara-in, this initiative has assisted in the removal of illegal dumpsite on the riparian land as well as the reclamation and restoration of the riparian land. Encroachment on the river and wetlands has been reduced as a result of the innitiative. On reclaimed sites, income generating projects such as tree nurseries have been established. The initiative has aided in the training of riparian communites in environmental conservation and entrepreneurship such as through good farming practice to improve food security and sustainable agriculture. Lastly, youth group and community policing have resulted in less incidents of raw sewer discharge into the river resulting in improved river water quality.

3.5. Swamp conservation and rehabilitation

The residents of the Ondiri Swamp encourage a diverse group of everyday people in the basin to pitch in and protect the swamp, through advocacy and volunteerism. Much of the work rests on the building of a common-cause alliances among the residents of Kikuyu. Other activities involves the development of the swamp into an ecotourism facility by the planting of indigenous trees and bamboo along the swamp edges. The trees and bamboos encourage more birds to nest and breed in the swamp area. The trees and bamboo also anchor the soil on the steep slopes and prevent eroded soil from entering the swamp, which is a significant cause of siltation.

The swamp's conservation and rehabilitation also go a long way toward conserving and enhancing ornithological biodiversity by increasing the nesting sites and habitat for various bird species in the area and serving as a breeding and resting ground for migratory birds as well as local species. Reforestation of the swamp absorbs carbon dioxide, thus contributing to reducing global warming. Bamboo planting activities provide nesting sites and habitats for birds and other fauna; the bamboo rhizomes also anchor topsoils along the steep slopes and the bank along the swamp. Thus, very effective in controlling soil erosion and in promoting soil health since it has excellent hydrological functions. Bamboo can absorb as much as 12 tonnes of atmospheric carbon dioxide per hectare, an important aspect of countering climate change effects resulting from the build-up of greenhouse gases in the atmosphere. The planted indigenous trees are sourced from tree nurseries run by women's groups living around the swamp.

4. Discussion

Since 1999 many plans have sought to alleviate the condition in Nairobi River Basin with minimal success. Water quality deterioration in the rivers has been a driving factor for river restoration projects on the Nairobi River basin. Public dissatisfaction with the lack of serenity and ambience of the environment along polluted rivers has made community groups in the basin carry out clean-ups and restoration activities along river banks. However, these activities are lacking the sustainability component as they lack continuity.

The NRBP, although implemented in three phases, was composed of various activities which seemingly focused on pollution control on the riparian reserve. These activities focused solely on the Nairobi River basin's ecological aspects, negating the hydrological and eco-technological characteristics. Thus, these interventions are not sufficient for achieving future sustainability as the quantity, timing and quality of the Nairobi river flow remains primarily determined by the land cover and land use in the whole landscape. The silo-approach adopted in program implementation among seemingly interrelated programs such as community organisations of Friends of Ondiri is separate from governmental initiatives. The basin's state continues to deteriorate due to insufficient focus on hydrological, ecological processes, and inter-relations (Kienja, 2017).

On the other hand, The 'Adopt a river' and 'Friends of Ondiri' initiatives solutions have sought to re-establish water, sediment, and nutrient retention in soils by promoting water infiltration and slowing down runoff response to precipitation. Also, revegetation of riparian areas around

Ondiri Swamp and along river banks provides a necessary buffer that modulates transport of sediments and nutrients from surrounding farms to the swamp and toward the Nairobi River respectively. Seemingly, these initiatives have promoted public participation in the basin's environmental issues, as evidenced by policing against land grabbers and property developers who attempt to encroach on river banks and wetlands. However, there is a need for synergy and collaborative initiatives that include the County government of Nairobi and Kiambu, water resources user associations (WRUAs), ministerial departments engaged in water, youth and women groups, residential associations, landlords, among others.

The groundwater/surface-water management in the Nairobi River basin has received minimal consideration in the basin's management discourse, with poor regulatory enforcement crippling efforts to attain sustainable management. The basin initiatives have failed to comprehensively address water stress and access problems that create conflicts between upstream and downstream users. There are cases where individuals in the upper reaches re-direct the rivers' flow course for domestic or economic use without regard to the downstream users. However, in the Nairobi River basin, the technical and institutional capacities to manage water resources are low (Olago, 2019). There is a failure to control and monitor and quantify the hydrological and ecological processes in water resources management schemes and ecosystems.

For example, for the Kikuyu Springs Aquifer, there is a need to regulate the amount of water extracted through either water quotas or water-tiered pricing instruments to ensure access among the water users replenishing the aquifer. Olago (2019) asserts that insufficient technical knowledge on urban aquifers and their interplay with the broader social-ecological system constrains holistic, practical and robust management systems.

Besides, the Kikuyu Spring aquifers protection status remains unresolved despite the implementation of monitoring studies. It noted that stakeholders in the basin operate under a 'silo' rehabilitation and restoration activity basis. Urban water infrastructure in the basin fails to keep up with the considerably stressed ecosystems and changing climate. Groundwater recharge is now recognised and is under the permit regime in the 2016 Act, which also has taken cognisance of public participation in the formulation and periodic revision of the strategies and private sector participation in water development and services provision. There is a step in the right direction. However, synchronising the different subsector management sector will be imperative, especially in the Nairobi River Basin case, which proves problematic in scaling them up. Thus, the basin's efforts are not matching up with the rate of ecosystems degradation.

However, underfunding issues also present a dilemma in the basin management efforts. There is an acknowledgement of the pertinence of monitoring initiatives as a successful example of the utility of evidence-based decision-making in the aquifer's ongoing protection status under discussion. Plans for protection though still in the pipeline, show a great need for other sectors, such as forestry, land use planning, and community members within the aquifer protection program. Water Resource Authority has gazetted fines and liability and prosecution for those found encroaching on the Ondiri swamp. However, there is still heavy contestation from competing stakeholders whose livelihoods depend on the conservation area's economic exploitation. Furthermore, regarding legislative status, Sustainable Development Goal 6 is incorporated into the Water Act of 2016. However, there is still minimal uptake of water-saving, reuse of water, or promotion of roof water harvesting at the household level to supplement supplies and mitigate drought impacts in the basin.

5. Conclusions

There has been widespread concern about the Nairobi River basin's state, evidenced by the numerous initiatives to reverse its deteriorating condition, especially in the past two decades. The various initiatives adopted contain some aspects based on the ecohydrological concept's principles. Most of the programs adopted fall in line with ecohydrology's ecological principle focus on identifying potential areas for enhancing sustainability potential, mapping the biosphere, and using restoration/ rehabilitation tools to redress the damage but with minimal success. Many initiatives, especially by non-governmental and community-based organisations, align with the hydrological principle which seeks to improve vulnerability assessment and flood control. Another principle which was minimally focused on within the Basin programs is the eco-technological engineering principles.

Although most of the implemented initiatives produced beneficial impacts within the basin, however, they were primarily generic in nature as they focused on the ecological and social systems while negating the hydrological systems. These initiatives are not matching up with the rate of ecosystem degradation. The studies conducted in the basin have not integrated complete research on biota and hydrology. Instead, most studies and initiatives have addressed physio-chemical pollutants, water quality, and community benefits derived from the various resources with little or no focus on the assessment and conservation of biodiversity. There is a minimal success with conservation initiatives adopted on the Nairobi River, but there is still an absence of a comprehensive ecohydrological approach. Furthermore, for the majority of the interventions, ecohydrological issues and socio-ecological factors are dealt with separately.

Full adoption of the ecohydrological principles and their integration in the current IWRM management planning should result in higher success in reversing the basin's degradation. However, there is inadequate funding for eco-technological engineering as well as fragmentation at the institutional level in implementing initiatives. Nonetheless, based on the fact that the conventional solutions are not as effective as expected and considering their limitations, there is an urgent need to apply a more sustainable approach. The comprehensive ecohydrology principles implementation within Nairobi Basin remains pertinent in delivering water for domestic use, agriculture, industrial and ecosystem services.

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References

Berkowitz, A. R., Nilon, C. H., and Hollweg, K. S. (2003). Understanding Urban Ecosystems. In *Understanding Urban Ecosystems*. https://doi.org/10.1007/b97613

Birongo, J. M., and Le, N. Q. (2005). An analysis of water governance in Kibera, Kenya. Roskilde University: Denmark.

Clancy, J. S. (2008). Urban ecological footprints in Africa. In *African Journal of Ecology*. https://doi.org/10.1111/j.1365-2028.2008.01041.x

Dejen, E., Vijverberg, J., and Sibbing, F. A. (2006). Spatial and temporal variation of cestode infection and its effects on two small barbs (Barbus humilis and B. tanapelagius) in Lake Tana, Ethiopia. *Hydrobiologia*, *556*(1), 109-117.

Githaiga, J. M. (2008). River Gilgil Wetlands Rehabilitation Intervention Environmental Impact Assessment. School of Biological Sciences, University of Nairobi, PO Box, 30197

Henry, R. K., Yongsheng, Z., and Jun, D. (2006). Municipal solid waste management challenges in developing countries - Kenyan case study. *Waste Management*, *26*(1), 92–100. https://doi.org/10.1016/j.wasman.2005.03.007

IHP. (2016). Ecohydrology As An Integrative Science From Molecular To Basin Scale: Historical Evolution, Advancement and Implement Activities.

Njoroge, B. N., Kimani, M., and Ndunge, D. (2014). Review of Municipal Solid Waste Management: A Case Study of Nairobi. *Research Inventory: International Journal Of Engineering And Science*, *4*(2), 2319–6483. www.researchinventy.com

Kabukuru, W. (2019). "Mass Demolitions Mark Start of Nairobi Regeneration" New African, Issue 592, March 2019 | Online Research Library: Questia. https://www.questia.com/magazine/1G1-581865520/mass-demolitions-mark-start-of-nairobi-regeneration

Kienja, K. (2017). Pollution of Urban Waterways in Nairobi: a Case Study of Mathare 4B Village, Nairobi, Kenya. https://ir.canterbury.ac.nz/bitstream/handle/10092/14938/MWaterRm thesis - Kevin Kienja.pdf?sequence=1

Kithiia, S. M. (2007). An assessment of water quality changes within the Athi and Nairobi river basins during the last decade. *IAHS-AISH Publication*, *314*, 205–212.

KNBS, (2019). 2019 Kenya Population and Housing Census. The Republic of Kenya.

Kwamboka, M. A. (2014). Effects Of Land Use Change on Streamflow, Channel Erosion and River Geomorphology: A Case Study Of Motoine/Ngong River Sub-Catchment, Nairobi River Basin, Kenya. http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:No+Title#0

Mbithi, J. (2013). Water-Borne Bacterial Pathogens in Surface Waters of Nairobi River and Health Implication to Communities Downstream Athi River.

McGill, R. (2018). Making Towns Work: Habitat III–What Relevance? Planning Theory and Practice, 19(1), 140–148. https://doi.org/10.1080/14649357.2017.1369237

Mincey, S. K., Hutten, M., Fischer, B. C., Evans, T. P., Stewart, S. I., and Vogt, J. M. (2013). Structuring institutional analysis for urban ecosystems : A key to sustainable urban forest management. 553–571. https://doi.org/10.1007/s11252-013-0286-3

Moss, B., Bidoglio, G., Pietrowsky, R., Breil, P., Bourgeron, P., Cullmann, J., Arduino, G., Jasser, I., Magnuszewski, A., Orenstein, D., Piper, G., Ratajski, S., Xia, J., Krauze, K., Wagner, I., and Zalewski, M. (2014). Synthesis and conclusions to the international symposium on ecohydrology, biotechnology and engineering: Towards harmony between the biosphere and society on the basis of long-term ecosystem research. *Ecohydrology and Hydrobiology*, *14*(1), 1–13. https://doi.org/10.1016/j.ecohyd.2014.03.001

Msuya, T. S., and Lalika, M. C. S. (2018). Linking Ecohydrology and Integrated Water Resources Management: Institutional challenges for water management in the Pangani Basin, Tanzania. *Ecohydrology and Hydrobiology*, *18*(2), 174–191. https://doi.org/10.1016/j.ecohyd.2017.10.004

Mwaura, M. N., Mukoya-wangia, S., Origa, J. O., and Mbatia, O. L. E. (2020). Influence of Technology Transfer Methods on Sustainability of Urban and Peri-urban Agriculture in Nairobi County. *Journal of Agriculture and Veterinary Science*, *13*(4), 59–65. https://doi.org/10.9790/2380-1304015965

Negussie, Y. Z., Urbaniak, M., and Zalewski, M. (2011). Ecohydrology for a sustainable future in Africa–the cases of Ethiopia, Kenya and Tanzania. *Ecohydrology & hydrobiology*, *11*(3-4), 223-230.

NEMA. (2015). ADOPT-A-RIVER INITIATIVE Mobilising and Empowering Youths to Champion Monitoring and Restoration of Rivers and other Wetlands within Nairobi River Basin.

Njuguna, S. M., Yan, X., Gituru, R. W., Wang, Q., and Wang, J. (2017). Assessment of macrophyte, heavy metal, and nutrient concentrations in the water of the Nairobi River, Kenya. *Environmental monitoring and assessment*, *189*(9), 1-14.

Nyika, J. (2017). Situational analysis of Nairobi river basin (NRB). *Water Practice and Technology*, *12*(3), 589–603. https://doi.org/10.2166/wpt.2017.061

Oiro, S., Comte, J. C., Soulsby, C., MacDonald, A., and Mwakamba, C. (2020). Depletion of groundwater resources under rapid urbanisation in Africa: recent and future trends in the Nairobi Aquifer System, Kenya. *Hydrogeology Journal*, *28*(8), 2635–2656. https://doi.org/10.1007/s10040-020-02236-5

Olago, D. O. (2019). Constraints and solutions for groundwater development, supply and governance in urban areas in Kenya. *Hydrogeology Journal*, *27*(3), 1031-1050.

Orsini, F., Kahane, R., Nono-Womdim, R., and Gianquinto, G. (2013). Urban agriculture in the developing world: A review. *Agronomy for Sustainable Development*, *33*(4), 695–720. https://doi.org/10.1007/s13593-013-0143-z

Polprasert, C., Pussayanavin, T., and Kottatep, T. (2015). Urban Development and Water Sustainability. Water and Urban Initiative, 01, 1–6. http://collections.unu.edu/eserv/UNU:2850/WUI_WP1.pdf

Rees, W. (1997). Urban ecosystems: the human dimension. *Urban Ecosystems*. https://doi.org/10.1023/A:1014380105620

Saha, A. K., and Setegn, S. G. (2015). Ecohydrology: Understanding and maintaining ecosystem services for IWRM. In *Sustainability of Integrated Water Resources Management: Water Governance, Climate and Ecohydrology* (pp. 121–145). Springer International Publishing. https://doi.org/10.1007/978-3-319-12194-9_8

Sarandón, R., Novillo, M., Muschong, D., and Borges, V. (2009). Lacar lake demonstration project for ecohydrology: Improving land use policy at lacar lake watershed based on an ecohydrological approach (San Martín de los Andes - Neuquén - R. Argentina). *Ecohydrology and Hydrobiology*, *9*(1), 125–134. https://doi.org/10.2478/v10104-009-0041-9

Silva, C. N. (2016). Governing urban Africa. Governing Urban Africa, 1–380. https://doi.org/10.1057/978-1-349-95109-3

Smit, W., and Parnell, S. (2012). Urban sustainability and human health: An African perspective. In Current Opinion in Environmental Sustainability. https://doi.org/10.1016/j.cosust.2012.07.004

Sobowale, O. R. (2019). River Restoration in Nairobi, Kenya: Exploring Public Participation and Learning Outcomes.

Tibaijuka, A. (2007). Nairobi and its Environment. In Nairobi, city development strategy top priority for the 21st Century future of the Kenyan capital.: Vol. Chapter 5.

UN DESA. (2018). 68% of the world population projected to live in urban areas by 2050, says UN | UN DESA | United Nations Department of Economic and Social Affairs. https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

UNESCO. (2015). Ecohydrology Platform. Ecohydrology WEB Platform. http://ecohydrology-ihp.org/demosites/demosites/list

UON. (2005). Survey and Situation Analysis of the Biological Characteristics of the Main Tributaries of the Nairobi Rivers, Reservoirs and Wetlands. http://hdl.handle.net/1834/7275

Wagner-Lotkowska, I., Bocian, J., Pypaert, P., Santiago-Fandino, V., and Zalewski, M. (2004). Environment and economy- dual benefit of ecohydrology and phytotechnology in water resources management: Pilica River Demonstration Project under the auspices of UNESCO and UNEP. *International Journal of Ecohydrology & Hydrobiology*, *4*(3), 345-352.

Wagner, I., and Breil, P. (2013). The role of ecohydrology in creating more resilient cities. *Ecohydrology & Hydrobiology*, *13*(2), 113–134.

Wagner, I., and Zalewski, M. (2009). Ecohydrology as a basis for the sustainable city strategic planning: Focus on Lodz, Poland. *Reviews in Environmental Science and Biotechnology*, *8*(3), 209–217. https://doi.org/10.1007/s11157-009-9169-8

Wasson, J. G., Barrera, S., Barrère, B., Binet, D., Collomb, D., Gonzales, I., and Rocabado, G. (2002). Hydro-ecoregions of the Bolivian Amazon: A geographical framework for the functioning of river ecosystems. The Ecohydrology of South American Rivers and Wetlands. Wallingford (UK)*: International Association of Hydrological Sciences*, 69-91.

Weru, G. (2012). Nairobi rivers pose health, safety hazards - Kenya | ReliefWeb. https://reliefweb.int/report/kenya/nairobi-rivers-pose-health-safety-hazards

Zalewski, M. (2015). Ecohydrology and Hydrologic Engineering: Regulation of Hydrology-Biota Interactions for Sustainability. *Journal of Hydrologic Engineering*, *20*(1), 1–14. https://doi.org/10.1061/(asce)he.1943-5584.0000999

Zalewski, M., and Wagner, I. (2005). Ecohydrology- the use of water and ecosystem processes for healthy urban environments. *Ecohydrology and Hydrobiology*, *5*(4), 263.

Zhao, J., Huang, Q., Chang, J., Liu, D., Huang, S., and Shi, X. (2015). Analysis of temporal and spatial trends of hydro-climatic variables in the Wei River Basin. *Environmental Research*. https://doi.org/10.1016/j.envres.2014.12.028

Implications of Rainfall Variability on Transhumant-patoralism in Ndop Central Sub-Division, North West Region, Cameroon

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Abstract

Rainfall variability has affected the pastoral system in sub-Saharan Africa because of dependence on rainfall for water supply. Seeking to know the extent of this rainfall variability and the vulnerability of pastoralists was the guiding premise of this work. To examine the impacts of rainfall variability on transhumant-pastoralism in Ndop Plain, a mixed research approach was used. Ninety eight questionnaires were administered to Mbororo rearers and interviews were carried out with local authorities. Using rainfall data, climatic indices and anomalies were established. Analysis of the results of this study reveal that rainfall in Ndop which is the main stay of the agro-pastoral systems, has been fluctuating over the last few decades (Coefficient of Variation=15.5%), with increasing anomalies on annual, seasonal and monthly basis. The observable impacts of rainfall variability are pasture degradation, the outbreak of diseases, conflicts between farmers and herders over resources, reduction in water courses as well as competition over water sources for cattle drinking and irrigation by farmers. The transhumance calendar and the pastoral code have not been able to remedy the situation given that demographic pressure on land and other resources has increased over the past years. Pastoralists have carried out a plethora of adaptive measures such as adopting resistant cattle species (90%), planting of Bracharia uphill(85.71%) and treatment of cattle during transhumance(80%). Despite this, they are still highly vulnerable to the effects of rainfall variability and if care is not taken, their current and future settlement options will be disrupted.

Keywords: Rainfall variability, transhumant-pastoralism, adaptation, Ndop Plain, North West Region, Cameroon.

1. Introduction

Rain-fed agriculture is the backbone of the Cameroonian economy as it provides jobs, food and add to the country's Gross Domestic Product. The agro-pastoral systems that depend solely on seasonal rainfall have been affected negatively by recent climatic aberrations. These are expected to adversely affect livestock production and productivity around the world both directly and indirectly (FAO, 2017). In Africa, the agro-pastoral production systems are mostly vulnerable to increased climate variability (Sithole and Murewi, 2014) as they are principally dependent on natural resources.

In Cameroon, transhumance is highly practiced in the Sudano Sahelian area of the Northern region of the country as well as parts of the western region. In the Ndop plain, transhumant-pastoralism is an activity that depends solely on rainfall for pasture growth and water supply.

The seasonal rainfall pattern has imposed a seasonal movement of rearers with their herds between the uplands and lowlands in search of pasture and water. This transhumant type of rearing is regulated by Decree No 76/420 of the 14 September 1976, modified by Decree No 86/755 24 June 1986 which fix modalities for carrying out transhumant-pastoralism. This activity is carried out by Mbororo minorities who have been in the course of sedentarization.

However, the regulations are conditioned by the natural occurrence of rainfall. Recent climatic trends have shown unreliable rainfall patterns, fluctuations in dates of onset and cessation of rains and increasing frequency of dry spells and droughts. The impacts of rainfall variability on these herders are enormous given that their source of livelihoods has been affected negatively. The Ndop plain which falls within the humid tropical climate and has been affected by rainfall variability, is characterized by overall fallings, inter-seasonal and inter-annual anomalies, fluctuation in number of rainy days as well as variations in the onset and retreat of the rains (Nkiene et al, 2016). The changing rainfall pattern has affected water and pasture availability for livestock (Kima et al, 2015). Under such conditions, livestock rearing is increasingly dependent on mobility across various spatio-temporal scales.

The need to develop better coping strategies prompted us to carry out this work. This article addresses issues related to the theme titled "water and human settlements of the future. This study is considered relevant as the sedentarized Mbororo herders may embark on their nomadic lifestyle as a response to water scarcity that is linked to rainfall variability.

2. Materials and methods

2.1. The study area

Ndop Sub-division of the North West Region, is located between latitude 5°37' N and 6°14'N and between longitude 10°23 E to 10°28'E. It has an altitude of about 1276m. It shares boundaries with Bambungo, Baba 1, Babessi, Bambalang, Bamali and with the Belo Sub Division. It has a humid

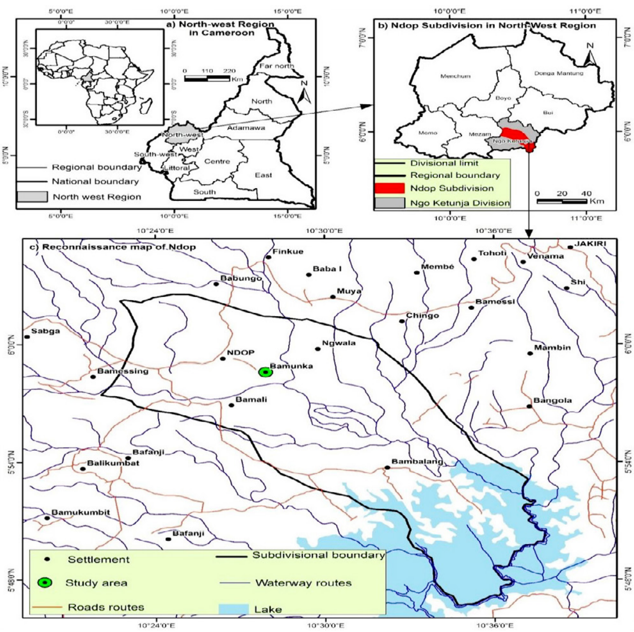


Figure 1: Location of the study area

Source: Realised by Nugah (2020)

tropical climate with an average maximum daily temperature of about 27.22°C and an average monthly rainfall total estimated at about 273mm for the wettest months. It has two seasons: a long rainy season (beginning from mid-March and ending in mid-November) and a short dry season (beginning from mid-November and ending in mid-March). These conditions favor agro-pastoral activities such as livestock rearing and intensive crop cultivation of different types and rice cultivation on the extensive swamps. It has a total population of about 200,000 inhabitants. Agriculture is practiced by a significant fraction of the total population. (Mphoweh,2007;Ndzeidze, 2008; Fonge et al., 2012).(Figure 1)

2.1.1. Data collection and analysis

The target population is made of Mbororo pastoralists who depend on cattle rearing for their livelihood. With a mixed research approach, primary data were collected with the use of 98 questionnaires, 4 in-depth interviews and field observations. Rainfall data were collected from three stations of different altitudes; the Ndop station for a period of 25years, the Bamenda station 54years and the Jakiri station 56years.

Questionnaires were treated in SPSS while interviews were exploited using content analysis. The tools used in the study of rainfall variability included statistical tools and climatic indices. The mean, variance and standard deviations of rainfall for different stations, were calculated to determine rainfall variability. Two indices were employed to examine the characteristics of extreme weather events in Ndop. They include the Gausian which can relate monthly rainfall to temperatures as stated P= 2T, and the Seasonality Index. This index can vary from zero if all the months have equal rainfall to 1.83 if all the rainfall occurs in a single month (Walsh et al, 1981). (*SI)*

$$SI_i \sum_{n=1}^{12} \frac{\left|X_{in-\frac{R_i}{12}}\right|}{R_i} \text{--} (1)$$

X_n = mean rainfall for month n; R_i = mean annual rainfall; P= precipitation and T=temperature.

The Gausian index and the seasonality index of Walsh and Lawler (1981) were used to define the seasonal contrasts. This index is a function of mean monthly and annual rainfall. This was pertinent because transhumant-pastoralism is an activity regulated by seasonal climatic changes. The coefficient of Variation was equally computed. These gave the baseline from which anomalous climatic situations and the degree of reliability of climatic elements were determined. The coefficient of variation (CV) is thus calculated as

$$CV= (\mu / \sigma)* 100 \text{---} (2)$$

In equation (2) μ= mean rainfall amount and σ = standard deviation

According to Manning (1956) in absolute terms, when the CV value is greater than 30, then the variable under study (temperature or rainfall) is considered unreliable or highly variable and when the CV value is lower, then the variable is reliable. The statistical calculations were performed using the EXCEL computer program to establish charts and curves.

3. Results

3.1. Rainfall variability and water resources for pastoral activities

Rainfall is the main source of water for agro-pastoral activities in the Ndop plain. Climatic variability has disrupted the reliability of rainfall. It is characterised by an average coefficient of variations of 13.6%. However, individual stations show differences in coefficient of variations (Table 1)

Table 1: Statistical indicators of rainfall variability in the Ndop plain of Cameroon

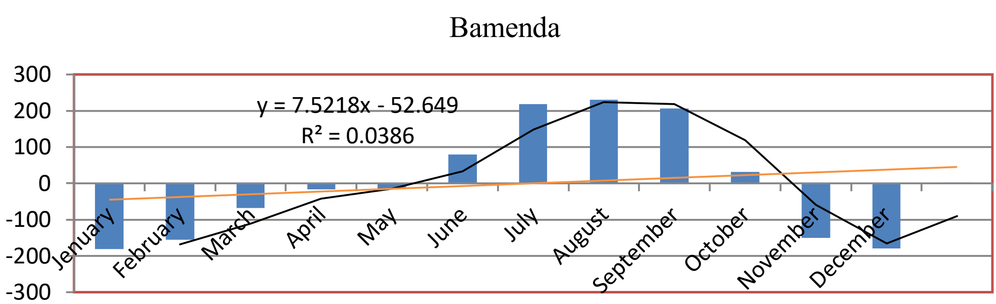
Stations	Location of the station	Altitude of the station	Mean Rainfall Total(mm)	Standard Deviat ion(mm)	Coefficient of variation (%)
Bamenda Station	Upland	1614m	2362,71	259,69	9,09
Jakiri Station	Upland	1920m	1993,7	122.84	16,23
Ndop Station	Plain	1150m	1851,96	119.48	15.50

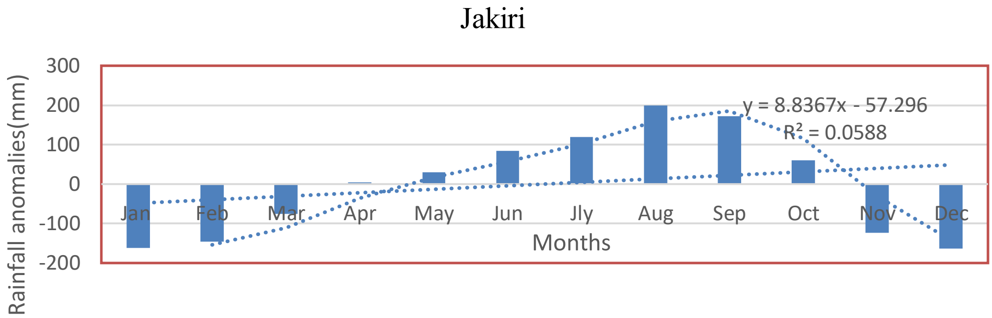
Source: Fieldwork, (Data from Bamenda, Jakiri and Ndop Meteorological Stations)

Table 1 shows variations in mean rainfall characteristics for all the stations. Bamenda station is characterized by a mean rainfall of 2362.71mm, standard deviation of 259.69mm and coefficient of variation of 9.09%. This coefficient of variation indicates that the rate of fluctuation around the mean of 2362.71mm is 9.09%. This rate is low but significant. For Jakiri station, the rate is 16.23% around the mean of 1993.7mm and standard deviation of 122.84mm. In the same light for the Ndop station, a coefficient of variation of 15.50% around the mean of 1851.96mm and standard deviation of 119.48mm were recorded. Stations are located at different altitudes and these results also indicate that relief has an impact on rainfall variability which is likely to trigger transhumance movements between the different relief areas. To establish temporal manifestations, rainfall anomalies and trends were studied at monthly and seasonal scales.

3.1.1. Monthly rainfall anomalies

Rainfall distribution follows a monthly pattern. Wet months record higher amounts of rainfall than dry months. Besides the monthly variations observed within the same months over the study periods and for different stations, anomalous deviations are also noticed in the data sets. As noted earlier, the mean monthly rainfall for Bamenda, Jakiri and Ndop are 191,68mm, 166.00mm and 156,20mm respectively. Positive and negative anomalies are experienced and they reflect the seasonal pattern of rainfall distribution in this area (Figure 2)





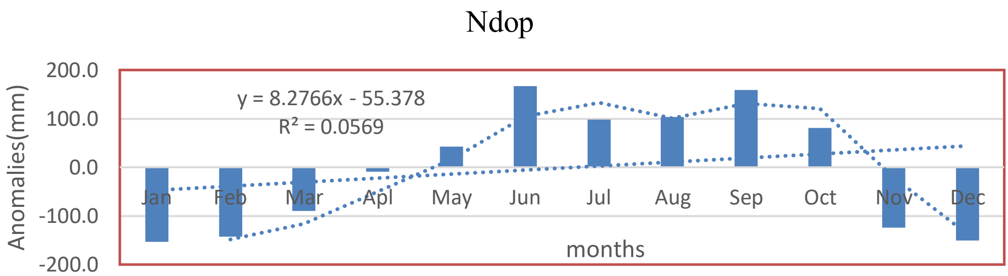


Figure 2: Monthly rainfall anomalies for Bamenda, Jakiri and Ndop (Nugah 2020)

Figure 2 shows monthly anomalies for Bamenda, Jakiri and Ndop Stations. The Bamenda stations portrays positive anomalies for the months June to October while November and December, January to May have negative anomalies. The months with rainfall above the normal or mean for the period are those of the rainy season but curiously, the months of March, April and May, recorded negative anomalies, whereas they are dry season months. The scenario in Ndop is the same with that of Jakiri. However, despite this situation, variability is seen in the rainfall amounts recorded per month, at different station. For Bamenda, excesses of over 200mm are noted for the peak rainy months but Jakiri had about 190mm and Ndop 160mm. These anomalies have implications on water resources. Positive anomalies indicate a period of water availability and the livelihood of floods while negative anomalies indicate dry months with less water for cattle and pasture growth.

3.1.1.1 Rainfall Seasonality pattern and anomalies

The Seasonality Index (SI) was developed by Walsh and Lawler in 1981.The analysis of seasonal rainfall variability and anomalies is not enough to establish the change in seasonal rainfall pattern. The seasonality presents seasonality index class limits and corresponding rainfall regimes. The regimes provide a description of the monthly rainfall distribution of the wet season rainfall. It ranges from equal distribution to extreme concentration, whereby almost all rain is concentrated in one out two months. The Seasonality Indices for Bamenda, Jakiri and Ndop were calculated and results presented on Table 2

Table 2 shows that the average calculated SI value for the three stations is 0.89. The value varies across stations, with the Bamenda station having 0.901, Jakiri with 0.822 and Ndop with 0.97. Referring from the Walsh and Lawler seasonality index scale, all values fall within the limit 0.80-0.99, implying that rainfall is markedly seasonal with a long dry season. The rainy season normally starts by mid-march and ends in October. Therefore, the rainfall pattern for this area would be expected to be seasonal as in most humid tropical climatic regimes. The

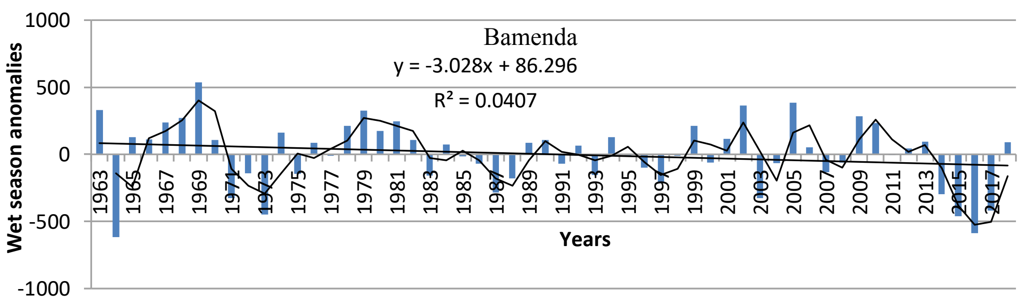
Table 2: Calculated Rainfall seasonality indices for Bamenda, Jakiri and Ndop with corresponding rainfall regimes

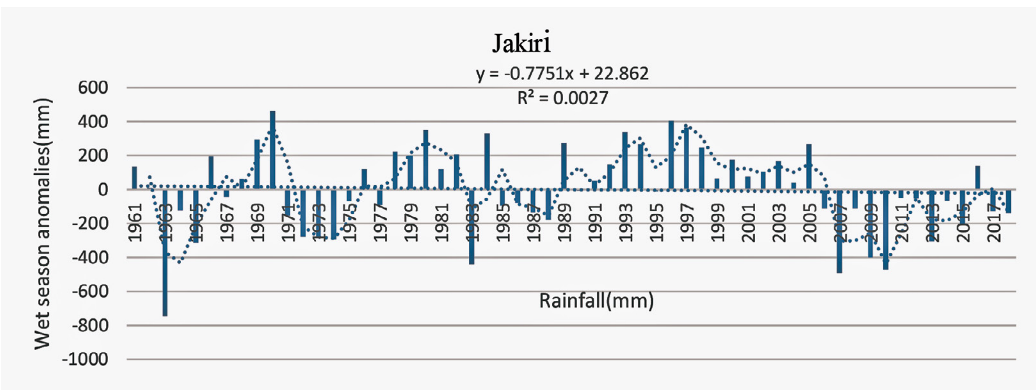
Station	Calculated SI Value	Class limit	Rainfall regime
Bamenda	0,901	0.80–0.99	Markedly seasonal with long drier season
Jakiri	0,822	0.80–0.99	Markedly seasonal with long drier season
Ndop	0,97	0.80–0.99	Markedly seasonal with long drier season
Average	0.89	0.80–0.99	

Source: Bamenda, Jakiri and Ndop Meteorological stations (2020)

shift from "seasonal" to "markedly seasonal with a longer dry season" is an indicator of rainfall variability. This shift is justified by the reduction in rainfall totals with increasing occurrence of dry spells. It entails that natural systems, including pasture lands, will be vulnerable to water shortages and dry spells. This seasonal shift has implications on the transhumant-pastoralism calendar. The movement of cattle between the Ndop plain and surrounding uplands is based on seasonal changes and regulated by the agro-pastoral code. Hence, such fluctuations have implications on agro-pastoral activities, especially transhumance.

Given that, rainfall and water supply in Ndop follow a seasonal pattern, anomalous occurences have been noticed. Positive and negative deviations from the seasonal mean rainfall amounts are indicators of climate variability that determines water availability for agro-pastoral activities. Marked deviations from the seasonal means of 2199, 71mm, 1923.06mm and 1791.68mm for Bamenda, Jakiri and Ndop respectively, have been presented for both the wet and dry seasons (Figure 3)





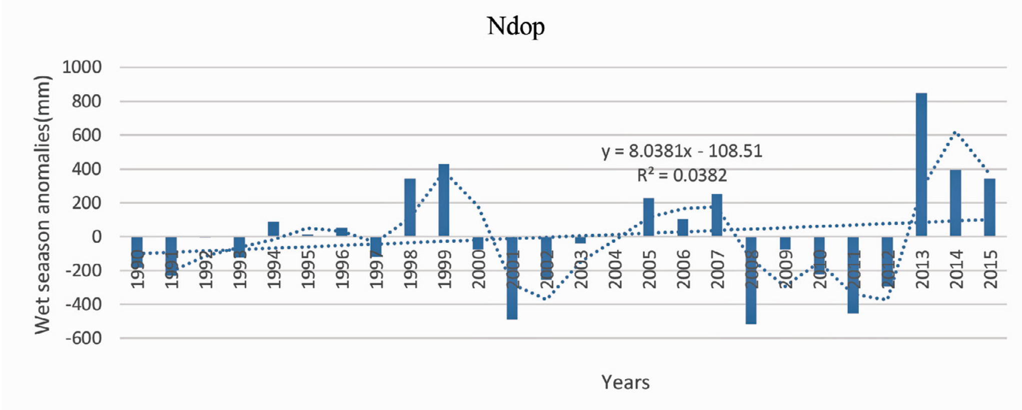


Figure 3: Wet season rainfall anomalies for Bamenda (1963-2017), Jakiri (1961-2017) and Ndop (1990-2015) (Nugah, 2020)

Figure 3 shows seasonal rainfall anomalies for Bamenda, Jakiri and Ndop. For Bamenda station, positive and negative deviations from the seasonal mean of 2199, 71mm are noted. The fluctuations range between +5oomm and -600mm but the number of years with positive anomalies are more than those with negative anomalies. The trend shows that wet season rainfall has been decreasing from 1963 to 2019. At the Jakiri station, positive anomalies are more than negative anomalies with a slightly falling trend for the wet season rainfall. It is observed that deviations of +420mm to -670mm were recorded around the mean of 1923.06mm and for the Ndop plain, the rainfall ranges from about +800mm to about -600mm around the mean of 1791.68mm. Though the rainy season is a period with abundant water supply, it is established that, some years had less water in the rainy season comparatively as indicated in the negative anomalies.

3.1. Implications of rainfall variability on transhumant pastoralism

Transhumant-pastoralism is the seasonal movement of herdsmen with their cattle in search of water and pasture. The growth of natural pasture depends on rainfall while water sources are equally rain-fed and seasonal. From field observations, rainfall variability is seen to have negative impacts on water and pastures amongst other elements (Table 3)

Table 3: Implications of rainfall variability on transhumant-pastoralism

Implications of rainfall variability	Frequency	% Frequency
Decreased water availability for cattle	98	100
Decreased pasture availability for cattle	87	88.7
Outbreak of diseases	79	80.6
Late maturity of crops due to late onset of rains	76	77.5
Disruption of the pastoral calendar	71	72.4
Frequent bushfires	69	70.4

Source: fieldwork 2020

Table 3 indicates a number of problems related to rainfall being identified by agro-pastoralists. Transhumant-pastoralists are vulnerable to rainfall variability due to its negative impacts on water sources, pasture growth and agricultural yields needed for cattle all year round. Ninety eight percent of the respondents indicated that, the amount of pasture available for cattle is decreasing and varies within the different transhumance areas in Ndop plain. About 87(88.7%) of the respondents acknowledge the decrease availability of water for cattle. About 79(80.6%) of the respondents indicated that, increases the outbreak of cattle diseases and about 71(72.4%) of the respondents acknowledged that, rainfall variability has disrupted the pastoral calendar. The common cattle diseases include trypanosomiasis, tuberculosis, contagious pleuropneumonia as well as the effects of endo-parasites caused by round worm and tape worm, ecto-parasitic effects caused by heavy thick infestation and ring and mastitis. Interviews with livestock officials indicated that the prevalence of these diseases has increased over the past few years and coincides with periods of water stress and dry spells. Disruption of the agro-pastoral calendar, 69(70.4%) frequent bushfires are some of the impacts of rainfall variability hindering the livelihood of the population of this area.

Water resources are drastically affected by the vagaries of weather. Few streams in the area witness a reduction of about 65% in the dry season making, it difficult for pastoralist to move over long distances in search of water for their cattle. The river courses of the uplands surrounding Ndop plain have been shrinking considerably. Some dry off completely during the dry season. With this situation, herders are forced to take their cattle down the plains. Coupled with the changing rainfall pattern in the area most streams shrink drastically or completely dry up. Plate 1 shows water body shrinkage that has implications for cattle during transhumance.

Photo A, a river on the lowlands © Nugah Alvina

Photo B, a seasonal stream upland © Nugah Alvina

Plate 1, shows how rivers in Ndop plain have reduced in volume over the past years. This has made it very difficult for transhumant pastoralists to carry out their activities especially in the dry seasons when they move over long distances in search of water for their cattle. Then, most of the rivers in the area that usually contain water throughout the year, are fast declining in quantity as seen in photo A. Most of these rivers do have water only in the rainy season as compared to the past years, making movements difficult.

Apart from changes, in the seasonal river courses, perennial streams such as river Noun have been shrinking significantly over the past years. Rearers used to carry their cattle to these streams and back on a daily basis but the reduction in size has created lesser water resources for the cattle herds (Photo 1)

Photo 3: Water pollution by cattle © Nugah Alvina

Source: Nugah, (2020)

Photo 1 shows a shrunk water course. Cattle used to stand at the banks and drink but shrinking has reduced their access to water. Only a lesser number of cattle can drink at a time while others have to go right deep into the stream as indicated by the arrow. This daily movement of cattle into the rivers and streams has led to water pollution reason being that, while drinking, some defecate while others urinate in the rivers and streams this renders it unfit for both cattle and human consumption.

Transhumant-pastoralists are also vulnerable to rainfall variability due to its negative impacts on pasture growth and agricultural yields needed for cattle year- round. The amount of pasture availability is reducing and varies within the different transhumance zones of Ndop plain as seen on plate 2.

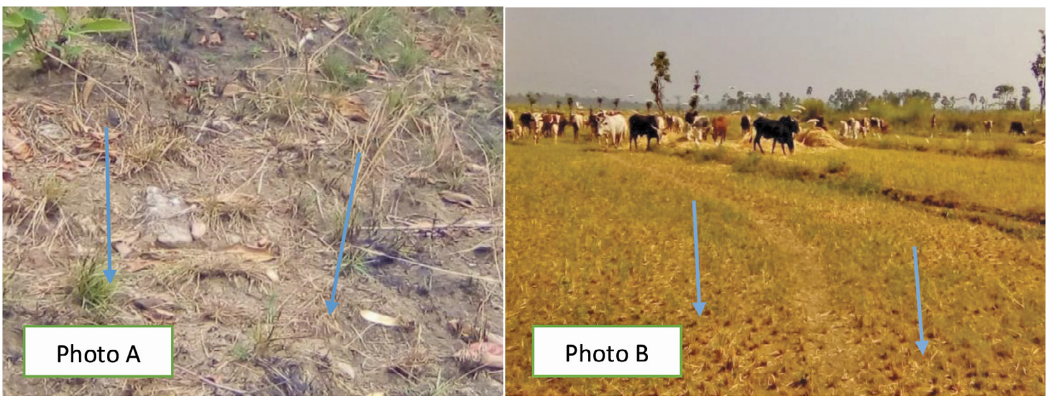


Plate 2: An illustration of pasture upland and lowland © Nugah Alvina

Source: Fieldwork December 2019

Photo A of plate 2 illustrates the surrounding hills of the Ndop plain while B the rice swamps of Ndop plain in the dry season. The changing rainfall pattern in this area has led to a decrease in pasture upland as seen on photo A, reason why transhumant-pastoralists become vulnerable between upland and lowland pastures on the swamps which are wet all year round. However, upland pastures in the rainy season reduces as cattle feed and trample on daily.

3.3 Reduction in wetlands

Wetlands are important fresh water reservoirs. They are defined as areas that are marshy, fen, peat land or water whether natural or artificial, permanent or temporal, with water that is static or flowing, fresh, brackish or salty, including areas of marine water, the depth of which at low tides does not exceed six metres (Ramsar Bureau 2000). The wetlands of the Ndop plain, are exploited for swamp rice cultivation and are also a major transhumance zone in the Ndop plain that attracts pastoralists from far and near during the dry season. This is because, the swamps provide good quantity and quality pastures needed for cattle during the dry months of the year. Thanks to the indigenes of this area who make use of these swamps through rice cultivation during the rainy season and vacate the area for transhumant- pastoralists in the dry season. (Figure 4)

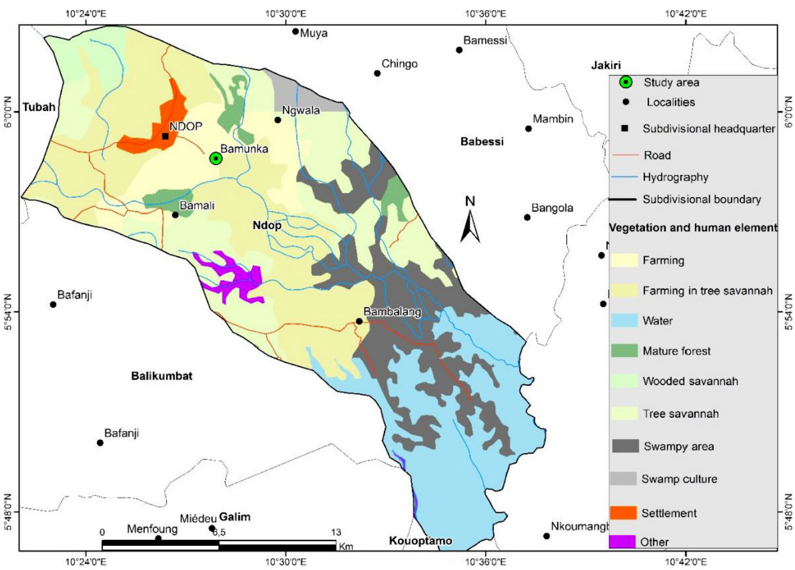


Figure 4: The swamps of Ndop Central Sub-division.

Realised by Nugah, 2020

Due to frequent dry spells in the area resulting from climatic variability, the area has witnessed a significant reduction in wetlands.

3.4. Impacts of rainfall variability on the livelihood of herders and their settlement

Rainfall variability and changes in climatic pattern have disrupted the pastoral calendar, leading to conflicts between pastoralists themselves and between farmers and grazers. It is noted that the root causes of these conflicts is from early/late start of rains or prolong dry season which disrupts the planning of activities and reduces pastoral resources. Conflicts between farmers/grazers aggravate from stray cattle destroying crop during transhumance, 27.55% disputes over water points, 23.46% encroachment into transhumance zones by farmers, 12.24 uncontrolled bushfires. While conflicts between grazers themselves aggravates over water resources that are shrinking and pastures that are degrading.

However, they are trying to adopt few adaptation measures so as to reduce the impacts of rainfall variability on the livelihood of herders and their settlement some of which includes; migration to other zones in search of water and pastures, adoption modern methods of rearing (ranching), pasture improvement through the cultivation of drought resistant fodder such as bracharia and guatamala but their efforts are limited to their low level of education, inability to expand grazing lands, unable to have climatic information on time.

This situation has implications on settlement patterns. The Mbororo pastoralists in the Ndop plain and the North West region in general, were nomadic pastoralists but recent environmental and socio-economic constraints have forced them to adopt a sedentary lifestyle. With these climatic and environmental stressors, herders who were already adopting a semi-nomadic lifestyle risk migration to other areas due to the reduction in available water and pasture.

4. Discussion

Rainfall in the Ndop plain varies in time and space with increasing number of extreme events such as dry spells and floods. Rainfall is a strong determinant of transhumant-pastoralism in Ndop plain as it marks the transhumance periods. In the Ndop plain, transhumance is vertical and conditioned by the availability of water and pasture. This seasonal movement of herdsmen with their cattle in search of water and pasture is being impacted by climate variability. The changing rainfall pattern has affected water and pasture availability for livestock and this is has affected rearing systems in sub-Saharan Africa as a whole as indicated by (Brottem *et al,* 2014), Kima et al, (2015). This work shows that, under such conditions, livestock rearing focuses on the importance of mobility across various spatio-temporal scales. However, this mobility is also being affected because herdsmen and cattle need water in the functioning of their system and so, will rarely survive without especially during the dry season with intense sunshine. Despite the presence of several streams in the area, transhumant-pastoralists still greatly suffer from water reduction for their cattle which is either being caused by changing rainfall pattern or rainfall variability on one hand, competition for various uses on the other hand.

The few streams in the area witness a reduction of about 65% in the dry season making it difficult for pastoralists to move over long distances in search of water for their cattle. Kurukalasurya and Rosenthal (2003) established that, climate change has affected hydrographical systems and water resources. Rainfall variability has distorted the agro pastoral calendar this has led to conflicts between farmers/grazers over pastoral resources such as conflicts over water resources, pastures, cattle getting into unharvest farms due to their inability to master and coup with the changing climate pattern, bush burning and encroachment into grazing zones. It concurs with the work of Ayantunde *et al.* (2014) who noted that, transhumance practices in the Sudano-Sahelian zones are facing increase challenge in the context of demographic pressure, leading to encroachment into grazing areas which constrains the mobility of animals.

Transhumant-pastoralists are noted for bush burning in the dry season when they are going on transhumance or during renewal of pasture at the beginning of rainy season in March which marks the beginning of farming season with the coming of the first rains, they set fire on dry pasture to get fresh pastures for their cattle. This is related to the works of Ayantunde et al. (2014), in which they noted uncontrolled bush fire as a major threat to natural resource management which may have direct or indirect on the ecosystem and livestock. Therefore, fires are not only hazardous to the environment but human destructions as well. Despite all the impacts of rainfall variability on transhumant-pastoralism, pastoralists are trying in their own little way to adapt to the situation for example migration to other zones. Migration is a form of adaptation within a broader set of potential adaptive response that individuals and households undertake to minimize their vulnerabilities to the pressure of environmental changes (Mcleman and smit 2006). The idea of migration to other zones within transhumant-pastoralists is from a cultural aspect which technically, is an adaptation option he did not mention the construction of boreholes to reserve water for cattle during and herdsmen the dry periods.

In the Ndop plain, rearers burn bushes so as to regenerate fresh pastures for their cattle. This method is considered environmentally unfriendly. Bentley et al., (2008) noted that, pasture management measures involve the sowing of improved varieties of pasture, typically replacing native grasses with higher yielding and more digestible forages, including perennial fodders, pastures and legumes. The aforementioned adaptation strategies are limited by pastoralists' low level of education. This is corroborated by Norris et al (2015) and Ravi et al (2013) who found a positive relationship between education and adaptation to changing rainfall patterns. Improved knowledge could lead to better adaptation systems and a sedentary mode of life for the Mbororos.

5. Conclusion

Herder migration is affected by seasonal rainfall patterns which are factors of water security. Rainfall variability in space and time is an indicator of the recent climate change that affects both natural and human systems. One of such sectors that is vulnerable to the vagaries of weather is the agro-pastoral sector, due to its dependence on natural systems in the Ndop plain. The main methods used in this paper are, coefficient of variation, Gausian and seasonality indices, field observations. Rainfall anomalies were equally calculated using mean, variance and standard deviation. Rainfall variability from Bamenda station is shown by coefficient variation 9.09%, this rate is too low but significant, for the Jakiri station rate is 16.23%. In the same light, Ndop stations a coefficient of variation of 15.50% These coefficients of variations statistical proves that rainfall has been fluctuating over time and the differences between stations portrays the spatial dimension of rainfall variability in this region. The fluctuations in the dates of onset and terminations of rains is an indicator of rainfall variability with droughts that affects the activity. From our findings, we concluded that, rainfall variability has affected the supply of water for agro-pastoral activities in the Ndop plain with (100%) of rivers shrinking while others dry off, (88.7%)pastures degrades, (80.6%)the outbreak of waterborne diseases, (72.4%) disruption of the pastoral calendar. All these have made transhumant-pastoralists vulnerable hence, conflicts resulting from Stray cattle destroy crop during transhumance (30.61%), disputes over water points (27.55%), encroachment into transhumance zone by cultivators (23.46%), attack on cattle by farmers (6.12%), With this scenario, transhumance which is the main source of livelihoods of the Mbororos have been negatively affected and this would possibly have implications on their present and future settlement options. Most herders therefor, in a response to ecological changes herders have adopted permanent settlements while moving only their animals and herdsmen during transhumance. This is such because transhumance has made them change from a completely nomadic to a sedentary mode of life as they are trying in their own little way to adapt to the impacts of changing rainfall pattern. The vulnerability of pastoralists to climatic stressors should be assessed by stakeholders so as to proactive adaptation measures.

Adaptation constraints are pointed towards the direction of low level of education and inadequate coping techniques. Thus, we see education and technical assistance as a key factor to foster pastoralist's adaptation. Also, authorities in charge of livestock management should include climate policies in their plan of action. Again, there is need for stakeholders to come up with projects for the construction of boreholes around the homestead of transhumant-pastoralists for cattle and pastoralists themselves this will go a long way to reduce migration to other zones in search of water.

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Definition of term

Transhumant-pastoralism is the regular movement of pastoralists and their livestock between fixed points in order to exploit seasonally available grazing resources.

References

Brottem, L., Turner, M., Butt., B and Singh A. (20014). Biophysical Variability and Pastoral rights to Resources: West African Transhumance Revisite. Hum Ecol DOI 10.1007/s 10745-014-9640-1.

Mckee, T.B., Doesken, N.J. and Kleist, J. (1995): Drought monitoring with multiple time scales. In: Preceedings of the ninth conference on Applied Climatology, American Meteorological society, Boston, pp 233-236.

Kima, A., Okhimamhe, A., Kiema, A., Zampaligre, N., Sule, I. (2015). Adapting to the impacts of Climate change in the sub-humid zone of Burkina Fasso, West Africa: Perceptions of agro-pastoralists. Pastoralism 5, 16(2015) doi:10.1186/s13570-015-0034-9.

Kurukulasuriya, P., and Rosenthal. (2003). Climate Change and Agriculture: A Review of Impacts and Adaptation.

Mbih, R., Driever, S., Ndzeidze, S., Mbuh, M., Carine, S., Bongadzem, C., and Wirngo, H. (2017). Fulani pastoralists' transformation process: A sustainable development approach in the Western Highlands of Cameroon, DOI 10.1007/s10668-017-9910-3.

McLeman, R. A. and Smit, B. (2006),"Migration as an adaptation to climate change", Climate Change, Vol. 76, pp. 5-31

Mpoweh, J., Tchindjang, M., and Mfoundoum, A. (2016). The degradation of raffia palms and its socio-economic and ecological consequences: The case study of Bamunka, Ndop North West Region Cameroon.

Nieuwolt, S. (1989). Estimating the agricultural risks of tropical rainfall. https://doi.org/10.1016/0168-1923(89)90047-6

Nkiene, V., Nkwemoh, C., and Tchawa, P. (2016). The Vulnerability of swamp rice production to the observed effects of rainfall variability and temperature variability in Ndop Sub-division, Cameroon. *Canadian Journal of Tropical Geography* available online At http://laurentian.ca/cjtg,accessed on the 2nd of June 2010.

Sithole, A., and Murewi, C. (2009). Climate variability and change over Southern Africa: Impacts andChallenges.

Tata, E., Komet, S., and Amawa, S. (2012). The Implications of Rainfall Variability on Cattle and Milk Production in Jakiri Sub-Division, North West Region, Cameroon, *Journal of Agricultural Science;*Vol. 4, No. 10.ISSN 1916-9752.

Walsh, D., and Lawler, M. (1981). Rainfall seasonality: Description, spatial patterns and change through time scale.

Identifying Priorities for Achieving Water-secure African Cities: City Blueprint Approach

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Abstract

Africa's population growth rate more than doubles the global average. Most growth will occur in urban areas, posing water security challenges in sub-Saharan African Cities (sSAC). This study aims to identify capacity-development priorities for strengthening urban water security in sSAC by enhancing and empowering the abilities of young professionals to achieve measurable and sustainable results through integrated assessment and policy-dialogues. Based on the assessment of five sSAC conducted by local young water professionals. The results indicate that economic and social pressures such as GDP, high burden of disease and limited female participation in paid jobs, form less favourable conditions for water management performances. Water management improvement priorities have been observed with respect to access to potable drinking water and improved sanitation. Observations show that access to improved sanitation has to go together with wastewater treatment in order to prevent large-scale water pollution and related spread of vector-borne diseases. In addition, solid waste management as well as access to drinking water require upfront investments but also long-term operational financial planning that includes a reasonable salary and professional training of personnel. These water management priorities may provide important foci that enable a more sustainable transformation of sSAC. The assessment approach has demonstrated to support well-informed decision-making through independent, interactive, empirically based and city-specific assessments. Finally, by putting young water professionals in the driving seat, they become the water professionals of the future that have the necessary skills to think across organisational boundaries, political mandates and scientific disciplines.

Keywords: Urban Water Management, Sub-Saharan Africa, City Blueprint Framework, Water Security, Urban Transformation.

1. Introduction

The serious water security challenges today - especially in African cities, threaten lives and livelihoods, and negatively impact people's health and productivity to mention but a few. Action to improve water availability at a quality fit for purpose and protection of life, property and ecosystems are becoming extremely urgent and more important than ever. Africa is under threat of not actually achieving its Water Vision 2025 and the UN Sustainable Development

Goals (Naidoo and Fisher 2020). Africa's population growth is the highest among all continents and more than double the global average. Population projections indicate that the global urban population will more than double to 2.5 billion in 2050 and further growth to 4.3 billion in 2100 (UN 2019). Most of this growth will be directed in cities and urban areas, posing a huge challenge on water security, especially in urban areas. Climate change is intensifying these challenges by droughts that exacerbate water scarcity and changing precipitation patterns, often leading to water-related disasters. Urbanisation and climate change are largely irreversible and have become the "The new normal".

IWRM has been defined by the Technical Committee of the Global Water Partnership (GWP) as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." The proposed working definition of urban water security is based on the United Nations (UN) Sustainable Development Goals (SDG) on water and sanitation and the human rights on water and sanitation (SDG 6). It captures issues of urban-level technical, environmental and socio-economic indicators that emphasize credibility, legitimacy and salience.

Cities are experiencing the impacts of climate change through water-related issues while the sustainable management of water resources remains crucial for urban climate resilience. Accordingly, frameworks that integrate urban water management with climate change adaptation become increasingly relevant (Ozerol et al. 2020). Despite the lack of integrated tools and frameworks to assess urban resilience (Marana et al. 2019), several approaches that focus on water management and governance have been developed in recent years. These methods either focus on sustainability in a broader sense, at national or international level (SDGs 2018; ND-Gain 2020; Green City Index 2012) or are rather specifically focussed on drinking water and sanitation (IB-NET 2017). Little empirical work however addresses assessments of urban IWRM with the aim of strengthening the science-policy dialogue. The City Blueprint methodology provides an empirically-based holistic insight in water security in cities and is being tailored to the African context unlike most other methodologies.

At present, there is no internationally standardized indicator framework for urban IWRM. The 'City Blueprint' approach brings together three frameworks (Koop and van Leeuwen 2015a; Koop et al., 2017). It is a first attempt and aims to enhance the transformation towards water-wise cities by city-to-city learning (Koop and van Leeuwen 2015b). The City Blueprint Approach provides a platform in which cities can share their best practices and learn from each other (Koop and van Leeuwen 2017).

In order to strengthen the capacity of African cities in addressing climate change, urbanisation and becoming water secure, two factors can be identified as potential game changers. Firstly, it is important to obtain a transparent, comprehensive and policy-oriented understanding of the current status of urban water challenges such as too little, too much and too polluted water. Secondly, the role of independent young professionals can play as the main drivers in proving such a science-policy dialogue. In order to seize these opportunities, this study aims to identify capacity-development priorities for strengthening urban water security in Africa by enhancing and empowering the abilities of young professionals to achieve measurable and sustainable results through an indicator-based integrated assessment and further policy-dialogues. As such, the case studies have been led by a gender-balanced group of young professionals in five cities: Abuja (Nigeria, conducted by Mr. H. Ozoani), Bangui (Central African Republic, conducted by Mrs. V. Grekonzy), Harare (Zimbabwe, conducted by Mrs. G. Mukwirimba and T. Marekwa), Libreville (Gabon, conducted by Mrs. G. Ovenga) and Yaoundé (Cameroon, conducted by Mr. I. Abdoulahi).

2. Methodology and Materials

Realising sustainable urban water cycle services in municipalities and regions is a crucial step to achieving urban water security. The consequences of climate change and rapid urbanisation rate in sub-Saharan cities leave them with no option but to grasp which elements of the water cycle are sustainable and which need to be improved. For any strategic planning process, the baseline assessment is a crucial first step to take. It should be conducted before the actual interventions start to serve as a benchmark to determine priorities, set goals and monitor progress (Fig. 1).

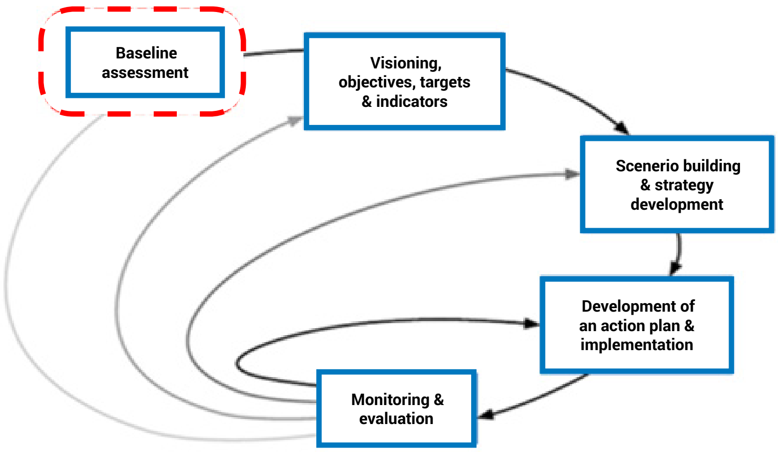


Figure 1. The City Blueprint Approach as the first step in the strategic planning process of municipalities and regions.

The assessment of the sustainability of IWRM was carried out, using the City Blueprint Approach in five African cities to give insights of their strengths, weaknesses and to give recommendations based on the analysis of the cities. The City Blueprint Approach is an ideal and practical communicative tool for any city that wants to transition to a water-wise city.

2.1 Assessment frameworks

The City Blueprint Approach is a diagnosis tool and consists of three complementary frameworks. The main challenges of cities are assessed with (1) Trends and Pressures Framework (TPF): https://library.kwrwater.nl/publication/61396712/. How cities are managing their water cycle is done with (2) the City Blueprint Framework (CBF): https://library.kwrwater.nl/publication/61397318/. Where cities can improve their water governance is done with (3) Governance Capacity Framework (GCF): https://library.kwrwater.nl/publication/61397218/.

2.1.1 Trends and Pressures Framework (TPF)

The TPF has a total of 24 indicators divided into four main categories which are: social, environmental, financial pressures and the fourth category, i.e., the World Bank governance indicators (Table 1).

Table 1. Overview of the TPF categories and indicators

Category	Indicators	
I. SOCIAL	1 Urbanization rate	
	2 Burden of disease	
	3 Education rate	
	4 Female participation	
II ENVIRONMENTAL	Flood risk	5 Urban drainage flood
		6 Sea level rise
		7 River peak discharges
		8 Land subsidence
	Water scarcity	9 Freshwater scarcity
		10 Groundwater scarcity
		11 Sea water intrusion
	Water quality	12 Biodiversity
	Heat risk	13 Heat island
	Air quality	14 PM2.5/10
III FINANCIAL	15 Economic pressure	
	16 Unemployment rate	
	17 Poverty rate	
	18 Investment freedom	
IV GOVERNANCE	19 Voice and accountability	
	20 Political stability	
	21 Government effectiveness	
	22 Regulatory quality	
	23 Rule of law	
	24 Control of corruption	

The 24 TPF indicators are standardized to a scale of 0-10 and divided in ordinal classes expressed as a 'degree of concern' as shown in Table 2.

Table 2. Scoring of the TPF indicators as degree of concern

TPF indicator score	Degree of concern
0 – 2	no concern
2 – 4	little concern
4 – 6	medium concern
6 – 8	Concern
8 – 10	great concern

2.1.2 City Blueprint Framework (CBF)

The CBF framework consists of 24 indicators divided over seven main categories: I basic water services, II water quality, III wastewater treatment, IV water infrastructure, V solid waste, VI climate robustness and VII plans and actions (Table 3). In the application of the CBF, 24 indicators are standardized according to a scale of 0-10 in which 10 points implies an excellent score and 0 points indicates a high improvement potential. This is done by comparing the values from an international range, using natural boundaries of 0 and 100% or by using ordinal classes. Often the min-max method is applied exemplified in equation 1:

$$\frac{value - minimum\ value}{maximum\ value - minimum\ value}\ X\ 10 = \text{Indicator score} \qquad (1)$$

For a detailed explanation of the indicators scores, one can consult the online questionnaire: https://library.kwrwater.nl/publication/61397318/.

Table 3. Indicators of the CBF

Category	Indicator
I. Basic water services	1 Access to drinking water
	2 Access to sanitation
	3 Drinking water quality
II. Water Quality	4 Secondary WWT
	5 Tertiary WWT
	6 Groundwater quality
III. Wastewater treatment	7 Nutrient recovery
	8 Energy recovery
	9 Sewage sludge recycling
	10 WWT energy efficiency
IV. Water infrastructure	11 Stormwater separation
	12 Average age sewer
	13 Water system leakages
	14 Operation cost recovery
V. Solid waste	15 MSW collected
	16 MSW recycled
	17 MSW energy recovered
VI. Climate adaptation	18 Green space
	19 Climate adaptation
	20 Climate-robust buildings
VII. Plans and actions	21 Management & action plans
	22 Water efficiency measures
	23 Drinking water consumption
	24 Attractiveness

2.2 Research method and case study description

Through a collaboration between KWR Water Research Institute and UNESCO Headquarters and five Field Offices, local young professionals with a background in water & environmental sciences have been supported to conduct this research in the city of Abuja (Nigeria), Bangui (Central African Republic), Harare (Zimbabwe), Libreville (Gabon) and Yaoundé (Gabon) (Fig. 2). The young professionals collected data on the key social, environmental and financial trends and pressures that can limit good water management – as well as the data needed for carrying out the City Blueprint assessments of water management performance. As a next step, a governance capacity analysis was conducted in Libreville and Yaoundé to identify the capacity-development priorities.

Figure 2. Map showing the 5 African cities on Africa's map

The assessments began in September 2019 and were completed in February 2020. To kick-off the assessments the young professionals were introduced to the CBA and had to read through the CBA reading materials on its rationale, methodology and applications. This was a good exercise as it provided good insight about their intended project. Simultaneously, the young professionals engaged in desktop research to complete the frameworks. The young professionals searched for the data through consulting public reports, websites, policy documents or scientific studies leading to preliminary scores of the indicators for which information was publicly available. The data for the assessments were gathered in two successive steps. First, an extensive literature study was carried out to determine the preliminary scores for all the indicators. Secondly, data collection interviews were carried out with municipalities and other relevant local stakeholders. An online webinar was organised by UNESCO headquarters and KWR Water Research Institute to present the methodology to be followed and instructions on conducting the assessment. The webinar provided an opportunity for questions the young professionals had, to be answered. Data collection interviews were carried out with municipalities and other relevant stakeholders. The young professionals were in regular contact with KWR and UNESCO headquarters for support in this process. In addition to the kick-of webinar, feedback sessions for each city were organised to go through every detail and discuss how to deal with methodological and practical barriers. Processing and analysis of the collected data following the CBA guidelines and development of reports was done.

An urban water security workshop was organised with the aim of jointly developing a roadmap for delivering water security in African cities based on the baseline assessment outcomes of the work implemented in the five cities. The workshop kicked off with keynote speeches, setting the scene for the discussion, by Dr. Callist Tindimugaya from the Ugandan Ministry of Water and Environment, and IWA Executive Director professor Kala Vairavamoorthy (KWR 2020). Presentations were prepared by the young professionals which they presented at the workshop together with their key recommendations to the local authorities. The workshop marked the beginning of a network of cities and the development of a city-to-city programme on water security. City workshops took place in each of the cities with local decision-makers, the results, recommendations and most viable solutions were presented. This was followed by discussions on how the cities can best improve their water management.

The study is now expanding with the assessment of Windhoek in Namibia as the goal is to include all African capitals to make sure no one is left behind. The young experts from Harare, already trained, are also supporting the Namibia initiative in a logic of training of trainers which ensures sustainability of the programme.

3. Results

The main findings of the five African Cities (Abuja, Bangui, Harare, Libreville and Yaoundé) are provided in this chapter.

Table 4. Case study brief description of each of the 5 African cities (population, population growth rate, climate & elevation, source of water, key stakeholders consulted)

City Name	Description	Key stakeholders consulted
Abuja (Nigeria)	Nigeria's Capital, Abuja City lies 477m above sea level and falls within latitude 745' and 739', and the climate is basically tropical. United Nations figures showed that Abuja grew by 139.7% between 2000 and 2010, making it the fastest growing city in the world. It currently has an estimated population of around 3.3 million people. Abuja receives part of its drinking water supply from the lower Usuma dam located in Bwari area council of the federal capital territory (https://www.watertechnology.net).	Federal Capital Territory water board Federal Capital Territory administration Abuja Environmental Protection Board ·Nigeria Integrated Water Resources Management Commission
Bangui (Central African Republic)	Bangui is the capital and largest city of the Central African Republic. As of 2012, the city had an estimated population of 734,350. Population growth is 2.14%/year, based on the 2019 population. According to Wikipedia Bangui has an elevation of 369 m. It has a tropical savanna climate (Köppen) with dry winters. The source of drinking water is the Oubangui River SODECA, boreholes.	Ministry of Energy and Water Resources Ministry of Urban Planning National Rural Water and Sanitation Agency Ministry of Public Health Water distribution company in Central Africa Department of the Public Service. Ministry of Planning and Economy National Water Agency
Harare (Zimbabwe)	Harare is the capital and most populous city of Zimbabwe. Population size of Harare increased from 1.87 million in 1997 to 2.24 million in 2014 growing at an average annual rate of 4.67%. Harare has an average population of 1.53 million people (excluding the satellite towns) in 2020 and estimated growth rate of 0.59% from 2019.It lies at an elevation of 1,483 metres and has a subtropical highland climate, temperate climate. Harare obtains raw water from four impoundments on the Manyame River. These are Harava and Seke dams which supply Prince Edward treatment works, and Chivero and Manyame dams which supply Morton Jaffray treatment works.	Harare city council Environmental Management Agency Zimbabwe National Water Authority Zimbabwe Statistics Agency Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement UNICEF Zimbabwe
Libreville (Gabon)	Libreville is the capital and largest city of Gabon. As of the 2013 census, its population was 703,904. It has an equatorial, hot and humid climate, characterised by very high rainfall (2000 to 3800 mm) and a large number of rainy days ranging from 170 to 200.	National Anti-Pollution Centre National Climate Council General Directorate of Water General Directorate of the Environment and Nature Protection The Heritage Society The Institute of Hygiene and Public Health

City Name	Description	Key stakeholders consulted
Yaoundé (Cameroon)	Yaoundé is the capital of Cameroon, with a population of more than 2.8 million, the second-largest city in the country after the port city Douala. The population of the greater metropolitan area is around four million and the urban area grows at a rate of 6%, based on data of 2006. It lies in the Centre Region of the nation at an elevation of about 760 metres above sea level. The climate is of an equatorial type with an average temperature of 23.5°C.	7 municipalities that comprise the city of Yaoundé. Ministries in charge of water and energy, environment and sustainable development, scientific research, transport, housing and urban development private sector companies, managers of water treatment plants (INGEPRES and SOPREC) and ANT-Cmr

3.1. Results of the Trends and Pressures Framework (TPF)

The Trends and Pressures Analyse for the five African cities have been provided and scores have been calculated and reviewed and are provided in Table 5. The TPF results show that the social, environmental, financial and governance challenges are substantial which form less favouring conditions for water management performances. In particular, economic, and social pressures such as a high burden of disease and limited female participation in paid jobs stand out. The Trends and Pressures Index (TPI), the arithmetic mean of the 24 indicators of the TPF of five cities are: Abuja (5.5), Bangui (5.1), Harare (4.9), Libreville (5.1) and Yaoundé (5.2). This means that cities face considerable social, environmental, financial and governance pressures that can affect their local water management.

For Abuja, all the current values of indicator 21 (government effectiveness), indicator 22 (regulatory quality), indicator 23 (rule of law) and indicator 24 (control of corruption) are all of concern and great concern. Accordingly, Abuja's water management can be hindered by these governance issues. Therefore, there is a need for early intervention with the relevant authorities in the Nigerian water sector to correct this situation and gradually eliminate its detrimental impact on the overall water management of the Federal Capital Territory. For Bangui, the results show a multitude of high concerns related to the burden of disease, education, air quality, economic pressure, poverty, political stability, effective government, and rule of law. The Harare results show a high level of concern in terms of burden of disease, education, economic pressure and regulatory quality. Many other World Bank governance indicators (indicators 19-24) also attracted high concern. Libreville has two major concerns in the areas of education and unemployment. Many other governance indicators (indicators 19-24) of the World Bank are also of concern. For Yaoundé, nine indicators have "serious concern" in the areas of burden of disease, education rate, vulnerability to river floods, land subsidence, air quality, economic pressure and political instability. These pressures can hamper the efforts of water managers to provide good urban water services, as measured by CBF. Table 5 provides the assessment scores of the five sub-Saharan African cities that have been assessed in this study.

Table 5. Overview of the Trends and Pressures Framework (TPF) of Abuja (Ab), Bangui (Ba), Harare (Ha), Libreville (Li), Yaoundé (Ya). Great concerns are depicted in bold

Category	Indicators	Cities				
		Ab	Ba	Ha	Li	Ya
I Social	1 Urbanization rate	9.3	5.5	4.8	5.7	7.8
	2 Burden of disease	10.0	10.0	9.0	7.0	9.3
	3 Education rate	9.4	9.7	9.7	9.9	9.3
	4 Female participation	5.2	3.4	2.1	5.4	2.8
II Environmental	5 Urban drainage flood	6.9	5.3	7.5	10.0	10.0
	6 Sea level rise	0.0	0.0	0.0	10.0	10.0
	7 River peak discharges	0.0	0.0	0.0	0.0	0.0
	8 Land subsidence	0.0	0.0	0.0	10.0	10.0
	9 Freshwater scarcity	0.0	4.0	0.0	0.0	0.0
	10 Groundwater scarcity	0.0	2.5	0.0	0.0	0.0
	11 Sea water intrusion	0.0	0.0	7.5	0.0	0.0
	12 Biodiversity	3.0	3.2	2.9	5.8	5.8
	13 Heat island	4.8	5.0	5.0	0.0	0.0
	14 PM2.5/10	8.9	2.9	2.9	10.0	10.0
III Financial	15 Economic pressure	9.8	10.0	9.8	7.6	9.9
	16 Unemployment rate	4.0	1.4	2.1	10.0	1.2
	17 Poverty rate	8.9	10.0	5.7	0.6	4.0
	18 Investment freedom	5.5	5.5	7.5	4.0	7.0
IV Governance	19 Voice and accountability	5.8	7.4	7.3	6.9	7.2
	20 Political stability	9.4	9.6	6.4	5.5	9.6
	21 Government effectiveness	7.0	8.4	7.4	6.6	8.4
	22 Regulatory quality	6.8	7.7	8.2	6.8	6.6
	23 Rule of law	6.8	8.4	7.5	6.4	7.2
	24 Control of corruption	7.1	7.5	7.4	6.7	7.3

3.2 Results of City Blueprint Framework (CBF)

The City Blueprint Framework for Abuja, Bangui, Harare, Libreville and Yaoundé have been provided, scores have been calculated and reviewed and are provided in Table 6.

The Blue City Index (BCI) scores which are the overall performance levels of the five cities based on their CBF indicator scores: Abuja (2.3), Bangui (1.9), Harare (3.7), Libreville (2.5) and Yaoundé (2.4). Cities can be ranked according to the BCI scores assigned to each of them. Four cities with BCI scores between 2 and 4, are classified as wasteful cities, except for Bangui with a score of 1.9, are classified as cities with insufficient basic water services. All the cities scored high in terms of water consumption. High water consumption means that the residents of these cities do not consume a lot of water.

For Abuja, new measures should particularly address CBF indicators with a score from 0 to 4. These priorities are related to wastewater treatment, reduction of leakages and solid waste management. Increased government financial support for worker training and capacity building for these priority areas will be highly advantageous. Development of more creative and sustainable urban water management and record-keeping practices that are consistent with global best practices would help improve the current situation.

Bangui shows high scores in terms of drinking water quality, average age of sewers, leaks in the water system, solid waste collected, green spaces and consumption of drinking water. On the other hand, there are enormous challenges in drinking water supply, treatment of wastewater and collecting and treating solid waste.

Table 6. City Blueprint Framework's scores of Abuja (Ab), Bangui (Ba), Harare (Ha), Libreville (Li) and Yaoundé (Ya)

Category	Indicator	Cities				
		Ab	Ba	Ha	Li	Ya
I Basic water services	1 Access to drinking water	4.0	3.0	6.5	5.5	6.8
	2 Access to sanitation	9.7	2.8	7.0	4.8	9.3
	3 Drinking water quality	9.5	9.3	9.4	9.9	4.8
II Water quality	4 Secondary WWT	2.1	4.6	6.0	0.0	3.5
	5 Tertiary WWT	0.3	0.0	6.0	0.0	0.0
	6 Groundwater quality	2.9	2.0	5.3	9.0	4.9
III Wastewater treatment	7 Nutrient recovery	0.0	0.0	0.0	0.0	0.0
	8 Energy recovery	0.0	0.0	0.0	0.0	0.0
	9 Sewage sludge recycling	9.7	0.0	2.50	0.0	0.1
	10 WWT energy efficiency	0.0	2.0	2.0	0.0	0.0
IV Water infrastructure	11 Stormwater separation	10.0	0.0	10.0	0.0	0.0
	12 Average age sewer	6.0	9.6	0.0	5.0	4.2
	13 Water system leakages	0.3	8.0	4.30	0.1	8.8
	14 Operation cost recovery	2.7	6.0	3.9	9.3	5.4
V Solid waste	15 Solid waste collected	1.9	10.0	8.50	9.4	7.7
	16 Solid waste recycled	0.0	0.0	1.0	2.0	0.2
	17 Solid waste energy recovered	0.0	0.0	0.0	0.0	0.1
VI Climate adaptation	18 Green space	4.4	10.0	10.0	10.0	1.3
	19 Climate adaptation	4.0	5.0	6.0	9.0	7.0
	20 Climate-robust buildings	0.0	0.0	7.0	5.0	7.0
VII Plans and actions	21 Management and action plans	2.0	4.0	6.0	7.0	7.0
	22 Water efficiency measures	5.0	4.0	4.0	5.0	7.0
	23 Drinking water consumption	10.0	10.0	8.90	10.0	9.3
	24 Attractiveness	4.0	1.0	4.0	4.0	6.0

The Harare results show that drinking water quality, stormwater separation, green space, solid waste collected and drinking water consumption indicators achieve high results. On the other hand, there are great challenges in wastewater treatment, solid waste treatment and the average age of sewer.

Libreville scores well on drinking water quality, groundwater quality, operating cost recovery, solid waste collection, green space, climate adaptation and drinking water consumption. However, it is clear from table 6 that access to sewage facilities, wastewater treatment and solid waste management are the main challenges facing the city.

Yaoundé scores highly on issues such as access to sanitation, solid waste collection, climate adaptation, water system leakages and drinking water consumption. However, it is clear that stormwater separation, wastewater treatment and solid waste management are the main challenges facing the city shown in table 6.

The City Blueprint indicators that indicated the largest room for improvement in the five cities relate to wastewater treatment, solid waste collection and treatment as well as infrastructure planning. Recommendations were drafted and viable solutions for the cities were proposed based on the CBF results. One of the major recommendations is the need for capacity building and dialogues between the government, city's officials, municipalities and other relevant stakeholders to promote unity, in order to find solutions to current and future problems in their urban water cycle services.

4. Discussions

4.1 Sub-Saharan African cities in transformation

It is evident that sub-Saharan African cities will undergo an unprecedented transformation in the coming decades. Water management will be at the core of this intriguing transformation that will shape the lives of hundreds of millions of people. However, little systematic empirically-based studies have focussed on urban transformations. Based on a qualitative historical analysis of Australia's urban water management (Brown et al. 2009) identified six cumulative stages of urban transition: the water supply city, the sewered city, the drained city, the waterways city, the water cycle city, and the water sensitive city. A similar categorisation has been proposed by (Koop and Van Leeuwen 2015b) based on the CBF assessment of 45 cities across the globe (Table 7).

Table 7. Levels towards water wisdom based on 45 City Blueprint assessments (Koop and Van Leeuwen 2015b)

BCI	Categorization of IWRM in cities
0 – 2	Cities lacking basic water services Access to potable drinking water of sufficient quality and access to sanitation facilities are insufficient. Typically, water pollution is high due to a lack of WWT. Solid waste production is relatively low but is only partially collected and, if collected, almost exclusively put in landfills. Water consumption is low but water system leakages are high due to serious infrastructure investment deficits. Basic water services cannot be expanded or improved due to rapid urbanization
2 – 4	Wasteful cities Basic water services are largely met but flood risk can be high and WWT is poorly covered. Often, only primary and a small portion of secondary WWT is applied, leading to large scale pollution. Water consumption and infrastructure leakages are high due to the lack of environmental awareness and infrastructure maintenance. Solid waste production is high and waste is almost completely dumped in landfills
4 – 6	Water efficient cities Cities implementing centralized, well-known, technological solutions to increase water efficiency and to control pollution. Secondary WWT coverage is high and the share of tertiary WWT is rising. Water efficient technologies are partially applied, infrastructure leakages are substantially reduced but water consumption is still high. Energy recovery from WWT is relatively high while nutrient recovery is limited. Both solid waste recycling and energy recovery are partially applied. These cities are often vulnerable to climate change, e.g., urban heat islands and drainage flooding, due to poor adaptation strategies, limited stormwater separation and low green surface ratios.

BCI	Categorization of IWRM in cities
6 – 8	Resource efficient and adaptive cities WWT techniques to recover energy and nutrients are often applied. Solid waste recycling and energy recovery are largely covered whereas solid waste production has not yet been reduced. Water efficient techniques are widely applied and water consumption has been reduced. Climate adaptation in urban planning is applied e.g., incorporation of green infrastructures and stormwater separation. Integrative, centralized and decentralized as well as long-term planning, community involvement, and sustainability initiatives are established to cope with limited resources and climate change.
8 – 10	Water wise cities There is no BCI* score that is within this category so far. These cities apply full resource and energy recovery in their WWT and solid waste treatment, fully integrate water into urban planning, have multi-functional and adaptive infrastructures, and local communities promote sustainable integrated decision making and behaviour. Cities are largely water self-sufficient, attractive, innovative and circular by applying multiple (de)centralized solutions.

Most sub-Saharan African cities, including the five cities assessed in this paper, seem to be transforming from a city lacking basic water services towards wasteful cities. However, the identified levels towards water-wisdom are far from optimal and reveal a process of problem-shifting that has happened in many cities across the globe (Koop 2019). Problem-shifting refers to a process where a management solution results in the creation of new problems. Patterns of problem-shifting have been observed in the 45 City Blueprint assessments across the full range of water management performances. First, cities that improve the access to basic water services tend to shift their problems towards strong pollution since treatment of the resulting waste streams is often unaccounted for. Second, cities that invest in pollution control, tend to become highly invested into waste management and wastewater treatment that does not account for the emerging scarcity of raw materials. In many cases, Africa's traditional small-scale circular economy approaches are being replaced with large-scale efficient but also linear systems (Ddiba et al. 2020). Third, many cities achieve full access to basic water services and improve their pollution control, but have largely disregarded the key role that water has in the spatial adaptation to climate change related challenges of water scarcity, flood risk management and water quality.

Given the unprecedented growth of sub-Saharan African cities, it seems that sSAC can simply not afford to go through the same transformation process as many European, American and Australian cities have gone through in the past centuries. Hence, the challenge is to leapfrog this array of at least partly avoidable problems. This paper has provided an integrated empirically-based assessment of water management in Abuja, Bangui, Harare, Libreville and Yaoundé which includes key facets such as access to potable drinking water and sanitation, solid waste management, water infrastructure management, urban planning, and wastewater treatment. The results of this integrated assessment enable the identification of water management priorities that may help other sub-Saharan African Cities too in leapfrogging their city towards a higher level of water wisdom.

Improve access to sanitation and wastewater treatment simultaneously

Drinking water consumption is rather low (and thus, scores high) and the drinking water generally complies with local quality standards. Another positive observation is that the share of green area in these cities is moderately high. On the other hand, approximately 67% if the population in these cities has access to sanitation facilities (indicator 2) and has to improve substantially in order to prevent the transmission of diseases such as cholera, diarrhoea, dysentery, hepatitis A, typhoid and polio. Efforts to achieve better living conditions have led to substantially more people getting access to sanitation in the form of flush toilets and septic tanks with less people relying on open defecation (Dominguez Torres 2012). However, because of rapid urban growth, the percentage of urban dwellers lacking access to improved sanitation remained relatively unchanged meaning the absolute number of urban dwellers that lack access to sanitation still increases in sub-Saharan African Cities. The pressure is accumulating in these cities. Even more so, the CBF indicators also show that wastewater treatment has a rather low coverage or is non-operational (indicators 4 & 5).

In addition, the recovery of nutrients or energy from wastewater is particularly low (7-10). The unprecedented growth in the number of urban dwellers with access to improved sanitation poses a radical change in the pathway of nutrient emissions in sub-Saharan Africa. Historically, most nutrients have been reused in agriculture or biologically degraded on land. Nowadays, most nutrients directly enter surface waters in high point source concentrations that lead to oxygen depletion and biodiversity loss, threatening drinking water, fishery, aquaculture and tourism services on which many people rely for their daily income and food. Even more so, prolonged episodes of water scarcity and storm events – amplified by climate change – further increase the vulnerability and exposure of cities' inhabitants to polluted water. Africa's nutrient emissions are projected to double or triple over the next 40 years (Ligtvoet et al. 2014). Since access to safe drinking water and sanitation are – for obvious reasons – the top priorities under Sustainable Development Goal 6, most city planners however fail to notice this ongoing water pollution thread in and around their cities. Wastewater treatment can therefore be considered an absolute priority for urban planning.

Long-term investment strategies for drinking water supply

Access to drinking water was on average about 50% in the five cities (indicator 1). Although access to drinking water is projected to increase across sub-Saharan Africa, particularly through increased access to piped water and public taps, unregulated wells and boreholes remain a primary source of drinking water for about a fifth of the urban dwellers (Dominguez Torres 2012). Upfront investments and maintenance costs of public water supply infrastructure is challenging. Accordingly, drinking water leakages or non-revenue water is around 20 to 30% in the five cities assessed (indicator 13). Hence, upfront investments in drinking water infrastructure need to be intertwined with long-term operational financial planning that includes a reasonable salary and professional training of personnel (indicator 14).

Enhance solid waste collection & treatment

Finally solid waste poses significant challenges to the five cities. Overall, the amount of solid waste that is produced is moderate or even low compared to western standards (indicator 15). However, the issue is related to solid waste collection and treatment (indicator 16 & 17). Solid waste recycling or energy recovery from solid waste is limited and open dump landfilling is often the default. Such waste management practices lead to the exposure of waste collectors to toxic materials, large-scale pollution soil, surface and groundwater pollution, and urban flooding due to the clogging of drainage systems by solid waste (Rahmasary et al. 2019; Rahmasary 2020). Such floods in turn can cause or exacerbate vector-borne diseases such as Dengue fever or Malaria. Solid waste collection and treatment can be an opportunity for employment and decreases health costs and social deprivation.

4.2 Urban transformation: Young professionals can make a difference

How to exploit city-to-city learning opportunities?

As the urban population in sub-Saharan Africa is projected to roughly double in size in the next three decades, Africa's urbanisation challenge is at the core of seizing these opportunities. Of the total global infrastructure investment requirements between 2005-2030 (US$ 41 trillion), more than half (US$ 22.6 trillion) is required for water supply, sanitation and wastewater treatment which is more than the combined investment requirements of energy, roads, rail, air and seaports (UNEP 2013). Building Africa's cities of the future poses many opportunities provided that urban planning is supported by independent, interactive, empirical-based and, above all, city-specific assessments of the integrated challenges of water, waste and climate change.

Many cities facing rather similar challenges and the almost unlimited potential of sharing know-how between these cities is widely recognised in academia (e.g. Shefer 2019; Kern and Bulkeley 2009) and put into practice through Transnational Municipal Networks (TMNs) such as C40, 100ResilientCities, the climate alliance and Energy-Cities. TMNs are particularly helpful if there are common regional, national or transnational policies, guidelines and financial stimuli (Gierst and Howlett 2013; Hakelberg 2011; Den Exter et al. 2014; Hawkins et al. 2016). For sub-Saharan Africa, investment banks such as the African Investment Bank form such a stimuli that can connect cities in a common aim as formulated in the seven aspirations as Agenda 2063 which all underpin the essence of inclusive growth and sustainable development of cities (Agenda 2063).

However, the time and effort required to translate general expectations into a specific set of learning targets and activities that can bring about mutual learning between cities, is all too often underestimated. Each city is a network in itself and in order to learn from other city networks, it may be necessary to first identify capacity-development priorities together with local stakeholders. Only then, specific city alliances may be established where various professionals representing different organizations can mutually learn from one another. The City Blueprint methodology demonstrated in this paper might just be such a 'city-matching' methodologies.

The role of young professionals: A win-win-win

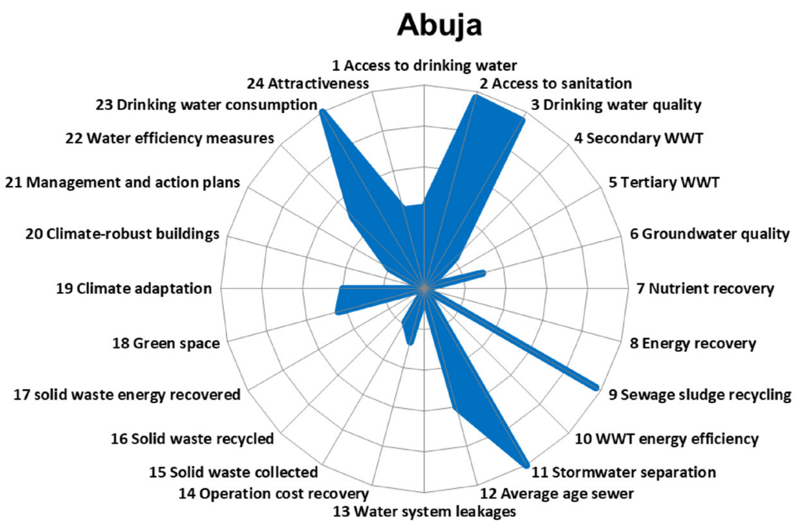
Through our study, it is demonstrated that the application of the City Blueprint Approach by local young professionals is both valuable and feasible because it taps into the almost unlimited potential of local young water professionals across sub-Saharan Africa. The collection of data has typically involved a lot of expert interviews and consultation of policy documents that have not been publicly accessible. The transparent collection and reporting of the data provides an independent, reliable and site-specific database that may attract investors. However, arguably more important, is that it also is a means of co-producing knowledge and overcoming management fragmentation within city-networks. With the support of local UNESCO offices, stakeholder meetings may enable the joint identification of water management priorities by these local stakeholders through the support of independent and integrated assessments. In addition, reassessments every three to five years may help to monitor and jointly evaluate progress. This approach can be repeated and improved across African cities. Based on the resulting data and network building, opportunities for city-to-city learning can be exploited. The reason why this is promising is that many sub-Saharan African cities face very similar challenges. Some of these cities may have developed rather successful programmes and policies. The experiences of these urban planners are invaluable for their professional peers in other cities. The more specific the formulation of improvement priorities and best practices are, the better cities can be matched. The subsequent (temporary) exchange of personnel, joint education and research initiatives or simply the power of a good example, can be a catalyst for improved urban water management and sustainable urban growth. Last but not least, the role that young professionals have in this progress is not to be underestimated. By doing these assessments they qualify themselves to be agents of change. They become professionals with the skills of thinking across organisational boundaries, political mandates and scientific disciplines.

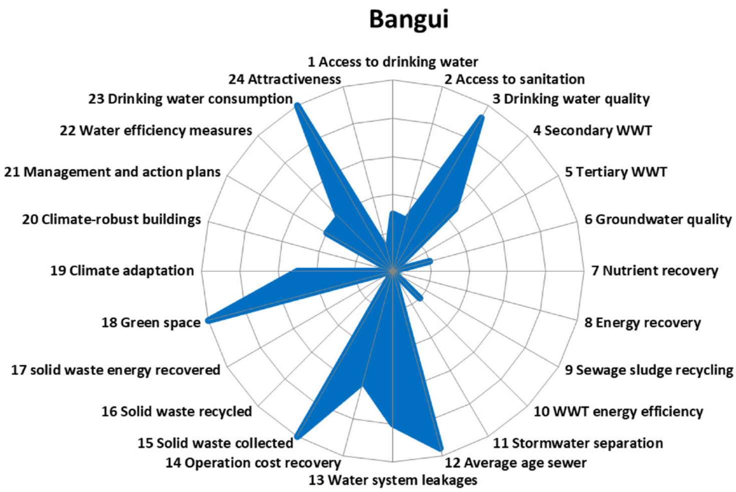
5. Conclusion

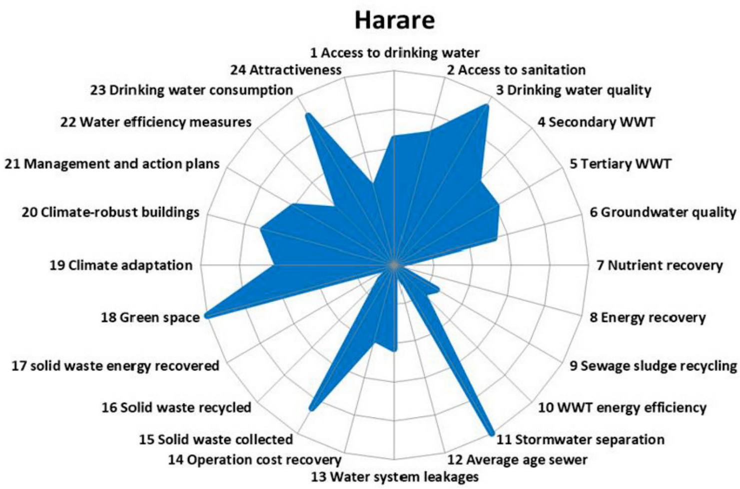
The young professionals were successful in meeting the aim of this study of applying the CBA in five cities and in providing science-policy dialogues. A larger fraction of Africa's population consists of young age groups and the youth should be largely and actively be involved in issues that concern their future. This study also clearly demonstrates the important role that young professionals can take in planning, decision-making and implementation phases of programmes to improve urban water management. They identified priorities for addressing integrated water challenges and went on to facilitate science-policy dialogues. The CBA provided good training on IWRM, water governance and stakeholder involvement by approaching stakeholders in the information phase (data gathering) and follow-up discussions (follow-up science-policy dialogues).

The radar charts of indicator scores for the CBF and the TPF are shown in Figs. 3 and 4 for the five African cities. The TPF (Fig. 4) shows that the social, environmental, financial and governance challenges are substantial which form less favouring conditions for water management performances. In particular, economic pressure and social pressures such as a high burden of disease and limited female participation in paid jobs stand out. The BCI scores which ranges from 0 to 10 gives the overall performance of the five cities based on their CBF indicator scores: Abuja (2.3), Bangui (1.9), Harare (3.7), Libreville (2.5) and Yaoundé (2.4). The improvement options are provided by the CBF indicators that showed the largest room for improvement in the five cities. These indicators relate to wastewater treatment, solid waste collection and treatment as well as infrastructure planning. River flooding, droughts and economic pressures have a great impact on the water sector of African cities. Wastewater treatment can be improved. Often only limited primary and secondary wastewater treatment takes place leading to large-scale pollution. In addition, solid waste collection and treatment are great challenges in African cities.

Recommendations were drafted and viable solutions for the cities were proposed based on the CBF results. These are to be presented in workshops with the cities' top-level decision-makers and other stakeholders, and discussions on options to improve water security are proposed to take place which is an approach to promote integration and unified work of stakeholders, simultaneously ensuring every group is involved in the issues that concern them.




Bangui
1 Access to drinking water
2 Access to sanitation
3 Drinking water quality
4 Secondary WWT
5 Tertiary WWT
6 Groundwater quality
7 Nutrient recovery
8 Energy recovery
9 Sewage sludge recycling
10 WWT energy efficiency
11 Stormwater separation
12 Average age sewer
13 Water system leakages
14 Operation cost recovery
15 Solid waste collected
16 Solid waste recycled
17 solid waste energy recovered
18 Green space
19 Climate adaptation
20 Climate-robust buildings
21 Management and action plans
22 Water efficiency measures
23 Drinking water consumption
24 Attractiveness


Harare
1 Access to drinking water
2 Access to sanitation
3 Drinking water quality
4 Secondary WWT
5 Tertiary WWT
6 Groundwater quality
7 Nutrient recovery
8 Energy recovery
9 Sewage sludge recycling
10 WWT energy efficiency
11 Stormwater separation
12 Average age sewer
13 Water system leakages
14 Operation cost recovery
15 Solid waste collected
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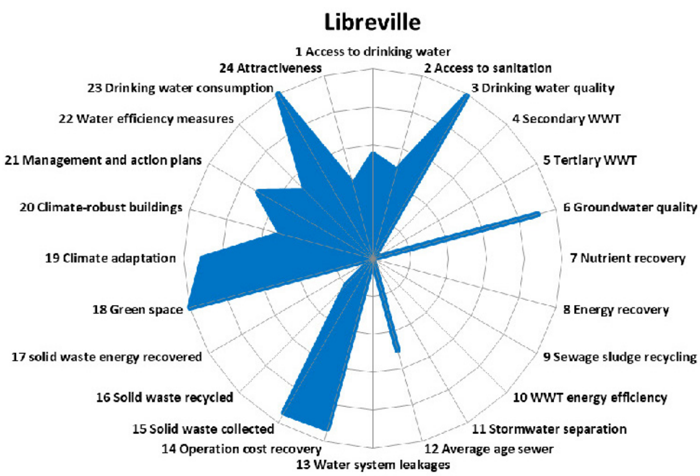
23 Drinking water consumption
24 Attractiveness


Libreville
1 Access to drinking water
2 Access to sanitation
3 Drinking water quality
4 Secondary WWT
5 Tertiary WWT
6 Groundwater quality
7 Nutrient recovery
8 Energy recovery
9 Sewage sludge recycling
10 WWT energy efficiency
11 Stormwater separation
12 Average age sewer
13 Water system leakages
14 Operation cost recovery
15 Solid waste collected
16 Solid waste recycled
17 solid waste energy recovered
18 Green space
19 Climate adaptation
20 Climate-robust buildings
21 Management and action plans
22 Water efficiency measures
23 Drinking water consumption
24 Attractiveness

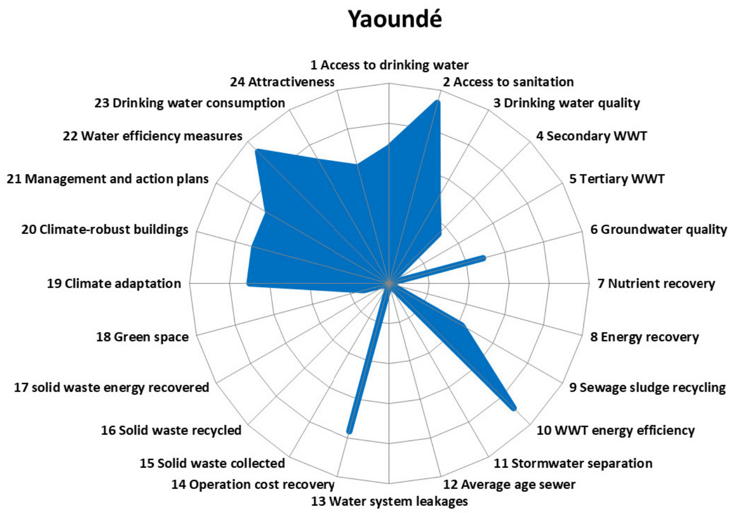
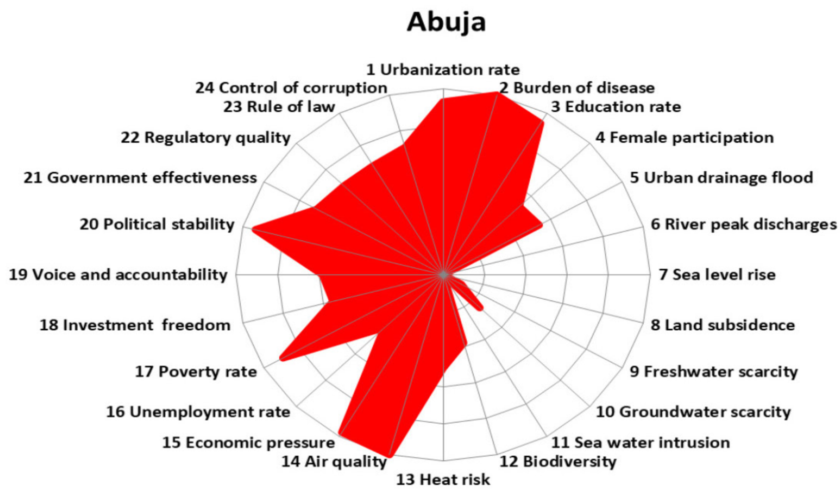
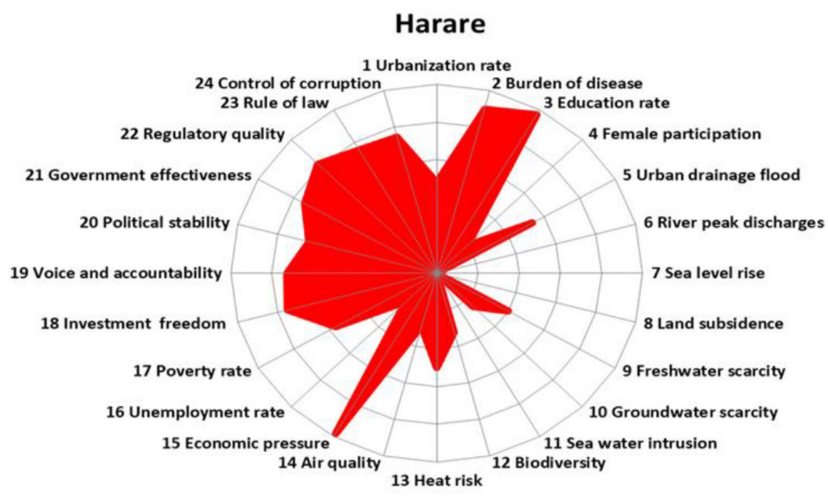
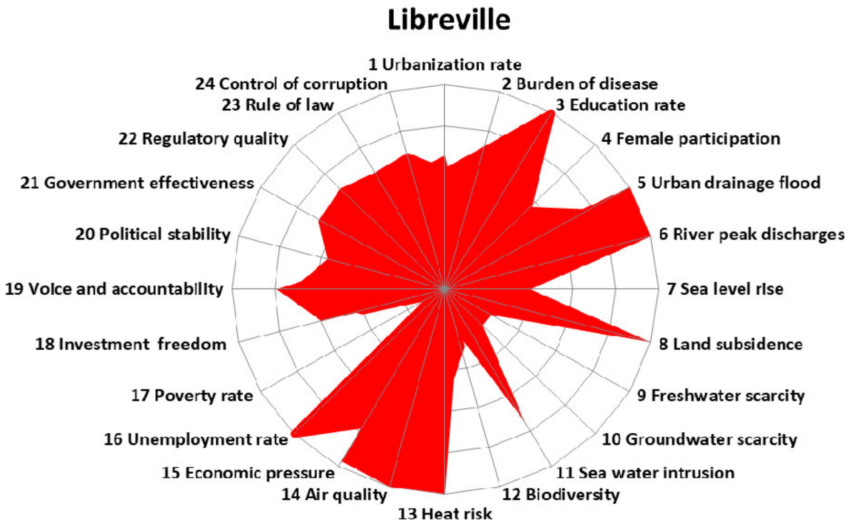


Figure 3. City Blueprints of Abuja (top), Bangui Harare, Libreville, and Yaoundé (bottom), based on 24 performance indicators. The geometric mean of the indicators, i.e., the BCI scores, are, 2.3, 1.9 3.7, 2.5 and 2.4 respectively







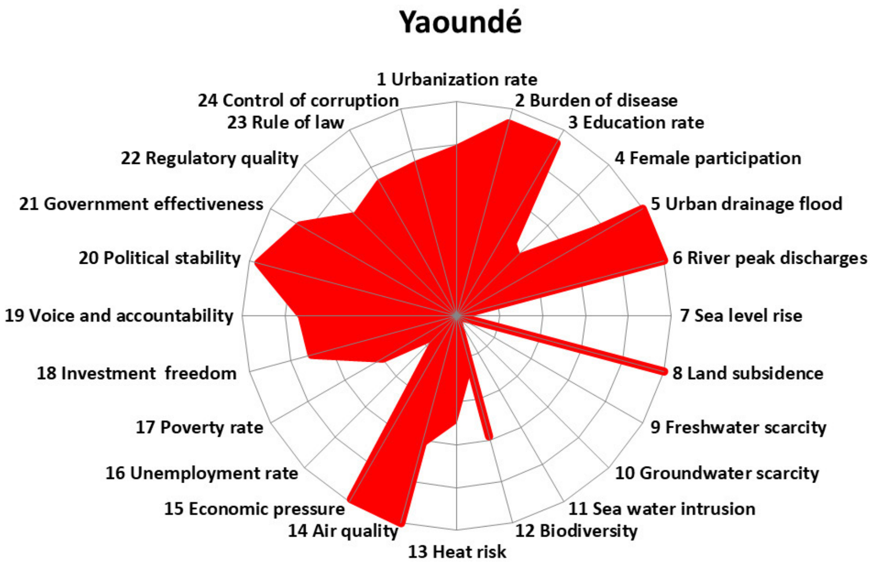


Figure 4. Trends and Pressures radar charts of Abuja (top), Bangui, Harare, Libreville, and Yaoundé (bottom), based on 24 performance indicators. The geometric mean of the indicators, i.e., the TPI scores, are, 5.5, 5.3, 4.9, 5.1 and 6.0 respectively

A workshop on water security in sub-Saharan African cities (Kampala, Uganda; February 2020) took place after the assessments to gather all the authors of the present article. This workshop has allowed to lay out a roadmap for enabling the uptake of the results of the assessments by practitioners and decision-makers in each city and the young professionals were involved in laying the road map that is the planning stage, not only as implementers or mere beneficiaries of the programme. One of the major recommendations was the need for capacity building and dialogues between the government, city's officials, municipalities and other relevant stakeholders to promote unity, in order to find solutions to problems in their urban water cycle services.

Accordingly, policy-dialogues with key stakeholders in each of the five cities have been organised by the young professionals to jointly identify viable solutions to enhance water security. This study in the 5 countries provided successful results showing that upscaling is a necessary next step. This can be organized in collaboration with UNESCO, the University of Bath and KWR. After diagnosis, finding the cure is necessary. This means that the results have to be presented at higher policy or political levels, to discuss the results, discuss the options and decide on investment decisions, if needed. Further steps are needed with relevant stakeholders to accelerate actions to make African cities water wise. In addition, based on the extensive experiences in these five cities, a methodological revision of the indicator assessment has been completed and a guideline for a city-to-city learning alliance has been initiated that has the ambition to include all capital cities in Africa, promoting the Pan-African approach. Africa's seven aspirations as formulated in the Agenda 2063 all underpin the essence of inclusive growth and sustainable development of its cities (Agenda 2063). As the urban population in sub-Saharan Africa is projected to roughly double in size in the next three decades, Africa's urbanisation challenge is at the core of seizing these opportunities. Of the total global infrastructure investment requirements between 2005-2030 (US$ 41 trillion), more than half (US$ 22.6 trillion) is required for water supply, sanitation and wastewater treatment which is more than the combined investment requirements of energy, roads, rail, air and seaports (UNEP 2013). Building Africa's cities of the future poses many opportunities provided that urban planning is supported by independent, interactive, empirical-based and, above all, city-specific assessments of the integrated challenges of water, waste and climate change. Our study demonstrated that such an approach is both valuable and feasible by tapping in the almost unlimited potential of local young water professionals across sub-Saharan Africa.

Disclosures

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References

Agenda 2063. The Africa we want. African Union Commission. ISBN: 978-92-95104-23-5

Brown RR, Keath N, Wong, THF (2009) Urban water management in cities, historical, current and future regimes. Water Science and Technology, 59:847–855

Ddiba D, Andersson K, Koop SHA, Ekener E, Finnveden G, Dickin S (2020) Governing the circular economy: assessing the capacity to implement resource-oriented sanitation and waste management systems in low-and middle-income countries. Earth System Governance. 4:100063

Den Exter R, Lenhart J, Kern K (2014) Governing climate change in Dutch cities: anchoring local climate strategies in organization, policy and practical implementation. Local Environment 9:1062-1080

Dominguez Torres C (2012) The future of water in African cities. Why waste water? The World Bank 74236

Gierst S & Howlett M (2013) Comparative climate change governance: lessons from European transnational municipal network management efforts. Environmental Policy Governance 23:341-353

Green City Index (2012) Siemens' Green Cities Index. https://apps.espon.eu/etms/index.php/this-big-city/qr/534-siemens-green-cities-index [Accessed on 10-11-2020]

Hakelberg L (2011) Governing Climate Change by Diffusion Transnational Municipal Networks as Catalysts of Policy Spread. Forschungszentrum Für Umweltpolitik, Freie Universitaet Berlin, FFU-Report 08-2011

Hawkins CV, Krause RM, Feiock RC, Curley C (2016) Making meaningful commitments: Accounting for variation in cities' investments of staff and fiscal resources to sustainability. Urban Studies 53:1902-1924

IB-NET (2017) The International Benchmarking Network for Water and Sanitation Utilities (IBNET). https://www.ib-net.org/ [Accessed on 10-11-2020]

Kern K & Bulkeley H (2009) Cities, Europeanization and Multi-level Governance; Governing Climate Change through Transnational Municipal Networks. JCMS 47:309-332

Koop SHA & Van Leeuwen CJ (2015a) Assessment of the Sustainability of Water Resources Management: A Critical Review of the City Blueprint Approach. Water Resource Management. 29:5649–5670.

Koop SHA & Van Leeuwen CJ (2015b) Application of the Improved City Blueprint Framework in 45 Municipalities and Regions. Water Resource Management, 29(13):4629-4647

Koop SHA & Van Leeuwen CJ (2017) The challenges of water, waste and climate change in cities. Environmental Development Sustainability 19(2):385–418

Koop SHA (2019) Towards water-wise cities: Global assessments of water management and governance capacities. Dissertation. https://dspace.library.uu.nl/handle/1874/378386 [Accessed 11-10-2020]

KWR (2020) Assessment of urban water management in African cities, KWR Water Research Institute, https://www.kwrwater.nl/en/actueel/assessment-of-urban-water-management-in-african-cities/ [Accessed on 10-11-2020]

Ligtvoet W, Hilderink H, Bouwman A, Puijenbroek P, Lucas P, Witmer M (2014) Towards a world of cities in 2050. An outlook on water-related challenges. Background report to the UN-Habitat Global Report. PBL Netherlands Environmental Assessment Agency

Marana P, Eden C, Eriksson H, Grimes C, Hernantes J, Howick S, Labaka L, Latinos V, Lindner R, Majchzak TA, Pyrko I, Radianti J, Rankin A, Sakurai M, Sarriegi JM & Serrano N (2019) Towards a resilience management guideline — Cities as a starting point for societal resilience. Sustainable Cities and Society 48:101531

Moors E (2020) Welcome to IHE DELFT, IHE DELFT Education and training guide, January 2020, pg. 1, Delft, Netherlands, http://www.un-ihe.org/sites/default/files/ihe-delft_eetguide-2020.pdf [Accessed on 28-11-2020]

Naidoo R & Fisher B (2020) Reset Sustainable Development Goals for a pandemic world. Nature 583:198-201

ND-Gain (2020) https://gain.nd.edu/our-work/country-index/ [Accessed on 10-11-2020]

Özerola G, Dolman N, Bormann H, Bressers H, Lulofs K, Bögec M (2020) Urban water management and climate change adaptation, A self-assessment study by seven midsize cities in the North Sea Region. Sustainable Cities and Society 55, 02066

Rahmasarya AN, Robert S, Chang IS, Jing W, Park J, Bluemling B, Koop S, van Leeuwen K (2019) Overcoming the challenges of water, waste and climate change in Asian cities. Environta Management 63(4):520-535

Rahmasary AN, Koop SHA, Van Leeuwen CJ (2020) Governing Indonesia's urban challenges of water, waste and climate change: Lessons from Bandung. Integrated Environmental Assessment and Management https://doi.org/10.1002/ieam.4334

SDGs (2018) Sustainable Development Goals: Goal 6: Ensure access to water and sanitation for all. https://www.un.org/sustainabledevelopment/water-and-sanitation/ [Accessed on 10-11-2020]

Shefer I (2019) Policy transfer in city-to-city cooperation: implications for urban climate governance learning, Journal of Environmental Policy & Planning, 21:61-75

UN (2018). Africa. Scale 1:1000. Map No. 4045 Rev. 8.1, 2018

UN (2019) World population prospects 2019, https://population.un.org/wpp/

UNEP (2013) United Nations Environmental Programme: City-level decoupling: Urban resource flows and the governance of infrastructure transitions. A report of the working group on cities of the International Resource Panel. Swilling M, Robinson B, Marvin S & Hodson M.

Efficacy of *Moringa Oleifera* Seed Powder as a Bio-coagulant in Purifying Raw Water for Potable Use: A Case Study of Makwa Village in Hwange District, Zimbabwe

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Abstract

Reduced availability of potable water in developing nations has led communities, especially in rural areas, to resort to the use of untreated water sources such as streams and rivers. Chemical coagulants such as aluminiumsulphate are used in primary water treatment. Moringa seed is a biological coagulant used in primary water treatment. The study assessed the efficacy of Moringa seed powder as a coagulant for potable water treatment. Water samples were collected in July 2019 along the Zambezi River from low, middle and upper part of Makwa Village (Katatai, Lowlift Pumping Station and Deka Drum), Analyses for pH, turbidity, sulphates, nitrates, chlorides, biological oxygen demand and total coliforms were done. Nitrates were high at Kataitai and Lowlift Pumping Station. Coliforms were present in all three sites. Powder concentrations of 0.5g/l, 0.10g/l and 0.15g/l were used for primary treatment. There was a significant difference in the sites of the assessed parameters (pH, turbidity, chlorides, biological oxygen demand, nitrates and total coliforms). Sulphates indicated no significance as slight increase was observed. Powder concentration of 0.5g/l followed by 0.10g/l and 0.15g/l was effective in reducing physico-chemical and biological contaminants in untreated water. Results show that seed powder can be effectively used in areas that do not have any means of potable water treatment. It is recommended that this study be performed in summer and winter seasons to detect possible variations in the effective treatment of physico-chemical and biological contaminants. A prototype design using seed powder can be done and tested for efficiency.

Keywords: primary water treatment, Moringa seed powder, physico-chemical contaminants, potable water, Zimbabwe.

1. Introduction

The need for clean and good quality water for human consumption is of prime concern in the world. A major emerging problem in developing nations is the decline in availability of clean water for domestic use (Vieira *et al*., 2010). Raw water from streams and rivers is generally unsafe for human consumption due to the presence of various impurities that pose threatsto human health (Berton*et al*., 2016). Due to possible impurities such as dissolved ions, bacteria and suspended solids of organic matter and clay, raw water must be treated before use for human consumption. According to United Nations International Children's Emergency Fund (UNICEF) 783 million people are without safe drinking water globally (Penn News, 2019).

The provision of clean water for human consumption has become a critical issue in sustainable development. Sustainable Development Goal (SDG) 6 targets the provision of clean water for human consumption globally. The ideal clean water should be clear, and free of pathogens and harmful chemicals. In the provision of clean and safe potable water quality monitoring and surveillance are required. The quality of water must suit World Health Organisation (WHO) potable water guidelines. In Zimbabwe Standard Association of Zimbabwe Potable Water Guidelines must also be met to prevent occurrence of water borne diseases (Hendrawati*et al.*, 2016) and to control the risks to the health of the public (Tunggolou and Payus, 2017).

Inorganic coagulants such as aluminium sulphate and ferric chloride are normally used in conventional water treatment in most African countries. However, these chemicals are expensive for treating water as they are imported and their facilities maintained at high costs (Ali *et al*., 2010). This high expense makes clean water deficit crisis worsen in most Zimbabwe rural communities. Most people in rural areas resort to unsafe water sources without any form of treatment like rivers. Normally these sources will be of low quality, thereby, exposing these communities to waterborne diseases such as cholera, gastro enteritis and typhoid. Irrigation, angling, tourism as well as land development, add to poor water quality.

Use of bio-coagulants for water treatment is emerging as one attractive eco-friendly method that can replace synthetic coagulants. Instead of using chemical coagulants for treating both water and wastewater, organic *Moringa oliefera* seed powder has been studied and patented in India as a natural and inexpensive method of water purification. Several published studies in India have used Moringa seed as adsorbent for the removal of inorganic pollutants and metals in dairy, tannery and leather industrial effluents (Sharma *et al*., 2006; Vieira *et al*., 2010; Murugandam*et al*., 2017). *Moringa oliefera* is a drought-tolerant tree that grows in semi-arid and arid areas (Lea, 2014). The plant is known for its nutritional, medicinal and water cleaning attributes (Maroyi, 2006; Vieira *et al*., 2010). It is reported that *Moringa oliefer*a seeds possess antimicrobial properties and have water soluble, positively charged proteins in their seeds that help treat water (Murugandam*et al*., 2017). It produces positive charges such that when added to raw water it attracts negative elements of bacteria and other toxic substances in raw water making water clean (Sanhez, 2018) and safe to drink.

Makwa Village gets water from the Low and High Lift Zimbabwe Power Company Pumping Station and the villagers have been experiencing shortages of potable water from 2016 to date due to mechanical failure of the water treatment plant. The chlorine and reverse osmosis plants installed by Zimbabwe Power Company in 2012 have ceased functioning. The community which was dependent on treatment plant, has resorted to drawing water from Zambezi River. Members of the community sometimes travel more than 10 kilometres to fetch clean water for drinking and cooking.

Little is known about the use of Moringa seed powder as a coagulant in most Zimbabwean rural communities. This is because little work has been published on its beneficial effects, especially in areas where it is readily available. There is therefore, a dire need for addressing this critical clean water shortage with locally available natural methods. The use of *M. oliefera* seed powder for treatment of water can be an affordable and viable approach. Moringa is readily available in Hwange communities. The detrimental human health effects and impacts associated with consuming raw water from the river will be minimized. It is in this light that the study was carried out to assess the efficacy of *Moringa oliefer*a seed powder in cleaning river water impurities for potable use for Makwa rural community.

The findings would help determine the actual dosage of *Moringa* seed powder that can be utilised for water purification. Despite the mechanical failure of the water treatments plants at Makwa Village, the community can temporarily access locally available *Moringa* seed powder and use it for treating raw water. Cases of water borne illnesses and deaths, especially cholera, were reported in the country in 2018, with Harare being the epicentre of the problem as a result of using untreated water (Voice of America, 2018). The study was to assess efficiency of Moringa seed powder concentration for water purification. Using *M. oliefera* seed powder as a water purification agent could be a low cost and sustainable method of treating raw water. Beside the Makwa community, other communities that are struggling to access clean and safe drinking water can benefit from a process that treats raw water using available simple traditional method of *Moringa oliefera* seed powder. Numerous detrimental effects associated with consumption of untreated river raw water such as typhoid and cholera can be reduced.

2. Materials and methods

2.1. Study site description

The study area is Makwa Village, in Hwange District, Matabeleland North Province. It is located approximately forty-five kilometres, north east of Hwange Town at coordinates 18º045´8.9"S 26º41´49.9"E and is 770 metres above sea level. The study area is characterised by hot, wet summers that extend from November to March. The rainfall patterns are erratic with annual rainfall estimated at less than 500mm. The average temperature during the summer months is between 32 ^{0}C and 34 ^{0}C and in winter, between 25 ^{0}C and 27 ^{0}C (Meteorological Organisation, 2017). The population of the study area is estimated to be above 1000. The village is located along the Zambezi River. Thus, the population is dependent on the river for various water uses. Many anthropogenic activities occur along the river, including canoeing, mining, fishing, livestock keeping and farming. The area is good for livestock production, and many gardens are dotted around the river. The area has two irrigation schemes: Makwa and Chezya irrigation schemes located one and seven kilometres respectively, away from the ZPC Pumping Plant. This study focused on Makwa Village because of the critical shortages of potable clean water that is experienced and availability of *Moringa oliefera* tree species there. Figure 1 shows the location of Makwa Village and three water sampling points.

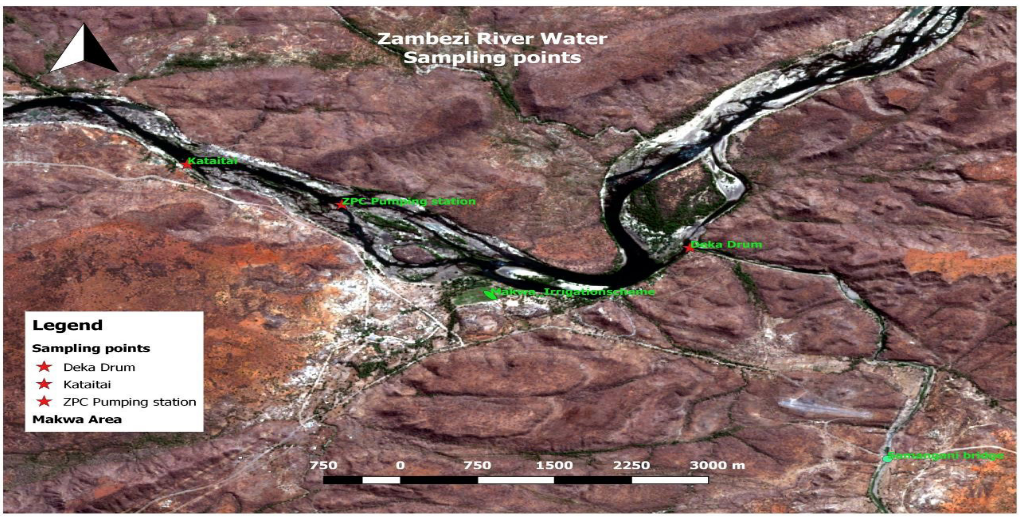

Figure 1. The Kataitai, Zesa Pumping Plant and Deka Drum water sampling points on the Zambezi River, Zimbabwe. Source: Google Earth Base map accessed on date 17th July, 2019.

2.1.1. Study type design

Surface water from the Zambezi River was collected using the grab sampling method. The experiment was set up following a complete block randomised design 3 x 4 replicated 4 times. The blocking factor was three sites of water collection along Zambezi River at three levels in Makwa area. The sites are Kataitai18.061471; 26.655766 (upper stream), Lowlift Pumping

Station in the middle (-18.0667; 26.67) and Deka Drum Resort (-18.07229; 26.702049) downstream along the Zambezi River in Makwa Village (*Figure 1*). Moringa seed powder concentrations used as bio-coagulant were 0.05g, 0.1g and 0.15g per 1000ml. Samples of river water from each site were treated using the three bio-coagulant concentrations of 0.5g/l,0.10g/l and 0.15g/l randomly assigned.

2.1.2. Preparation of *Moringa oliefera* seed powder

Brown dried mature *Moringa* seeds were sourced from different trees located in Hwange Township. Maturity was determined by existence of dried cracked pods (Parisara*et al*., 2018). *Moringa oliefera* seed powder was prepared at Lupane State University laboratory. Seeds were removed from the seed pods, washed in distilled water to remove impurities, and dried at 60 degrees Celsius for 5 days (Bolariwa*et al.,* 2017), in an incubator so as to remove moisture. *Moringa* seeds were de-husked to obtain seed kernels. Discoloured or softened seeds were discarded (Jahn, 1988). Seed kernels were crushed using a mortar and pestle to produce seed powder. A blender was used to produce fine powder. The *Moringa* seed powder was sifted using a King Test laboratory steel sieve (B.S.ISO 3310) with aperture size of 500 micro metre so as to obtain fine powder of high specific surface area to coagulate impurities. The powder was kept in a clean and sterilised container in the laboratory at room temperature, ready for use (Plate 1 and 2).

Plate 1and 2. Preparation of Moringa seed into powder using a blender © Loreen Ndlovu/Mpala Canisius

2.1.3. Water sample collection

Raw water samples were collected along Zambezi River in Makwa Village in July 2019. Sixty litres of river water was collected using the grab sample method at Kataitai, Lowlift Pumping Station and Deka Drum Resort on the Zambezi River for laboratory analysis tests. Raw water for microbial tests was placed into cooler boxes with ice for rapid cooling. Representative water samples were subjected to laboratory analyses tests for physico-chemical and biological parameters (turbidity, biological oxygen demand, chlorine, pH, phosphates, nitrates, sulphates and microbiological analysis tests (total coliforms) at Lupane State University laboratory (Plate 3 and 4).

 

Plate 3 and 4. Water collection sites (Kataitai and Deka Drum) along Zambezi River © Loreen Ndlovu/ Mpala Canisius

2.1.4. Laboratory analysis

Raw water collected along Zambezi River in Makwa, Hwange area, was analysed at Lupane State University laboratory for water parameters (pH, turbidity, biological oxygen demand, chlorides, total coliforms, phosphates, nitrates and sulphates) before and after adding *Moringa* seed powder. Three different concentrations were prepared by weighing 0.05g, 0.1g and 0.15g of *Moringa oliefer*a seed powder (Bakare, 2016), into separate 1000ml graduated glass bottles using Acculab ALC-310.3 analytic balancer.

The efficacy of *Moringa* seed powder coagulant was evaluated following the jar test technique. Using a horizontal shaker, shaking rapidly at 200rpm for 5minutes and slowly at 50 rpm for 10 minutes. River water and *Moringa* seed powder were shaken to allow complete mixing of natural coagulant and to aid ineffective colloidal particles (Bakare, 2016). Samples were replicated four times for variability. Raw water samples were allowed to have a 3hour contact time with the organic coagulant and left undisturbed to settle. Treated water was filtered using Whatman filter paper, size Number 41 and samples were taken for data analysis. The data obtained were used to determine if *Moringa* treated water was within the WHO range of drinking water quality and if Zambezi River was safe as a source for drinking water. Turbidity was measured using Lovibond potable turbidity meter and an electronic pH meter for determining pH. A 5day incubation method was used to test for biological oxygen demand. The Beckman Coulter UV/VIS Spectrometer was used to measure nitrates (nitrate-nitrite correction method), phosphates (Olsen method) and sulphates (turbidometry). Chlorides were determined using Mohr Argentometric method. Total coliforms were assessed using the multiple tube fermentation technique and MPN table was used to know the total bacteria count per 100ml. The laboratory tests were done before and after adding*Moringa* seed powder as from July 2019 to October 2019and the analysis were based on the differences obtained.

2.1.5. Data analysis

The primary data obtained from water laboratory tests using *Moringa* seed powder was subjected to statistical analysis, two-way Analysis of Variance (ANOVA) using Genstat 14. Assumptions of ANOVA were tested using Batlett test for homogeneity of variance at 95% significance level. Normality of data was tested using Shapiro Wilk test. Microsoft Excel 10 programme was used to present data using summary tables.

3. Results

The study is conducted to assess the efficacy of *Moringa oliefera* seed powder as a bio coagulant for the primary treatment of Zambezi River in Makwa, Hwange District. Zambezi River water is tested accordingly before and after treating with powder from mature dried *Moringa* seeds at varying concentrations of 0.5g/l, 0.10g/l and 0.15g/l for several water parameters (pH, turbidity, chlorides, nitrates, sulphates, BOD and total coliforms). Water samples are analysed for these water parameters understudy after a 3-hour contact time. To ensure that this water treatment system produces safe and clean water, the results obtained were compared with World Health Organisation drinking water guidelines.

3.1. Status of physicochemical and biological parameters of water for the three sites along Zambezi River in Makwa area before and after adding *Moringa* seed powder

Water samples collected along Zambezi River at Kataitai, Lowlift Pumping Station and Deka Drum Resort are analysed in Lupane State University laboratory for the physico-chemical and biological parameters before and after adding *Moringa* seed powder and the results obtained are shown in Table 1. Water samples collected in Kataitai and Lowlift Pumping Station have nitrates above the WHO limit and all sites had coliforms, while the other parameters were within the required WHO drinking water range as shown below in Table 1.

Table 1. Physico-chemical and biological characteristics of water before and after adding *Moringa* seed powder

Pollutant/ Parameter	Kataitai		Lowlift Pumping Station		Deka Drum		WHO Drinking Water Guidelines
	Before	After	Before	After	Before	After	
pH	9.14	8.61	9.08	9.12	7.32	6.54	6-9
Turbidity (NTU)	3.48	1.94	4.41	2.67	3.46	2.79	<5 NTU
Chlorine (mg/l)	70.9	44.8	81.6	48.3	46.1	33.2	300 mg/l
BOD (mg/l)	0.33	0.30	0.33	0.21	0.35	0.31	30-100 mg/l
Nitrates (ppm)	87.6	32.9	83.98	22.37	7.54	3.05	50 mg/l
Sulphates (ppm)	0.52	0.81	1.02	-1.23	21.11	24.34	500 mg/l
Total Coliforms (MPM/100ml)	7	7	7	4	17	4	0/100 ml

Before: Before treatment with powder, After: After treatment with powder.

3.1.1. Effect of physico-chemical and biological parameters analysed in response to sites, *Moringa oliefera* seed powder concentrations and interaction of sites and concentrations

The location of water sampling along Zambezi River, efficacy of Moringa seed powder concentrations as a primary treatment for purification of water and their interactions had a significant influence ($p < 0.001$) on the levels of physico-chemical and biological parameters (turbidity, pH, BOD, nitrates, sulphates, chlorine and total coliforms) that were tested after being subjected to Moringa treatment as revealed by the F-test results. Sulphates levels did not differ significantly with concentrations of Moringa powder as highlighted in the (Table 2).

3.1.2. Effect of Moringa oliefera seed powder concentrations, sites and their interaction on Turbidity levels (NTU)

There is a significant difference (p<0.001) in sites, Moringa seed powder concentrations (p<0.001) and their interaction (p=0.02) in reducing turbidity levels in river water. The three sites are significantly different from each other as shown by different letters in Sites $\overline{x}$ in Table 3. Concentrations of Moringa seed powder also shows significant differences in reducing turbidity levels in river water. All water samples from the three locations show a positive response to various Moringa concentrations in reducing turbidity. The concentration of 0.05g/l *Moringa* seed powder is more effective in reducing turbidity in raw water and has the lowest observed mean value of 1.18NTU after treatment.

3.1.3. Influence of sites of water collection and concentrations of *Moringa* seed powder and their interactions on pH

Significant statistical differences (p<0.001) between site of water collection, various concentrations of *Moringa* seed powder and the interaction between the two were noted. *Moringa* concentrations slightly reduced pH in Deka Drum Resort from 7.32 to 6.24 followed by Kataitai (9.14 to 7.87) and in Low Lift Pumping Station (9.08 to 9.07) as shown in Table 4 and Figure 2. Moringa seed powder concentrations of 0.05g/l and 0.15g/l are effective in reducing pH in water across all sites.

3.1.4. Influence of Moringa seed powder concentrations, sites of water collection and their interactions on chlorine (mg/l) levels

There are significant differences (p=0.02) between samples from the three locations and *Moringa oliefera* seed powder doses. Sites (p<0.001) and Moringa powder concentrations (p<0.001) shows a significant difference on chlorine. Chlorine levels decreases after adding different doses of Moringa seed powder in different sites. The Lowlift Pumping Station has the highest initial chlorine of 81.6 mg/l which reduce to 33.5mg/l at a concentration of 0.10g/l. Kataitai site has 70.9mg/l of chlorine which reduces to 31.9mg/l at a concentration of 0.05g/l. Deka Drum Resort has an initial chlorine value of 46.1mg/l that decreases to a value of 23mg/l at concentration of 0.15g/l. The 0.15g/l concentration reduces chlorine levels in all sites followed by 0.05g/l and 0.10g/l doses (Table 5).

Table 4. Table of means for pH after adding *Moringa* seed powder

Moringa seed powder concentrations (g/litre)					
Sites	0.00	0.05	0.10	0.15	Sites $\overline{x}$
Deka Drum Resort	7.32d	6.29e	6.24e	6.32e	6.54c
Kataitai	9.14b	7.89d	9.56a	7.87d	8.61b
Low Lift Pumping					
Station	9.08c	9.07c	9.22b	9.13b	9.12a
Concentrations $\overline{x}$	8.51a	7.75c	8.34b	7.77c	8.09

	Sites	Concentration	S*C
P. value	<0.001	<0.001	<0.001
S.e.d	0.15	0.17	0.29
L.s.d (5%)	0.30	0.34	0.60
CV%	5.1	5.1	5.1

Table 2. Summary of results of ANOVA of water physico-chemical and biological parameters

Parameters		pH		Turbidity NTU		Chlorine mg/litre		Nitrates ppm		Sulphate ppm			BOD mg/litre		Total coliform MPM/100ml
Source of Variation	df	m.s	F.pr	m.s	F.pr	m.s	F.pr	m.s	F.pr	m.s	F.pr	m.s	F.pr	m.s	F.pr
Site	2	29.69	<.001	3.38	<.001	993.17	<.001	3672.23	<.001	3231.93	<.001	0.04	<.001	42.75	<.001
Concentration g/litre	3	1.83	<.001	15.04	<.001	3186.91	<.001	8700.51	<.001	1.102	0.493	0.02	<.001	174.74	<.001
Site* Concentration$\bar{x}$	6	1.14	<.001	1.12	0.012	255.58	0.020	1776.03	<.001	16.30	<.001	0.01	<.001	32.06	<.001

Table 3. Turbidity (NTU) table of means after adding *Moringa* seed powder

Moringa seed powder concentrations (g/litre)					
Sites	0.00	0.05	0.10	0.15	Sites
Deka Drum Resort	3.36c	1.74d	2.27c	3.79b	2.79a
Kataitai	3.48b	0.92e	1.42d	1.94c	1.94c
Low Lift Pumping					
Station	4.41a	0.88e	2.28c	3.09b	2.67a
Concentrations	3.75a	1.18d	1.99c	2.94b	2.94b
		Sites	Concentration	S*C	
P. value		<0.001	<0.001	0.012	
S.e.d		0.21	0.24	0.41	
L.s.d (5%)		0.42	0.49	0.84	
CV%		23.8	23.8	23.8	

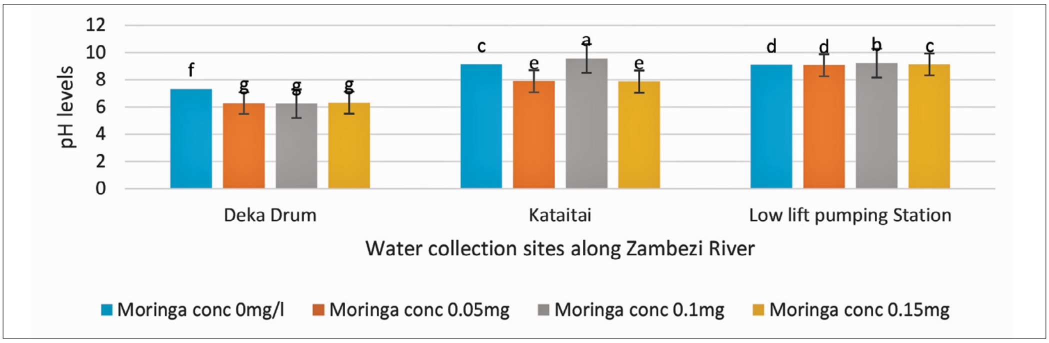

Figure 2. Effect of Moringa seed powder concentrations and sites interactions on pH levels. Different letters in bars shows least significance difference at 5% levels and similar letters shows no difference. Standard error of difference of means is shown by the vertical bars.

Table 5. Table of means for chlorides (mg/l) after adding Moringa seed powder

Moringa seed powder concentrations (g/litre)					
Sites	0.00	0.05	0.10	0.15	Sites $\bar{x}$
Deka Drum Resort	46.1c	33.7d	30.1e	23.0f	33.2c
Kataitai	70.9b	31.9d	42.6c	33.7d	44.8b
Low Lift Pumping					
Station	81.6a	42.6c	35.5d	33.7d	48.3a
Concentrations $\bar{x}$	66.2a	36.1b	36.1b	30.1c	42.1
		Sites	Concentration	S*C	
P. value		<0.001	<0.001	0.020	
S.e.d		3.31	3.32	6.62	
L.s.d (5%)		6.71	7.75	13.43	
CV%		22.2	22.2	22.2	

3.1.5. Influence of sites of water collection, concentrations of Moringa seed powder and their interactions on Nitrates (ppm)

The results of the influence of Moringa seed powder concentrations and water collection points and interaction of both have a significant difference (p<0.001) on nitrates. Kataitai has the highest levels of initial nitrates of 87.60ppm followed by Lowlift Pumping Station, 83.98ppm and Deka Drum Resort shows the least nitrates of 7.54ppm before treatment. Moringa seed powder concentration of 0.05g/l displays a sharp decline of nitrates in all sites shown by the low mean value of 3.23 ppm. As the Moringa seed powder doses increases nitrates reduce in all sites (Table 6 and Figure 3).

Table 6. Nitrates (ppm) table of means after adding *Moringa* seed powder.

Moringa seed powder concentrations (g/litre)					
Sites	0.00	0.05	0.10	0.15	Sites$\bar{x}$
Deka Drum Resort	7.54e	1.05h	1.51g	2.09f	3.05c
Kataitai	87.60b	6.47e	16.26d	21.35e	32.92a
Low Lift Pumping					
Station	83.98b	2.16f	1.36c	1.98f	22.37b
Concentrations $\bar{x}$	59.7a	3.23d	6.38c	8.47b	19.44
		Sites	Concentration	S*C	
P. value		<0.001	<0.001	<0.001	
S.e.d		0.26	0.31	0.53	
L.s.d (5%)		0.54	0.62	1.07	
CV%		3.8	3.8	3.8	

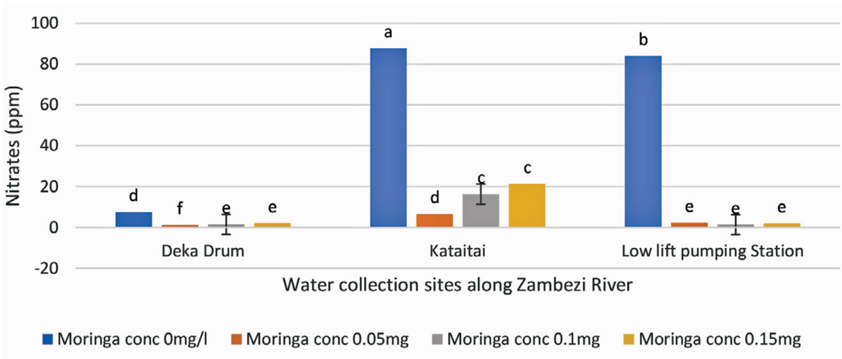

Figure 3. Effect of Moringa seed powder concentrations and sites interactions on nitrates.

3.1.6. Influence of sites of water collection, concentrations of Moringa seed powder and their interactions on sulphates (ppm)

Statistical analysis of the obtained results show significant differences (p<0.001) in water collection points in relation to sulphates as well as in interaction between collection points and Moringa powder concentrations. *Moringa oliefera* seed powder had no significant difference (p=0.493) on sulphates. Three concentrations have almost similar effects in reducing sulphates in water however concentration of 0.15g/l have the lowest mean of 7.97ppm (Table 7) and is efficient in reducing sulphates.

3.1.7. Influence of sites of water collection, concentrations of Moringa seed powder and their interaction on biological oxygen demand (mg/l)

There is a significant difference (p<0.001) between the interaction of Moringa seed powder concentrations, sites and interaction of both on BOD levels. BOD showed decrease in all sites when three doses of Moringa seed powder concentrations were added. Initially, Deka Drum Resort recorded 0.35mg/l of BOD levels followed by Kataitai and Lowlift Pumping Station with similar BOD values of 0.33 mg/l. Concentration of 0.05g/l proved to be very effective in altering BOD in all sites followed by 0.10g/l and 0.15 g/l (Table 8).

Table 7. Table of means for sulphates (ppm) after adding Moringa seed powder

Moringa seed powder concentrations (g/litre)					
Sites	0.00	0.05	0.10	0.15	Sites $\bar{x}$
Deka Drum Resort	21.11a	25.98a	26.37a	23.90a	24.34a
Kataitai	0.54c	0.58c	0.65c	1.46b	0.81b
Low Lift Pumping					
Station	1.02b	-2.25d	-2.27d	-1.44d	-1.23c
Concentrations $\bar{x}$	7.55b	8.11a	8.25a	7.97a	7.97
		Sites	Concentration	S*C	
P. value		<0.001	0.493	<0.001	
S.e.d		0.41	0.47	0.82	
L.s.d (5%)		0.83	0.96	1.67	
CV%		14.6	14.6	16.6	

Table 8. Table of means showing BOD (mg/l) levels after adding Moringa seed powder

Moringa seed powder concentrations (g/litre)					
Sites	0.00	0.05	0.10	0.15	Sites $\bar{x}$
Deka Drum Resort	0.35a	0.33b	0.29d	0.25e	0.31a
Kataitai	0.33b	0.25e	0.31c	0.31c	0.30b
LowLift Pumping					
Station	0.33b	0.13f	0.14f	0.23e	0.21c
Concentrations $\bar{x}$	0.34a	0.24d	0.25c	0.26b	0.27
		Sites	Concentration	S*C	
P. value		<0.001	<0.001	<0.001	
S.e.d		0.013	0.015	0.27	
L.s.d (5%)		0.027	0.031	0.054	
CV%		13.9	13.9	13.9	

3.1.8. Influence of sites of water collection, concentrations of Moringa seed powder and their interaction on total coliforms (MPN/100ml)

Statistical analysis of results revealed significant differences ($p<0.001$) between the varying seed powder doses and their interactions in relation to total coliform. Total coliforms were positive in all samples. However, there was decrease of total bacteria count in all water sampled points. Moringa seed powder concentration of 0.10 g/l after 3 hours contact time had the greatest reduction of microbial count across all sites followed by 0.15g/l and lastly with 0.05g/l (Table 9 and Figure 4).

Table 9. Table of means showing Total coliforms (MPN/100ml) count after adding Moringa seed powder

Moringa seed powder concentrations (g/litre)					
Sites	0.00	0.05	0.10	0.15	Sites $\bar{x}$
Deka Drum Resort	17a	6c	2d	2d	7a
Kataitai	7b	4d	2d	3d	4b
Low Lift Pumping Station	7b	3d	1e	4d	4b
Concentrations $\bar{x}$	10a	4b	2d	3c	5
		Sites	Concentration	S*C	
P. value		<0.001	<0.001	<0.001	
S.e.d		0.45	0.52	0.91	
L.s.d (5%)		0.92	1.06	1.84	
CV%		26.7	26.7	26.7	

**NB: Sites (blocks); Concentrations (treatments); S*C (interaction between sites and concentrations)*

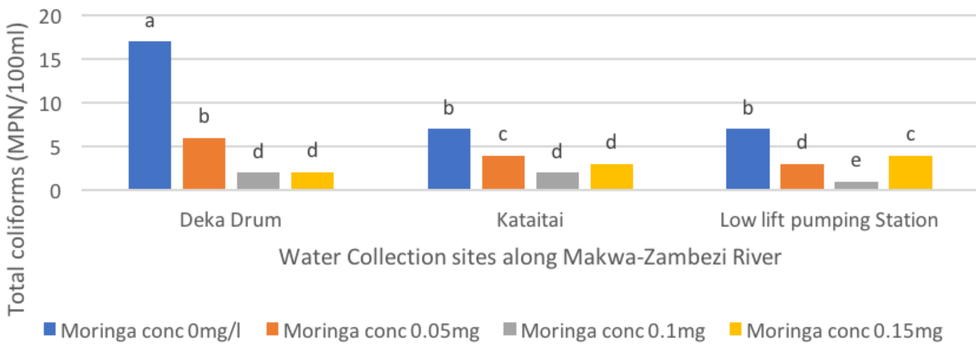

Figure 4. Influence of sites of water collection, concentrations of Moringa seed powder and their interaction on total coliforms. Letters in bars show least significance difference of means at 5% level and vertical bars shows standard error of difference of means

4. Discussion

Nitrates are higher than the WHO standard at Kataitai and Lowlift Pumping Station water collection sites because of human activities in the area such as industry and agriculture activities discharging effluent into the river. Presence of coliforms across all sites in Makwa-Zambezi River can be attributed to community vegetable gardens and nearby Makwa irrigation scheme that uses animal excreta as manure. During watering some of the animal waste effluent would have percolated into the river resulting in bacterial contamination. Moringa was responsible for neutralization and adsorption (Vier*aet al*., 2010). Addition of various *Moringa oliefera* seed powder concentrations decreases turbidity levels. The decrease of turbidity levels also shows variations across sites because river flow is different in down, middle and upper sides of the river. Moringa seed powder dose of 0.05g/L has a great effect in Lowlift Pumping Station (0.88NTU), Kataitai, reducing to 0.92NTU and Deka Drum Resort site having 1.74 NTU, followed by 0.10g/L and 0.15g/L. This is due to the fact that as the concentration of Moringa is increased in untreated water, small particles of seed powder continue to remain suspended in water, thereby causing the turbidity levels to increase. The reduction of turbidity is due to the presence of a cationic protein in Moringa seed that binds all suspended particles, causing them to flocculate to the bottom of the containers (Varkey, 2018). The values obtained after the analysis meets the WHO (5NTU) guidelines for potable water.

Water collected in Kataitai, Lowlift Pumping Sation and Deka Drum Resort had an alkaline pH of 9.14, 9.08 and 7.32 respectively. After treatment with *Moringa oliefera* seed powder all concentrations were able to alter pH levels in all sites and was not adversely affected as it ranged between 9.13-6.32, which is within the recommended acceptable range of pH for drinking water by WHO and SAZS560. Amino acids present in the protein of Moringa seed powder accept a positively charged proton from water resulting in the release of negatively charged hydroxyl group making the water samples basic through natural buffering (Amagloh and Benang, 2009; Viera*et al*., 2010).

Chlorine levels decreased after adding different doses of Moringa seed powder in different sites. Initially Lowlift Pumping Station 81.6mg/L and Kataitai 70.9mg/l, showed high values for chlorides followed by 46.1mg/l in Deka drum. The concentration of 0.15g/l was observed being the one that reduced chlorine in all sites. Increasing the concentrations of Moringa seed powder in untreated water means more proteins were released in water decreasing chlorine levels. Negatively charged chloride ions in water react with positively charged protein of Moringa seed thereby reducing the amount of chlorine in water. Initially, high chlorine in Kataitai and Lowlift Pumping Station can be due to mining and industry activities occurring releasing waste water with ferric chloride into these water points. Chlorides values across three sites met the recommended limit of 200mg/l.

Nitrates carry negatively charged ions thus when various concentrations of Moringa seed powder was added they are reduced. Seeds of Moringa were used in this research as organic natural polymer containing polypeptide with cationic polyelectrolyte properties good for adsorption and reducing this chemical impurity (Kawo and Daneji, 2011). Water samples collected along Kataitai, Lowlift Pumping Station and Deka Drum responded positively when various concentrations of Moringa seed were put in relation to nitrate levels reduction. The chemical parameter met the WHO standard of potable water.

Sulphates levels did not show any significant decrease when Moringa seed powder concentration was added which is contrary to what Kawo and Daneji (2011) who found that sulphates ions were reduced when Moringa seed powder was added to the water. Sulphate's slight increase after adding Moringa seed powder can be attributed to technical errors (UV/VIS Spectrophotometer readings; dilution factor of distilled water to water samples) as well as during laboratory measurements.

The results revealed that Moringa seed powder contains anti-microbial effect as there is a reduction in the total number of coliforms that were initially found high in water collected in the three sites. *Moringa oliefera* seed powder attract and stick to bacteria and virus in river raw water destroying harmful bacteria (Bukur*et al*., 2010). Alkaline conditions in treated water created by the bio-coagulant, also contributes to reduced total coliforms.

It was observed that the bacteria were not completely removed although the quantity of coliforms reduced, all treated water samples are positive. This affirms the earlier research studies conducted, that after filtering Moringa seed powder, particles can remain in treated water thereby causing regrowth of bacteria as some bacteria grow in proteins conditions (Huda *et al*., 2011). Treated water samples were tested for bacteria after two weeks it is observed that the most probable number was high and do not meet the WHO potable water guidelines. The risk of water contamination within the system is low with low concentrations of *Moringa oleifera* seed powder.

Moringa seed powder has an acetone effect in water. When added in untreated water, it binds together all organisms in water and reduced BOD levels in water. The addition of *Moringa* seed powder reduced BOD due to increase in*Moringa oliefera* powder causing increased oxygen required to oxidize them. The obtained BOD levels were within the required WHO potable water set guidelines in all sites.

5. Conclusions

The study reveals that water samples collected from the Zambezi River has physico-chemical parameters within the WHO limits except for water samples from Kataitai and Lowlift Pumping Station that has higher nitrates levels. All sites had coliforms above the WHO limits. The study results show that concentrations of 0.05g/l and 0.10 g/l are efficient in treating raw water. These concentrations reduce the physico-chemical parameters in water samples and can be used to remove contaminants in unclean water especially in areas where there no primary treatment of potable water. Primary treatment of physico-chemical and biological impurities in river water using *Moringa oliefera* seed powder biological coagulant is efficient in all water collection sites. Moringa seed powder can be used to treat unclean water as an effective primary treatment method. Efficient filtration method coupled with the seed powder can be used to reduce total bacterial count in treated water.

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References

Abah, J., Simasiku, E.K. and Nakwaya, D.N. (2018). Assessment of Zambezi River Water Quality Using Macroinvertebrates Population Density. Journal of Fisheries and Aquatic Science, (13), 12-20.

Ali, E.M., Muyibi, S. and Salleh, H.M. (2010). *Moringao leifera* as natural coagulation for water treatment. Thirteen International Water Technology Conference, IWTC 13, Hurghada, Egypt.

Amagloh, F.K. and Benang, A. (2009). Effectiveness of *Moringa oliefera* seed as Coagulant for water purification. African Journal of Agricultural Research Vol.4 (1), 119-123.

Athira, C.K. and Harshan, K.G. (2015). Efficiency of *Moringa oliefera* seed powder for Quarry water treatment. International Journal of Science and Research, IJSR 78.96 Index.

Berton, E., Stewart, R., Zhang, H. and O'Hallora, K. (2016). Hybrid water treatment cost prediction model for raw water intake optimization. Environmental Modelling & Software, (75), 230-242.

Hendrawati, Y.I.R., Nurhasni, R.E. and Drusman, L.K. (2016). The use of *Moringa oleifera* seed powder as Coagulant to Improve the Quality of Wastewater and Ground water. *IOP Conf. Series: Earth and Environmental Science. doi*:10.1088/1755-1315/31/1/012033).

Huda, A.J., Kristin, J.A., Lauren, R.M., Darrell, V. and Stephanie, B. (2011). Antimicrobial sand via Adsorption of Cationic *Moringa oleifera* Protein; Langmuir, 28 (4), 2262–2268.

Kawo, A.H. and Daneji, I.A. (2011). Bacteriological-chemical evaluation of water treated with seed powder of Moringa oliefera Lam. BajopasVol 4, (2). Available at http://dx.doi.org/10.4314/bajopas.v4i2.42.

Lea, M. (2014). Bioremediation of Turbid Surface Water Using Seed Extract from the *Moringa oleifera* Lam. (Drumstick) Tree. CurrProtocMicrobiol, (33),1-8.

Maroyi, A. (2006). The Utilization of *Moringa oleifera* in Zimbabwe: A sustainable Livelihood Approach p165.

Muruganandam, L., Saravana, K.M.P., Amarijit, J., Sudiv, G. and Bhagesh, G. (2017). Treatment of waste water by coagulation and flocculation using biomaterials. IOP Conf. *Series: Materials Science and Engineering,* 263 (10.1088/1757-899X/263/3/032006).

Penn News 18 July (2019). Researchers study inexpensive process to clean water in developing nations. Retrieved from https://news.psu.edu/story/358048/2015/06/09/research/researchers-study in expensive-process-clean-water-developing.Cited 10 August 2019.

Sharma, P., Kumari, P. and Srivastava, M. (2006). Removal of cadmium from aqueous system by shelled *Moringao leifera* Lam. seed powder. *Bioresource Technology*, 97 (2), 299-305.

Tunggolou, J. and Payus, C. (2017). Application of *Moringa oliefera* Plant as Water Purifier for Drinking Water Purposes. Journal of Environmental Science and Technology, (10)5, 268-275.

Varkey. A.J. (2018). A Breakthrough in water purification using an oligodynamic metal and *Moringa oleifera* seed. Doi: 10.10209444/preprints 201803.0091. v1.

Vieira, A.M.S., Vieira, M.F., Silva, G.F., Aruajo, A.A., Fagundis, K.M.K., Veit, M.T. and Bergamasco, R. (2010). Use of *Moringa oleifera* Seed as a Natural Adsorbent for Wastewater Treatment. *Water Air Soil Pollution*, (206), 273–281.

Voice of America (11 September 2018). Zimbabwe Declares State of Emergency Over Cholera Outbreak. Retrieved from https://reliefweb.int/report/zimbabwe/zimbabwe-declares-state-emergency-ercholera-outbreak.Cited 10 March 2019.

World Meteorological Organization (2017). World Weather Information Service, Hwange. Retrieved from http://worldweather.wmo.int.Cited 3 March 2019.

Appendices

Appendix 1: ANOVA results for nitrates(ppm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SITE	2	7344.4637	3672.2318	6571.89	<.001
Concentration (mg/litre)	3	26101.5364	8700.5121	15570.59	<.001
SITE.Concentration (mg/litre)	6	10656.2100	1776.0350	3178.42	<.001
Residual	36	20.1160	0.5588		
Total	47	44122.3262			

Appendix 2: ANOVA results for pH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SITE	2	59.9269	29.9635	172.86	<.001
Concentration(mg/litre)	3	5.4822	1.8274	10.54	<.001
SITE.Concentration(mg/litre)	6	6.8414	1.1402	6.58	<.001
Residual	36	6.2404	0.1733		
Total	47	78.4909			

Appendix 3: ANOVA results for phosphates(ppm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SITE	2	0.08741	0.04371	1.09	0.347
Concentration (mg/litre)	3	0.15598	0.05199	1.30	0.291
SITE.Concentration (mg/litre)	6	0.24864	0.04144	1.03	0.421
Residual	36	1.44490	0.04014		
Total	47	1.93692			

Appendix 4: ANOVA results for sulphates(ppm)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SITE	2	6463.859	3231.929	2392.85	<.001
Concentration (mg/litre)	3	3.307	1.102	0.82	0.493
SITE.Concentration (mg/Litre)	6	97.813	16.302	12.07	<.001
Residual	36	48.624	1.351		
Total	47	6613.603			

Appendix 5: ANOVA results for turbidity (NTU)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SITE	2	6.7621	3.3810	9.85	<.001
Concentration(mg/litre)	3	45.1120	15.0373	43.81	<.001
SITE.Concentration(mg/litre)	6	6.7151	1.1192	3.26	0.012
Residual	36	12.3577	0.3433		
Total	47	70.9469			

Appendix 6: ANOVA results for chlorine(mg/l)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SITE	2	1986.35	993.17	11.33	<.001
Concentration ((mg/litre)	3	9560.72	3186.91	36.35	<.001
SITE.Concentration (mg/litre)	6	1533.50	255.58	2.92	0.020
Residual	36	3156.12	87.67		
Total	47	16236.70			

Appendix 7: ANOVA results for biological oxygen demand(mg/l)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SITE	2	0.5481	0.2741	0.50	0.609
Concentration(mg/litre)	3	10.5726	3.5242	6.46	0.001
SITE.Concentration(mg/litre)	6	5.7016	0.9503	1.74	0.139
Residual	36	19.6380	0.5455		
Total	47	36.4603			

Appendix 8: ANOVA results for total coliforms(MPN/100ml)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SITE	2	17958.292	8979.146	2486.53	<.001
Concentration(mg/litre)	3	124069.417	41356.472	11452.56	<.001
SITE.Concentration(mg/litre)	6	63206.208	10534.368	2917.21	<.001
Residual	36	130.000	3.611		
Total	47	205363.917			

E. ENGINEERING HARMONY FOR A SUITABLE WORLD

The Future of Tropical Water Resources: Using Palaeolimnology to Inform Sustainable Management

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Abstract

Lakes are an important resource. They provide vital ecosystem services and employment for many communities worldwide. Maintaining lakes as ecosystem providers without damaging the lake ecosystems themselves, against a background of increasing human use of landscapes and climate change, requires careful and informed management. Key to such management is an understanding of how lakes will respond to ongoing and future changes in their catchments. Long-term monitoring, through regular measurements of lake chemistry for example, can help provide this understanding but such data are rare, particularly for tropical lakes. Using a palaeolimnological approach can provide an alternative to long term monitoring. This paper compares the information that monitoring data and lake sediment records can bring to an understanding of lake change in western Uganda. Water chemistry data show a general pattern to lakes with higher Chlorophyll-a and TP values over the last 15 years, although not all lakes follow this pattern. Sediment cores from Lakes Kamunzuka and Nyungu both show changes in diatom flora through the latter half of the twentieth century and increases in dry mass accumulation rate between c. 1980 and 2000. This study highlights the importance of a co-ordinated monitoring approach to provide the data needed to benchmark management decisions. The importance of understanding each lake on its own merits, from a monitoring or palaeolimnological perspective is also highlighted. Combined, these approaches provide an approach to inform management decisions to sustain lake ecosystems in a healthy state, for the benefit of all users.

Keywords: Uganda, lakes, water chemistry, sediment cores, diatoms.

1. Introduction

In parts of western Uganda where potable water supplies via groundwater pumps are sparse, clusters of crater lakes supply valuable freshwater resources to rural communities, in addition to providing opportunities for aquaculture, tourism, and wider ecosystem services (Saulnier-Talbot et al., 2014). Like water bodies globally, the lakes are subject to multiple stressors, including the impacts of climate change (e.g. changes in precipitation, increases in temperature) and human activity within the lake and its catchment (e.g. changing land use, introduction of fish) (Ormerod et al., 2010). In western Uganda these stressors are amplified in the context of a growing population alongside low levels of water infrastructure.

Globally, lakes have experienced increased phytoplankton blooms, and therefore a decline in water quality since the 1980s (Ho et al., 2019). There is particular concern over the sensitivity of tropical African lakes to climate change and anthropogenic pressures; climatic warming and enhanced sediment and nutrient flux to lakes has already led to an increased frequency of algal blooms and eutrophication in eastern African lakes in recent decades (Ndebele-Murisa et al., 2010; Odada et al., 2020). This is likely to have significant negative impacts upon livelihoods that are reliant on lakes, such as aquaculture, which is threatened by a reduction in fish abundance and diversity (Ndebele-Murisa et al., 2010) and an increased frequency of fish kill events associated with declining water quality (Odada et al., 2010).

The future water quality of the crater lakes is uncertain. This is due, in part, to the understudied nature of tropical lakes in general, when compared to other regions of the world (Escobar et al., 2020) and the limitations with monitoring of remote systems. As with many other regions of the world, the lack of long-term monitoring of the lakes limits understanding of the drivers and dynamics of water quality in this part of Uganda.

Implementing sustainable management of tropical lakes to ensure their long-term sustainability as a water resource and critical ecosystem service is important in the delivery of UN Sustainable Development Goals (SDGs) 6 (clean water and sanitation), 13 (climate action), and 2 (zero hunger), which have been identified as priority SDGs requiring action in eastern Africa (Gill et al., 2019). Furthermore, ensuring equitable access to water resources is a key step in achieving gender parity (SDG 5) in sub-Saharan Africa (UN Water, 2006).

In order to inform sustainable management of lake systems, and to predict and mitigate their responses to future stressors, there is a need to understand how lakes respond to different drivers over multiple timescales. Ideally, this would include the use of, for example, continuous water chemistry data collected over a "long" time frame (e.g. pre- and post-impact). However, in many parts of the world, these data do not exist. In the crater lake region of western Uganda water chemistry data have been collected sporadically over the course of the 20th Century. The earliest measurements from the area were that of lake depth and conductivity, taken during the Cambridge Expeditions in 1931 (Beadle, 1932). A number of field campaigns to the region followed in the 1960s, 70s and 90s, and the number of water quality parameters measured increased and included: Secchi depth (an indicator of turbidity), dissolved oxygen, chlorophyll-a (Chl-a), and nutrient (total phosphorus and total nitrogen) concentrations of the lake waters (Beadle, 1932; Talling and Talling, 1965; Kilham, 1971; Melack, 1978; Kizito et al., 1993; Chapman, 1998; Crisman, 2001). In almost all cases, these datasets were collected during the dry season (December-February or June-July) and comprise a single sample, offering only a snapshot in time, and resulting in a patchy and incomplete time series. The collection of lake data and water samples from across the crater lake region has persisted into the 21st Century, with the most recent datasets collected in 2019.

In the absence of long-term water quality monitoring and associated datasets, it is possible to make use of a palaeolimnological approach, to understand long-term changes in the lake systems. Palaeolimnology uses the sediments that accumulate at the bottom of lakes to infer how lakes have changed in the past and the drivers of these changes (Dalton et al., 2009). These natural archives can extend back many hundreds of years (Battarbee, 2000; Birks and Birks, 2006; Fritz, 2008). A number of palaeolimnological studies from the western Uganda crater lake region exist in published literature (Rumes et al., 2005; Ssemmanda et al., 2005; Eggermont et al., 2006; Russell et al., 2007; Bessems et al., 2008; Russell et al., 2009; Rumes et al., 2011; Ryves et al., 2011; Mills and Ryves, 2012; Colombaroli et al., 2014; Gelorini et al., 2014; Mills et al., 2014; Mills et al., 2018) and have been used to understand changes in climate and environment over the last 2,000 years.

This paper presents a collation of water chemistry data collected from crater lakes in Uganda to investigate trends in water quality change over the past two decades. Sediment core records from two lakes which have been subject to contrasting levels of human disturbance are presented in this paper to demonstrate how palaeolimnology can infer long-term changes in water quality. The paper discusses how palaeolimnological records can be used as a benchmark for lake conditions, in the absence of lake monitoring data, and as a tool to inform their sustainable management.

2. Materials and methods

2.1. Study sites

Volcanic crater lakes associated with the East African Rift System (EARS) occur in clusters in the west and southwest of Uganda (Melack, 1978). The lakes are associated with the Toro-Ankole volcanic field and are thought to have formed as a result of volcanic activity (maars or phreatomagmatic craters), possibly as recently as 6,000 years ago (Temple, 1971). The lakes lie within 4 distinct groups: the Kasenda, Fort Portal, Katwe-Kikorongo, and Bunyaruguru clusters (Figure 1). The northern lakes of the Fort Portal and Kasenda clusters are located at high altitude (1520 and 1,220-1,400 m.a.s.l.) whereas the Katwe-Kikorongo cluster to the south lies on the rift valley floor (895-925 m.a.s.l), and the southernmost cluster (Bunyaruguru) extends into the southern uplands (975-1,250 m.a.s.l).

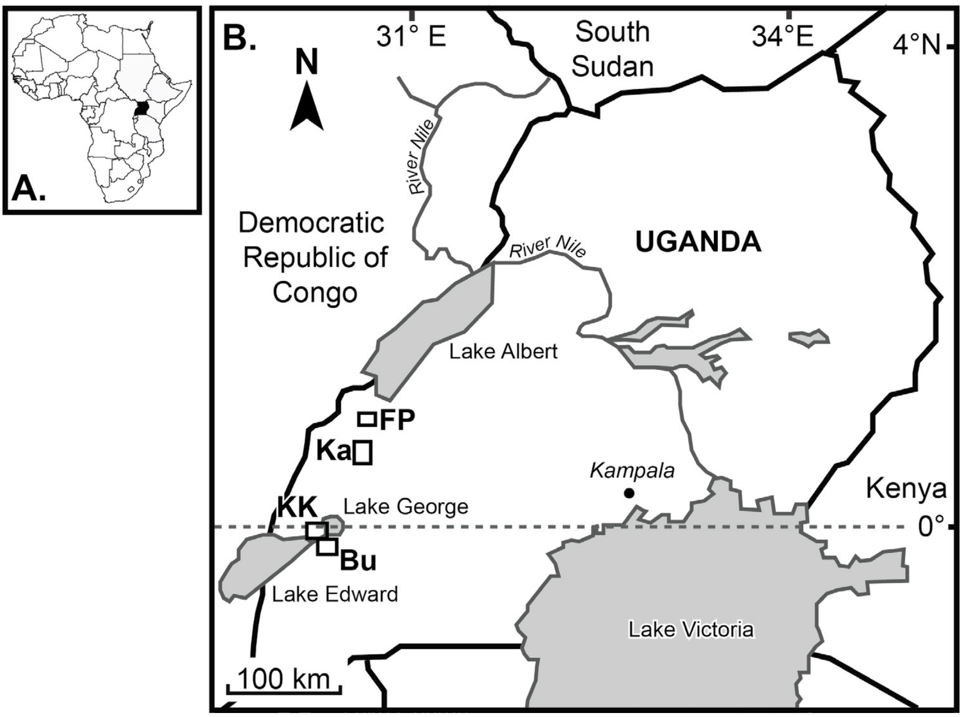

Figure 1. Map of study area showing (a) the position of Uganda in eastern Africa, and (b) a map of Uganda identifying the location of the crater lake clusters in the western part of the country as described by Melack (1978): Fort Portal (FP), Kasenda (Ka), Katwe-Kikorongo (KK), and Bunyaruguru (Bu).

Uganda experiences a tropical climate with a bimodal rainfall pattern during March-May and October-December (Nicholson, 1996; Nicholson, 2000). Rainfall earlier in the year (March-May) tends to be longer, heavier, and more reliable than that from October to December (Nicholson, 2017). The crater lakes located at higher altitudes receive c. 1,300-1,600 mm yr^{-1} of rainfall, whereas those located on the rift valley floor receive c. 750-1,000 mm yr^{-1} (Uganda Government Department of Land and Surveys, 1962). The mean annual temperature in the region is 22.4°C, varying by c. 2°C throughout the year (based on average monthly temperatures 1901-2016; World Bank Group, 2020).

The lakes span a range of ecotones and vegetation types, from the moist evergreen forests of the rift valley shoulders to the grass savannah of the equatorial rift valley floors (Uganda Government Department of Land and Surveys, 1962; Kizito et al., 1993; Gelorini et al., 2011). Human activities have unevenly impacted the vegetation and land cover of the region including the crater lake catchments; outside of the National Parks and Central Forest Reserves natural forest and shrub has been cleared, and many of the lake catchments contain small-scale subsistence agricultural plots and plantations (Ssemmanda et al., 2005; Gelorini et al., 2011). Lakes located within the National Parks and Central Forest Reserves have catchments that have remained relatively undisturbed by clearance.

The surface waters of 80 crater lakes have been sampled for analysis over the last 20 years (see Introduction), and span both freshwater (70 lakes) and saline lakes (10 lakes). For the purposes of this study, the focus is only on freshwater systems (those with a conductivity of <1,500 µS cm^{-1}) and those that have a minimum of two data points in time in each of the key water chemistry parameters that can be used to understand changes in water quality (conductivity, total phosphorus (TP), total nitrogen (TN) and Chlorophyll-a (Chl-a)). The final list of 21 lakes that were used in this paper are given in Table 1.

Table 1. Location and sampling information for the lakes and data used in the water chemistry analyses (NP = National Park, CFR = Central Forest Reserve)

Lake	Code	Cluster	Longitude	Latitude	Depth (m)	Protected?
Kyaninga	Kyan	Fort Portal	30°17’46.6”E	0°42’8.11”N	57	
Saaka	Saak	Fort Portal	30°14’34.4”E	0°41’19.2”N	7.8	
Kanyanmukali	Kan	Kasenda	29°20’9.23”E	0°24’01.4”N	10.8	
Kasenda	Kas	Kasenda	30°17’19.6”E	0°26’5.01”N	13.5	
Katanda	Kand	Kasenda	30°15’42.6”E	0°29’0.67”N	145	
Kifuruka	Kif	Kasenda	30°17’9.87”E	0°29’33.2”N	5.3	
Kyerbwato	Kyer	Kasenda	30°19’20.8”E	0°26’14.8”N	12.7	Kibale NP
Lugembe	Lug	Kasenda	30°16’48.9”E	0°27’10.0”N	18.6	
Murusi	Mur	Kasenda	30°17’29.3”E	0°25’47.1”N	57	
Nkuruba	Nkur	Kasenda	30°18’1.53”E	0°31’10.8”N	34.8	
Myamswiga	Niga	Kasenda	30°17’4.99”E	0°30’35.0”N	75	
Wandakara	Wand	Kasenda	30°16’10.1”E	0°25’11.3”N	12.1	
Chibwera	Chi	Bunyaruguru	30°8’20.25”E	0°9’0.04”S	11.7	
Kamunzuka	Kam	Bunyaruguru	30°9’19.96”E	0°15’33.6”S	61	Kasyoha-Kitomi CFR
Kamweru	Kwer	Bunyaruguru	30°7’28.49”E	0°15’20.6”S	45	
Katinda	Kat	Bunyaruguru	30°6’15.82”E	0°13’2.38”S	17	
Kyasanduka	Kyas	Bunyaruguru	30°2’57.06”E	0°17’16.0”S	2	Queen Elizabeth NP
Mirambi	Mir	Bunyaruguru	30°9’21.14”E	0°10’26.08”S	2.6	
Nkugute	Mkug	Bunyaruguru	30°5’54.73”E	0°19’14.8”S	58	
Nyamogusingiri	Nyam	Bunyaruguru	30°1’36.29”E	0°18’55.3”S	4.4	Queen Elizabeth NP
Nyungu	Nyun	Bunyaruguru	30°6’0.00”E	0°15’27.1”S	27	

Sediment cores were collected from two crater lakes in the Bunyaruguru crater lake cluster with contrasting lake catchments (Figure 2). Lake Nyungu (0°15'22.9" S, 30°05'42.5" E) is a 27 m deep lake, with a catchment that has been heavily modified by human activity; nearly all of the natural vegetation has been replaced by banana plantations. The lake is used for fishing, with large nets permanently in place, and as a source of drinking water for local communities. In contrast, Lake Kamunzuka (0°15'49.8" S, 30°09'18.5" E; 60 m deep) is located within the Kasyoha-Kitomi Central Forest Reserve (CFR), and as result of this protected status the vegetation within the lake catchment is largely natural/secondary forest. The lake is used as a water resource and for fishing, and human activity such as clearance for small scale agriculture is evident just beyond the boundaries of the CFR.

2.2. Water chemistry analysis

The water chemistry data used here are a combination of recently collected samples (2019) that were processed at the University of Nottingham, and a collated series of older data from published datasets (Rumes et al., 2011, Mills and Ryves, 2012, and Nankabirwa et al., 2019).

Water chemistry parameters were all measured on surface water samples (at a depth of c. 0.5 m below the water surface) and include: conductivity (μS cm^{-1}), pH, temperature (°C), dissolved oxygen (mg l^{-1}), Secchi depth (cm), total nitrogen (TN, mg l^{-1}), total phosphorus (TP, mg l^{-1}), and chlorophyll-a (Chl-a, mg l^{-1}). In previously published studies conductivity, pH, temperature, and dissolved oxygen concentrations were measured *in situ* using a Quanta Hydrolab multi-parameter water quality probe. The same parameters were measured in 2019 using a YSI EXO 1 multiparameter sonde water chemistry probe. Water transparency was measured using a Secchi disk.

Methodologies for the analysis of TN, TP, and Chl-a differed between studies, with datasets from Mills and Rumes using the same analytical laboratories and methods (see Rumes et al, 2011; Mills and Ryves, 2012). Data from Nankabirwa et al (2019) used a different approach, with samples for all three analyses processed using a Hach Lange DR800 Spectrophotometer. The analytical methods for the samples collected by Hunt (2019) are summarised below.

The total nitrogen content of each unfiltered water sample was digested using an oxidising reagent, then reduced by shaking with ammonium chloride and spongy cadmium pellets and measured against a blank calibration standard at 543 nm, following the methodology of Jones (1984). Total phosphorus content of each unfiltered water sample was determined using the methodology of Mackereth et al. (1978); samples were oxidised with an acid persulphate solution and measured using colorimetric spectrophotometry against a blank calibration standard at 885 nm.

Measurement of the concentration of Chl-a in lake water samples were obtained using the residue left on 0.7 μm glass fibre filter after water was filtered in the field. On return the University of Nottingham, the dry filter papers were soaked in an extraction solution and the absorbance of light by the samples measured at 665 nm, 645 nm, 630 nm and 750 nm using a spectrophotometer, and calculated following the method of Richards and Thompson (1952).

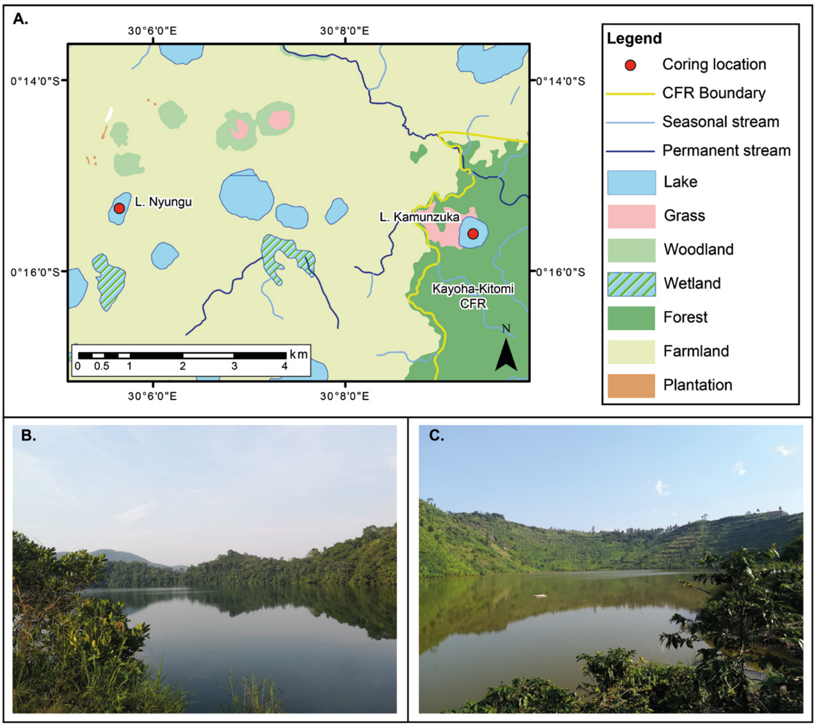

Figure 2. A small-scale map of part of the Bunyaruguru crater lake cluster showing (A) the locations of lakes Kamunzuka and Nyungu, the two lakes where sediment cores were retrieved. The colours on the map represent the land use types. Two photos show the dominant catchment vegetation in (B) Kamunzuka (woodland) and (C) Nyungu (farmland - though as seen in the picture, the majority of the catchment is dominated by banana plantation) © Laura Hunt

2.3. Sediment records

2.3.1. Core collection and Lead-210 dating

Sediment cores were collected in 2007 from the deepest parts of Lakes Nyungu and Kamunzuka (25.2 m and 62.0 m, respectively) using a HON Kajak gravity corer. The sediment cores were extruded and sectioned at 0.5 cm intervals These samples were stored in a cool box before being transported back to Loughborough University, where they were stored in a dark refrigerator (4°C) prior to analysis.

Five subsamples from each core were analysed for ^{210}Pb, ^{226}Ra, and ^{137}Cs by direct gamma assay using Ortec HPGe GWL series well-type coaxial low background intrinsic germanium detectors (Appleby et al. 1986) at the Liverpool University Environmental Radioactivity Laboratory. Lead-210 dates for each core were calculated using the constant rate of supply model (CRS; Appleby and Oldfield, 1978; Appleby, 2001) and compared with the stratigraphic date of 1963, as determined by the ^{137}Cs record, to obtain radiometric dates for the cores.

2.3.2. Loss-on-ignition (organic and carbonate content) and DMAR

The methodology of Dean (1974) was used to estimate the organic and carbonate content of the sediment cores. Sub-samples of a known dry weight were placed in a furnace at 550°C for 2 hours. The at 925 °C for 4 hours. The reweighed sample allowed an estimate of the carbonate content. The results from the LOI and ^{210}Pb dating were used to calculate the dry mass accumulation rate (Appleby and Oldfield, 1978).

2.3.3. Diatom and ordination analyses

Diatoms were analysed from the Kamunzuka and Nyungu cores at 2 cm and 0.5 cm resolution respectively. Diatom samples were prepared using the method of Renberg (1990). Sub-samples of sediment were digested using 30% w/v hydrogen peroxide and placed in a water bath at 90°C for 4 hours. Following digestion, a few drops of 10% hydrochloric acid were added to remove any carbonates. The samples were washed with distilled water and left to settle for 24 hours. The supernatant was decanted, and the washing process repeated 4 times. Samples were placed onto coverslips and mounted onto microscope slides using Naphrax. At least 300 valves per sample were counted in parallel transects under oil-immersion phase-contrast light microscopy at x1000 magnification on a Leica DMRE research microscope. A variety of general (Krammer and Lange-Bertalot, 1986-1991) and regional floras (Gasse, 1986; Cocquyt, 1998) were used, and valves identified to species level where possible. Stratigraphic diatom assemblage data were plotted using C2 (Juggins, 2003).

Ordination analysis was undertaken on the diatom assemblage data from both lakes. Based on the generated gradient lengths from an initial Detrended Correspondence Analysis (DCA), it was determined that a Principal Components Analysis (PCA) would be undertaken on the samples from Kamunzuka, and a DCA applied to Nyungu. Analyses were completed using Canoco 4.5 (Ter Braak and Šmilauer, 2002).

3. Results

3.1. Modern water chemistry results

The total phosphorus (TP) concentration in surface waters across all lakes in all years ranges from 0 mg l^{-1} (Lake Kamunzuka, 2007) to 1.6 mg l^{-1} (Lake Kanyanmukali, 2015); with a median value of 0.08 mg l^{-1}. Sixteen of the 21 lakes presented all show an increase in TP from 2007 to 2019. Whilst little is known of the phosphorus dynamics of these smaller tropical lakes, published research from eastern Africa suggests that very high phosphorus values (1 mg l^{-1}) are usually common in saline lakes, and values >0.15 mg l^{-1} are usual in shallow, productive lakes (Talling and Talling, 1965). In this dataset, 2 lakes (Mirambi and Murusi) have values similar to those observed in hyper-saline systems, and the majority of lakes (14) have values that are close to, or exceed >0.15 mg l^{-1}; yet only 2 of these lakes are shallow systems (Kyasanduka at 2 m deep, and Nyamogusingiri at 4.4 m deep). Therefore, the higher TP (>0.15 mg l^{-1}) values in some of the deeper, freshwater lakes are likely attributable to human activity in the catchment, and internal cycling of the phosphorus (Talling and Talling, 1965). Total nitrogen (TN) has more variability than TP values, with the lowest value of 0.07 mg l^{-1} (Lake Kamunzuka, 2007) and a maximum value of 6.33 mg l^{-1} (Lake Kyasanduka, 2019). Across the 21 lakes, Chl-a varies from 0.69 µg l-1 (Lake Kamunzuka, 2007) to 203 µg l-1 (Lake Kyasanduka, 2007). The majority of lakes sampled across all years have Chl-a concentrations >10 µg l^{-1}.

The water chemistry data (Table 2) were analysed using unconstrained ordination to understand the underlying trends in the data, and the relationship between lakes through time. The analyses focused on three time periods where there were (almost) complete datasets across the 21 lakes: 2007, 2015, and 2019. Principal Components Analysis (PCA) was undertaken using Canoco 4.5; all water chemistry data were log-transformed prior to analysis. The PCA of the water chemistry data was undertaken as four separate datasets (Figure 3), three of which focussed on datasets from the Bunyaruguru and Kasenda clusters (Figure 3a-c) comparing different years, and then a PCA that analysed all lakes together (Figure 3d). Fort Portal lakes were not analysed separately as there were only 2 systems that passed the initial dataset screening.

Table 2. Lake water chemistry data used in the PCA analyses. Cond = conductivity (µS cm-1), Secchi = Secchi depth (cm, indicator of turbidity), TP = total phosphorus (mg l-1), TN = total nitrogen (mg l-1), and Chl-a = Chlorophyll-a (µg l-1). The datasets available are from 2007 (Rumes et al., 2011), 2015 (Nankabirwa et al., 2019) and 2019 (collected by Hunt, and methodologies described in this paper). Shaded cells = missing data / no data collected

Lake	2007 [Rumes]										2019 [Hunt]				
	Cond	Secchi	TP	TN	Chl-a	Cond	Secchi	TP	TN	Chl-a	Cond	Secchi	TP	TN	Chl-a
Kyaninga	420	585.0	0.01	0.10	0.81	408	410.7	0.03	0.50	2.63					
Saaka	612	45.0	0.08			655	48.5	0.15	1.80	90.45					
Kanyamukali	920	65.0	0.42	0.44	7.16	992	90.0	1.6	1.05	14.85					
Kasenda	312	83.0	0.04			322	91.5	0.07	0.70	32.27	235	105.0		0.76	15.15
Katanda	419	200.0	0.04	0.77	25.43	428	200.0	0.03	0.50	6.80					
Kifuruka	411	82.0	0.08			356	38.5	0.12	3.90	70.9					
Kyerbwato	411	165.0	0.02	0.23	1.72	400	216.0	0.13	0.50	6.50					
Lugembe	407	135.0	0.05	0.53	5.69	453	54.5	0.08	1.10	25.95					
Murusi		140.0	0.02	0.31	3.75							100.0	1.26	0.76	4.22
Nkuruba	370	101.0	0.04	0.66	26.31						315	137.0	0.39	0.79	4.32
Nyamswiga	330	110.0				370	87.0	0.16	0.50	18.95					
Wandakara	1125	70.0	0.06	0.75	11.35	1239	40.5	0.15	3.00	97.65	1172		0.57	1.60	
Chibwera	457	135.0	0.05	0.30	6.74	455	89.0	0.1	0.70	25.46					
Kamunzuka	58	770	0	0.07	0.69						56	250.0	0.14		2.45
Kamweru	170	55.0	0.07	0.66	13.85	166	101.0	0.06	0.85	29.9					
Katinda	743	53.0	0.04	0		772	29.5	0.15	3.57	164.75	755			2.43	153.25
Kyasanduka	237	24.0	0.47	0.89	203.03	263	30.7	0.26	3.50	91.83	265	19.0	0.38	6.33	139.62
Mirambi	642	90.0	0.04	0.63		693	82.0	0.07	0.50	20.05	653		1.06	1.8	19.07
Nkugute	121	90.0	0.05	0	5.89	123	99.3	0.04	0.77	19.17					
Nyamogusingiri	618	44.0	0.06	2.00	14.79	760	25.0	0.13	4.03	163.67	741	40.0	0.42	3.99	4.752
Nyungu	430	8.0	0.26			418	19.5	0.22	2.75	183.00	459	29.5	0.37	1.44	33.13

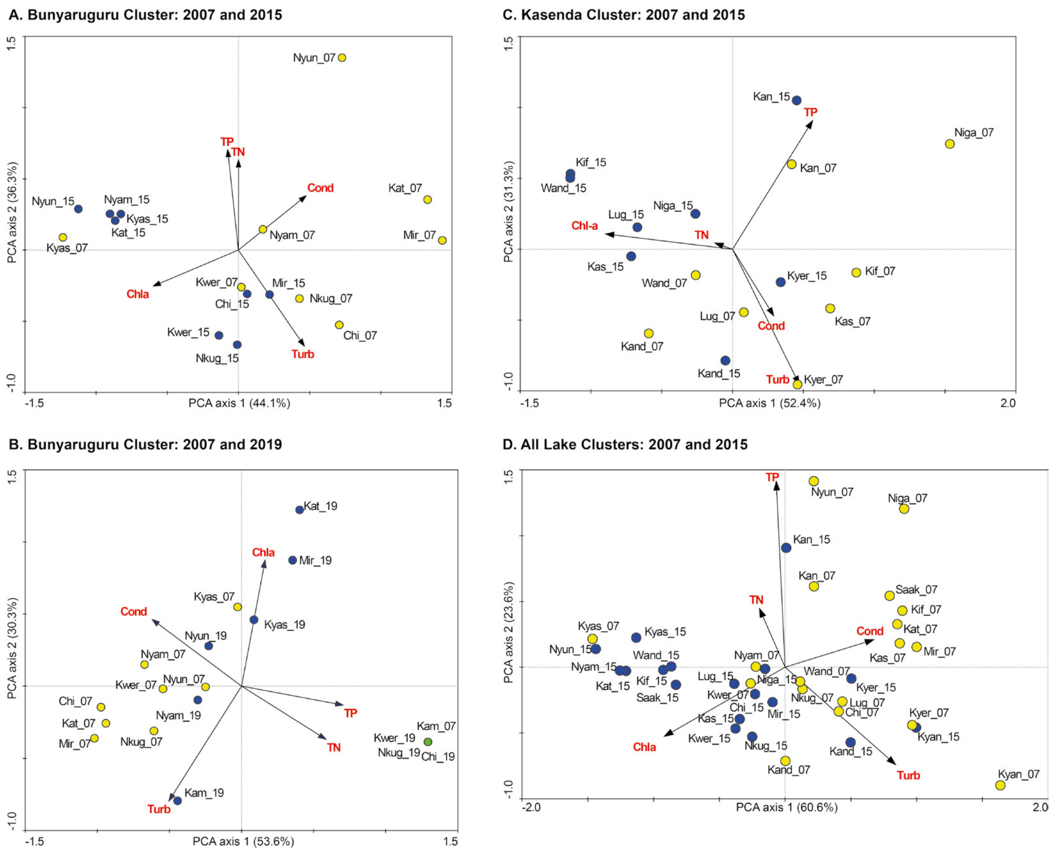

Figure 3. Results of the water chemistry Principal Components Analysis (PCA) carried out on four example datasets. (a) PCA of 2007 and 2015 water chemistry of eight lakes within the Bunyaruguru lake cluster (Lake Kamunzuka was removed from this analysis due the lack of data for 2015). (b) PCA of 2007 and 2019 water chemistry of nine lakes within the Bunyaruguru lake cluster. (c) PCA of 2007 and 2015 water chemistry of eight lakes within the Kasenda lake cluster (Lakes Murusi and Nkuruba were excluded from analysis due to lack of data from 2015). (d) PCA of all lakes from the Fort Portal, Kasenda, and Bunyaruguru clusters that had complementary datasets from 2007 and 2015 (Lakes Kamunzuka, Murusi and Nkuruba were excluded from this analysis). PCA axis 1 and axis 2 percentages are given on each diagram. The arrows represent the dominant water chemistry trends in each analysis (Cond = conductivity, Turb = turbidity, TP = total phosphorus, TN = total nitrogen, Chla = Chlorophyll-a). All data were log-transformed prior to the PCA

While there are some minor differences between the four ordination sub-sets, in all cases Chlorophyll-a and/or TP appear to be strongly correlated to PCA axes 1 and 2, which suggests that these parameters are major drivers of the lake systems. In the four datasets, axis 1 accounts for 44% (Bunyaruguru: 2007 vs 2015) to 60% (All Clusters: 2007 vs 2015) of all variance observed in the datasets; and in all cases, the first 2 PCA axes explain around 80% of the variance in the data. Furthermore, in all four ordinations - regardless of comparative time frame (e.g. 2007 vs 2015, 2007 vs 2019) or lake cluster, there is a split observed in the lake samples, with more recent samples associated with higher Chlorophyll-a and TP values.

3.2. Lake trophic status

Lakes were assigned a lake trophic status on the basis of their Chl-a content, as defined by Nankabirwa et al. (2019). A minimum of two Chl-a concentration measurements were made at 19 lakes across the Bunyaruguru, Fort Portal and Kasenda crater lake clusters between

2006 and 2019, which were used to assign the lakes a trophic status change (Table 3). The change in trophic status of the lakes over the sampling period has been varied; some lakes across the region experienced no change in trophic status between sampling points, and others experienced a net increase or reductions in trophic status between 2006 and 2019.

Six of the 19 lakes had the same trophic status at each point in time that lake water Chl-a concentration was measured. One lake (Lake Nyungu) experienced no net change in trophic status but did experience a higher trophic status in 2014/15 (hypertrophic) compared to measurements taken in 2006 and 2019 (eutrophic).

Table 3. Trophic status of lakes, as defined by Nankabirwa et al. (2019) in 2006 (Mills and Ryves, 2012), 2007 (Rumes et al., 2011), 2015 (Nankabirwa et al., 2019), and 2019 (collected by Hunt, and methodologies described in this paper). Blank cells = missing data/no data collected

Lake	Depth (m)	Trophic Status				Change in trophic status
		2006	2007	2015	2019	
Bunyaruguru Cluster						
Kyasanduka	2		Hyper	Hyper	Hyper	No change
Nyam.Basin	4.4		Meso	Hyper	Oligo	Decrease
Chibwera	11.7		Meso	Eutro		Increase
Katinda	17			Hyper	Hyper	No change
Mirambi	22			Eutro	Meso	Decrease
Nyungu	27	Eutro		Hyper	Eutro	No net change
Kamweru	45		Meso	Eutro		Increase
Nkugute	58		Oligo	Meso		Increase
Kamunzuka	61	Oligo			Oligo	No change
Fort Portal Cluster						
Kyaninga	57		Oligo	Oligo		No change
Kasenda Cluster						
Kifuruka	5.3	Meso		Hyper		Increase
Kanyamukali	10.8		Meso	Meso		No change
Wandakara	12.1	Meso	Meso	Hyper	Eutro	Increase
Kyerbwato	12.7		Oligo	Meso		Increase
Kasenda	13.5	Oligo		Eutro	Meso	Increase
Lugembe	18.6		Oligo	Eutro		Increase
Nkuruba	34.8		Eutro		Oligo	Decrease
Murusi	57		Oligo		Oligo	No change
Katanda	145		Eutro	Meso		Decrease

Twelve lakes experienced a net change in their trophic status between the earliest and most recent sample collection. Eight lakes experienced a net increase in their trophic status (increase in Chl-a concentration), whereas 4 lakes experienced a decrease in trophic status (reduction in Chl-a concentration).

3.2. Palaeolimnological records

3.2.2 . Lake Kamunzuka

Lake Kamunzuka has a good ^{210}Pb record, with a high surface concentration which declines regularly with depth, reaching equilibrium with the supporting ^{226}Ra at approximately 40 cm (Figure 4). The highest ^{137}Cs concentration occurs at c. 14 cm, in good agreement with the depth of 1963 as calculated from the ^{210}Pb dates using the CRS model (c. 17 cm).

The diatom assemblage from Lake Kamunzuka (Figure 5) is dominated by the epiphytic *Gomphonema gracile* (comprising 60-90% of the assemblage), with a number of notable changes. The planktonic species *Aulacoseira ambigua* is present between AD 1910-1840 (38-28 cm), declining from a maximum abundance of c. 20% to c. 2.5%. This species is succeeded by another planktonic species, *Fragilaria tenera*, which is present from AD 1830 (39 cm) at 20%, and slowly declines to <3% through record until all but disappearing from AD 1930 onwards (25 cm). Four other species are consistently present throughout the core: the planktonic *Staurosira construens* (3-6%) and *Aulacoseira granulata* (c. 7%) and the epiphytic *Encyonema minuta* (c. 5%) and *Gomphonema parvulum* (c. 6%). The most notable change with the records of these species is that from c. 1990 (10 cm) *Staurosira construens*, *Aulacoseira granulata*, and *Encyonema minuta* all decline to <1%, whilst *Gomphonema parvulum* reaches its maximum abundance (c. 20%). These assemblage changes are also demonstrated in the PCA analyses (Figure 5), with declining sample scores throughout the record, but obvious changes occurring c. AD 1870 (34 cm) and AD 1990 (10 cm).

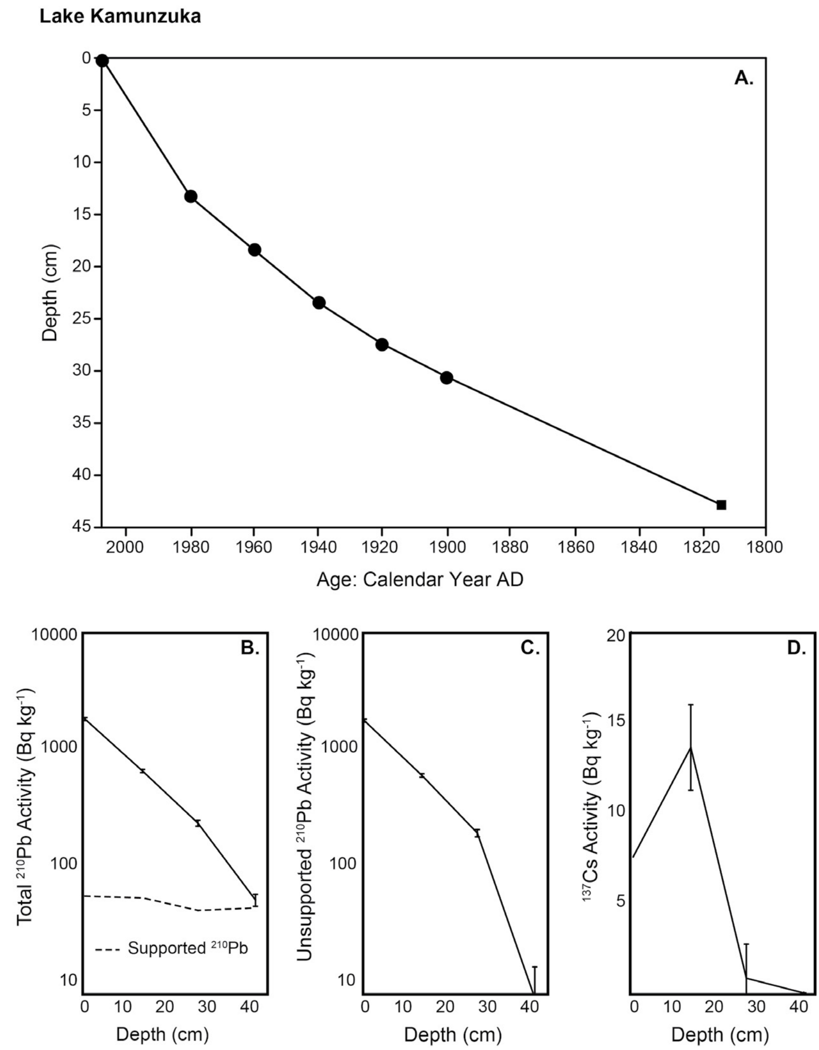

Figure 4. Lead-210 chronology for Lake Kamunzuka. (a) Dates were determined using linear extrapolation between the dated horizons [circles], the basal data [square] is based on extrapolated data. Fallout radionuclides are also shown: (b) total and supported ^{210}Pb, (c) unsupported ^{210}Pb, and (d) ^{137}Cs concentration versus depth

The sediments are rich in organics, with loss-on-ignition values between 20-40%; carbonate values are low (<5%) (Figure 5). The organic content is stable at c. 20% from AD 1810-1970 (42-15 cm). After AD 1970 the organic content increased steadily to 40%. Likewise, the DMAR is constant at c. 0.05 g cm^{-1} yr^{-1} between AD 1810-1920 (42.5-27 cm), before increasing to 0.1 g cm^{-1} yr^{-1} from AD 1920 (27 cm) (Figure 6). Peak DMAR is reached c. 1980 (0.15 g cm^{-1} yr^{-1}, 13 cm) before declining towards the top of the core.

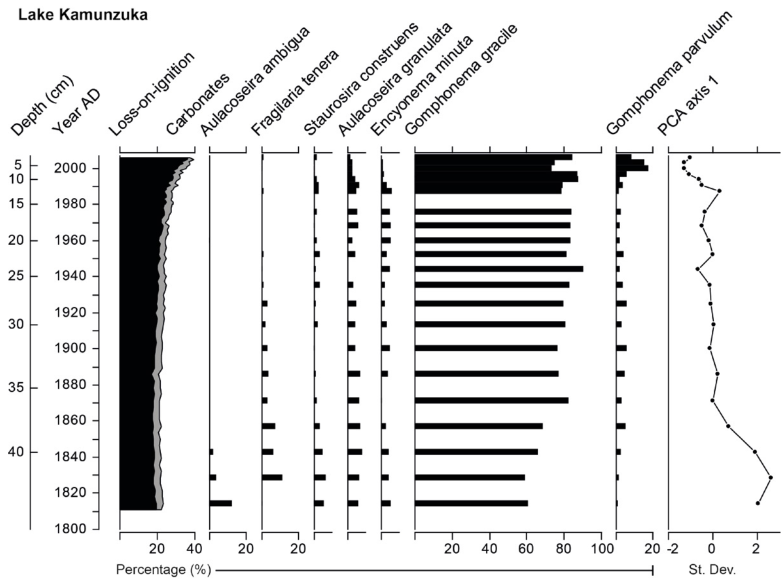

Figure 5. Results of the palaeolimnological analysis of the Lake Kamunzuka sediment core showing the down core results of loss-on-ignition (organic content) and carbonate content. The diatom assemblage data shows all species >5% abundance alongside the PCA axis 1 samples scores.

3.2.3. Lake Nyungu

The ^{210}Pb record from Nyungu, while not irregular, does demonstrate a change of gradient at c. 20 cm, attributed to an acceleration in sedimentation rate (Figure 7). Equilibrium with the supporting ^{226}Ra occurs at c. 25 cm and the highest ^{137}Cs concentration occurs at c. 18 cm. This is in agreement with the position of 1963 as calculated using the CRS model.

There is a clear divide in the diatom assemblage data between AD 1950 (18 cm) and AD 1960 (15 cm) (Figure 8). The earlier part of the record, the assemblage is dominated by the planktonic species.

Nitzschia lancettula, which reaches a maximum abundance of c. 70%. Two epiphytic species, *Amphora copulata* and *Encyonema muelleri*, are also consistently present in quantities of c. 5-15%. There is an obvious decline in the dominant *N. lancettula* between AD 1900 (26 cm) and AD 1910 (24 cm). During this short-lived phase, the aerophilous and shallow water diatoms *Luticola mutica* and *Hantzschia amphioxys* increase to a maximum abundance of c. 20%, as does, although to a lesser extent, *Diadesmis contenta* (c. 10%). From AD 1950 (18 cm), the diatom assemblage switched to a system dominated by the epiphytic *Gomphonema pumilum* and the high nutrient indicator *Nitzschia palea* (10-60% of the assemblage). Other epiphytic and shallow water diatoms (*D. contenta*, *Navicula cryptonella*, *Nitzschia amphibia* and *Gomphonema parvulum*) occur in abundances between 10-20%. It is noted that the excursions in the organic and carbonate data are mirrored with concomitant increases in the

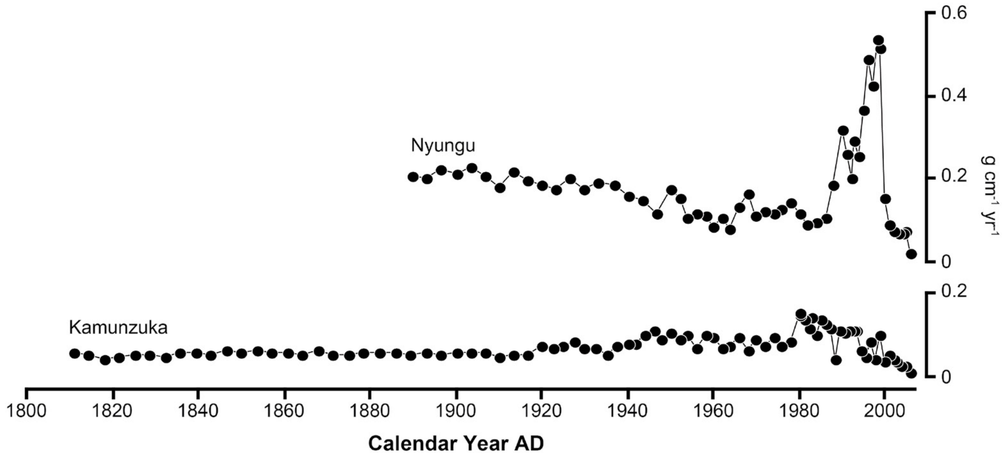

Figure 6. Calculated dry mass accumulation rates (DMAR) from lakes Kamunzuka and Nyungu over the last 200 years.

aerophilous taxon *D. contenta* at AD 1990 (8 cm) and AD 1998 (4 cm). The results of the DCA (Figure 8) show a decline in sample scores through time, with the major change occurring c. AD 1950.

Prior to AD 1950 (18 cm), the sediments from Nyungu have a low organic (c. 5%, Figure 6) and low carbonate content (c. 6%). After AD 1950 the sediments became organic-rich, increasing to a maximum of c. 30%. There are 3 notable excursions in the LOI data where values decline

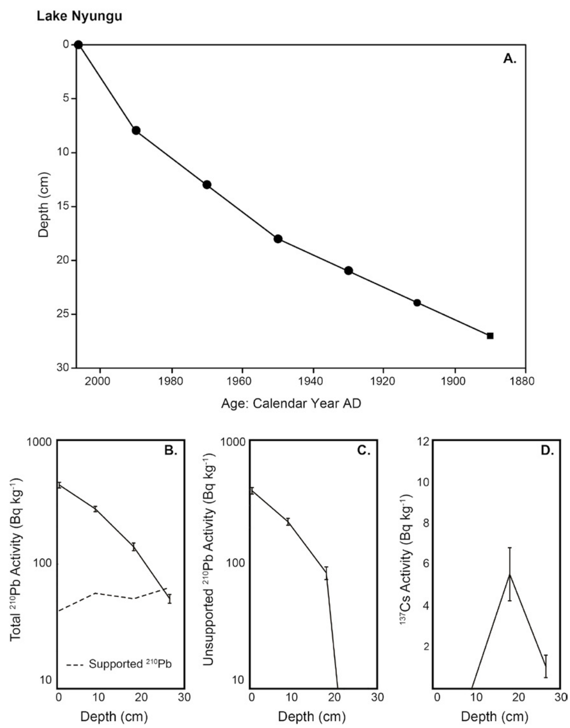

Figure 7. Lead-210 chronology for Lake Nyungu. (a) Dates were determined using linear extrapolation between the dated horizons [circles], the basal data [square] is based on extrapolated data. Fallout radionuclides are also shown: (b) total and supported 210Pb, (c) unsupported 210Pb, and (d) 137Cs concentration versus depth

to 10-15%, these occur at AD 1970 (13 cm), AD 1990 (8 cm), and AD 1998 (4 cm). Carbonate values also increase to c. 30%. The carbonate record also shows similar data excursion to the organic record, where values drop to c. 15%. The DMAR is generally low and fluctuates between 0.1-0.2 g cm-1 yr^{-1} from AD 1890-1980 (27-11 cm). A substantial and rapid increase in DMAR occurs between AD 1980 (11 cm) and AD 1998 (4 cm) to a maximum value of 0.5 g cm^{-1} yr^{-1}. Values then decline towards the top of the core (to values <0.1 g cm^{-1} yr^{-1}).

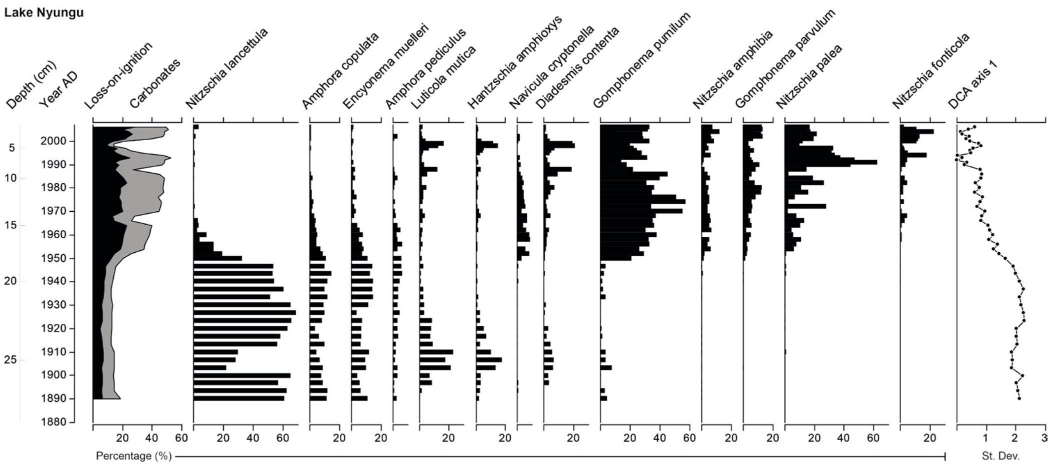

Figure 8. Results of the palaeolimnological analysis of the Lake Nyungu sediment core showing the down core results of loss-on-ignition (organic content) and carbonate content. The diatom assemblage data shows all species >5% abundance alongside the PCA axis 1 samples scores.

4. Discussion

The modern limnology datasets and palaeolimnological studies from Lakes Nyungu and Kamunzuka presented here provide insight into the changes in water quality that the crater lakes have experienced, across multiple timescales, over the past 150 years. The different approaches highlight the challenges associated with working in areas with sparse monitoring data, and the merits that a palaeolimnological approach can have in understanding lake systems that lack long term monitoring datasets. The results of the water chemistry dataset analyses (4.1, 4.2) and palaeolimnological studies (4.4) are discussed below, as well as the challenges associated with working with such sparse water chemistry datasets (4.3) and the role that palaeolimnology can play in informing sustainable lake management (4.5).

4.1 Modern water chemistry

The full 80 crater lake dataset (2.1) comprises lakes that have at least one water chemistry sample in the last 20 years (most commonly, a conductivity measurement); this comprises nearly all of the crater lakes that are documented in the western region of Uganda. To allow for a robust analysis, a criterion of requiring 2 data points from separate years for key parameters reduced this dataset by 75% (to 21 lakes). Some lakes have certain parameters collected more often than others (e.g. conductivity) reflecting the focus of particular research e.g. for developing conductivity transfer functions (Eggermont et al., 2006; Mills and Ryves, 2012) and data collection is often not systematic due to logistical constraints of field campaigns, including time in the field, the crater lake area of focus (higher number of lakes from the Kasenda and Bunyaruguru clusters have been repeatedly sampled) and site-specific access issues.

Tropical African waters have high phosphorus concentrations in comparison to unpolluted European waters. The reason for this excess could be due to phosphorus being limited in its availability to algae, or that there is insufficient demand by algae to exhaust supplies, suggesting an alternative nutrient (e.g. nitrogen) is the limiting growth factor (Kalff, 1983). The relationship between total phosphorus (TP) and total nitrogen (TN) for the lakes studied here is illustrated in Figure 9. The red and blue lines represent the TN: TP ratios of 15:1 and 7:1 (Vollenweider and Kerekes, 1982). Lakes are typically P-limited when the ratio is >15, and N limited when the ratio <7. Across the 3 years in the dataset there is a large amount of scatter, but there is a clear pattern in the data set when comparing between years. The data from 2007 suggest that there was a range in whether lakes were P or N-limited with many sitting between the two, with only 3 sites clearly having a limiting nutrient (2 lakes are clearly N-limited, 1 lake is P-limited). Moving into 2015, whilst there are still many lakes that sit between the 2 ratios, several lakes are clearly P-limited (4 lakes) and N-limited (3 lakes). The clearest shift occurred within the 2019 datasets, where nearly all lakes are now N-limited, which suggests an excess of phosphorus in the lake systems, and follows the hypothesis of Talling and Talling (1965) who suggested that N-limitation rather than P-limitation might be regionally prevalent in eastern Africa.

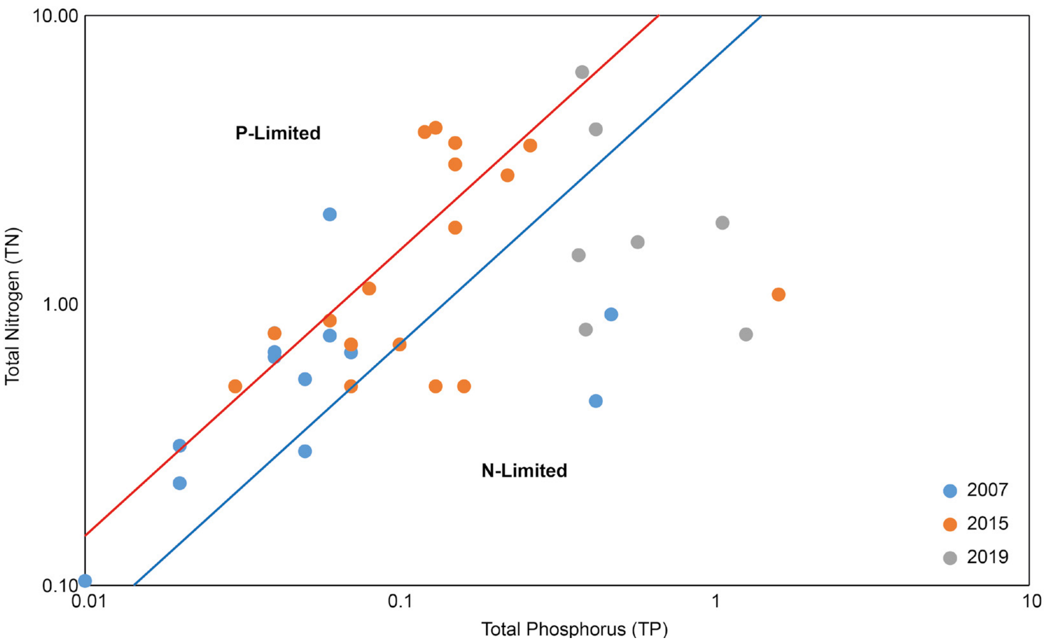

Figure 9. Total phosphorus (TP) versus Total nitrogen (TN) of the 21 crater lakes in each of the year categories. The solid lines represent 7:1 (blue) ratio and 15:1 (red) ratio. Lakes that are phosphorus limited (ratio N: P > 15:1) plot above the red line, those that are nitrogen limited (ratio N: P <7:1) plot below the blue line. Lakes that plot between the two lines may be limited by either phosphorus or nitrogen (Vollenweider and Kerekes, 1982)

The majority of measured nitrogen concentrations in the crater lakes are well below 1.5 mg l^{-1}, although 7 lakes (in at least one of the 3 years) have values that exceed this: lakes Katinda, Kyasanduka, Mirambi, Nyamogusingiri, Saaka, Kifuruka, and Wandakara. The high nitrogen values may be attributable to the large amount of human impact in the lake catchment, and inputs from animal and human waste. However, the distribution of phosphorus values with regards to the quantity of human impact within the lake catchment is less clear. This suggests that the relationship between catchment agricultural activity and total phosphorus values are far more complex and may be due to several confounding factors such as catchment geology and within-lake processes such as phosphorus cycling, affecting deposition and subsequent release of phosphorus from sediments under anoxic bottom waters.

The input of phosphorus to lake systems has likely increased in the recent past due to catchment disturbance e.g. through the clearance and burning of the natural forest for subsistence agriculture. This in conjunction with periods of intense rainfall and the steep crater slopes aids the transport of nutrients to lakes. The retention of phosphorus and nitrogen by undisturbed, well-vegetated catchments means very little is transported to lakes (Borman and Likens, 1970). Conversely, lakes situated in agricultural drainage basins with rich soils (and those receiving e.g. animal manure fertilisers) receive extremely high nutrient loads (Kalff, 2003). Human impacts, such as deforestation can result in a huge response in the aquatic systems due to the modification of catchment hydrology (Borman and Likens, 1970) and through nutrient loss from land to water through erosion and runoff. Subsequent effects are dependent on land use (e.g. bare soil, cultivation or regrowth of 'natural' vegetation). In eastern Africa, the impact of human disturbance is thought to increase in proportion to population growth (Verschuren, 2002). Climate changes can also influence the loss of nutrients from a catchment to a lake through changes in rainfall, soil moisture, and changes in runoff and erosion. Identifying which of these potential factors drive change in a given lake is difficult (Anderson, 1995; Mills et al., 2017).

4.2. Changes in lake trophic status

While the decline in lake water quality in 7 of 19 lakes across the crater lake region (Table 3) is a cause for concern in terms of declining water quality, the main conclusion that can be drawn is that the nature of change in trophic status in lakes across the region is extremely varied. There is no clear temporal or spatial pattern with regards to the changing trophic status of the lakes. The lack of a regionally uniform change suggests that the drivers of increased algal productivity, as measured by Chl-a, including eutrophication are filtered by individual lakes (Magnuson et al., 2004) or that the drivers of eutrophication within the lakes are, themselves, catchment and lake specific. Whether the lakes are responding to catchment scale change, or are filtering a regional signal, the heterogeneous nature of the trends observed across the lakes highlight the need to take a lake-by lake approach to understanding how each lake is responding to environmental changes, or to take a landscape scale approach in order to understand how different lakes respond to common regional drivers (e.g. Moorhouse et al., 2018).

The drivers of algal blooms in tropical lakes are the nutrient content of lake water, the climate, and the hydrology of the lake systems; nutrient content of lake water is most closely related to lake trophic status in the tropics (Giani et al., 2020). The water chemistry data presented here show that nearly all of the lakes across the region have experienced an increase in either, or both, lake water TN and TP concentrations. It is likely that the increase in TN and/or TP lake water concentrations have had some influence on driving the increase in trophic status observed at seven of the lakes; all of the lakes that experienced an increase in trophic status between 2006 and 2019 experienced an increase in at least one major nutrient (TN or TP), and similarly both the TN and TP concentration of lake water, and the trophic status of Lake Katanda decreased across the study period. However, a number of lakes that experienced an increase in TN and/or TP experienced no change in trophic status, and a number of lakes (including Lakes Nyungu, Mirambi, Nyamogusingiri and Nkuruba) experienced a reduction in lake trophic status. This means that nutrient concentrations of the crater lake waters are not the only driver of changes in lake productivity. Other influences, such as individual lake hydrology, or climate variability on a regional scale may be acting to counteract or exacerbate the influence of changing nutrient flux into the lakes.

The lakes in the study that were hypertrophic during the study period (such as Lakes Kyasanduka, Nyamogusingiri, Katinda, Kifuruka, and Wandakara) tended to be shallower (<20m deep). This could possibly be because shallower tropical lakes tend to be more productive than deeper lakes (Lewis, 1987). More hypertrophic lakes were located in the Bunyaruguru crater lakes than in the Kasenda crater lake clusters, although this may be an artefact of the lakes that were included in the study (more shallow lakes in the Bunyaruguru cluster were sampled than in the Kasenda cluster).

4.3. Comparing water datasets through time

The water chemistry data presented provides a snapshot of the direction and magnitude of change in lake water quality over the course of the past two decades. However, a number of challenges are faced when working with incomplete datasets that have been compiled by multiple researchers, which limits the comparisons that can be made between datasets, and therefore understanding of how the lakes have changed through time.

The earliest conductivity measurements at the crater lakes were made in 1932 (Beadle, 1932) and have been taken sporadically over the course of the 20th Century (Beadle, 1932; Talling and Talling, 1965; Kilham, 1971; Melack, 1978; Kizito et al., 1993; Chapman, 1998). The technologies used to make these measurements differ significantly to those used today, thus limiting our ability to compare these older data to more modern limnological datasets (Kizito et al., 1993). The use of differing technologies and methods to obtain modern limnological data, in particular water chemistry data, means that difficulties in comparing datasets persists, even when working with more recent datasets. For example, different methods are used by Nankabirwa (2019) to other researchers to obtain nutrient concentrations in lake water, and while the same laboratory was used to analyse water samples collected by Rumes, Verschuren, and Mills prior to 2007, samples collected by Hunt (2019) were analysed in a different laboratory, which could introduce further discrepancies.

As the datasets have mostly been collected sporadically during a number of field campaigns during the dry seasons (January-February and June-July), the data have a seasonal bias. As few measurements have been collected during the rainy seasons, understanding of the lakes during these periods is limited. The implementation of ongoing monitoring at a number of lakes, similar to the monitoring project at Lake Nkuruba as part of the Kibale Fish and Monkey Project, which has monitored the lake on a fortnightly basis since 1992 (Saulnier-Talbot et al., 2014), would help counter this bias.

The compilation of the datasets during a number of field campaigns by multiple researchers, each with different aims, means that the lakes visited and the limnological parameters measured and samples taken for analyses varies between datasets. This means that the datasets collected differ from each other, resulting in significant gaps in the datasets, and makes direct comparisons between datasets harder. By standardising the methods used, the types of observations made and the samples collected for analyses across tropical Africa, the comparability of these datasets and the conclusions drawn from them could be vastly improved.

4.4. Palaeolimnological records from Lakes Nyungu and Kamunzuka

The diatom records from lakes Kamunzuka (Fig. 5) and Nyungu (Fig. 7) provide insight into changes in both lake systems through time. Diatoms are microscopic, unicellular algae that have been used extensively to infer past environmental changes in lakes (Battarbee, 2000). Different species of diatoms are sensitive to, or have a preference for living in, waters of specific chemistries. For example, some diatom species can withstand high levels of salinity, whilst others will not tolerate high levels of nutrients. As such, diatoms are an excellent indicator of changes in water chemistry through time, from decades to hundreds of thousands of years (Stoermer and Smol, 1999), and have been used to infer changes in the salinity of lake waters driven by changes in precipitation (Mills and Ryves, 2012) and for understanding the timing and impact of nutrient enrichment of lake waters (Davidson and Jeppesen, 2013). In eastern Africa, correlations have been established between diatom species composition and pH (Gasse et al., 1995), salinity (Hecky and Kilham, 1973), conductivity (Gasse et al., 1995) and ionic composition (Gasse et al., 1983).

Kamunzuka is a deep (c. 60 m) and clear lake, with a large euphotic depth (>20 m) which allows epiphytic *Gomphonema* species (those attached to plants) to dominate alongside the planktonic *Aulacoseira* species. The dominant Gomphonema species (*Gomphonema gracile*) has a preference for waters with a low nutrient content (Patrick and Reimer, 1975). The only obvious perturbation that occurs in this lake is during the earliest phase of the record (c. AD 1830) where there is a slight decrease in the relative abundance of *Gomphonema gracile* and a higher percentage of *Fragilaria tenera*, perhaps indicative of large inputs of very fresh waters (Kelly et al., 2005). The presence of *Aulacoseira granulata* throughout the record attests to high silica and high light conditions. For *Aulacoseira* species to occur there must be turbulence within the water column, to aid buoyancy and to keep the genus suspended in the photic zone.

There is coherence between the amount of sedimentation (Fig. 6) and the diatom data, with the most obvious excursion, occurring c. AD 1980-1995, where there is an increase in the DMAR and a concomitant shift in the diatom assemblage, as evidenced by change in the PCA samples scores, driven by the increase in the diatom *Gomphonema parvulum* which is often used as an indicator of environmental stress (Sabater, 2000).

In Lake Nyungu, prior to AD 1950, the diatom assemblage data suggest that the lake was deep and fresh (*Nitzschia lancettula*), with vegetated lake shores (*Amphora copulata*, *Encyonema muelleri*). A major switch in the diatom assemblage occurs at c. AD 1950, and the planktonic freshwater *N. lancettula* disappeared from the record by AD 1965. The loss of the epiphytic diatom species suggests that the previously established littoral vegetation was destabilised, and the once clear water system was replaced by a more turbid lake with an assemblage dominated by periphytic and benthic species, most notably *Gomphonema pumilum* and *Nitzschia palea.* Aerophilous species *Hantzschia amphioxys*, *Luticola mutica* and *Diadesmis contenta* are also consistently present throughout this zone. The presence of *Gomphonema pumilum* perhaps attests to lower oxygen content in the lake water than the earlier assemblage (Gasse, 1986). The increase and variation in the *Nitzschia palea* record from c. AD 1990 appears to be closely related to increases in the input of catchment sediments to the lake system (Sabater, 2000). *Nitzschia palea* is an indicator of turbid waters with a heavy load of decomposed organic matter (Leland et al., 2001) as well as being indicative of eutrophic/hyper-eutrophic conditions (van Dam et al., 1994).

Overall, Lake Kamunzuka with its more ‘natural’ catchment reveals very little variation in its diatom assemblage since AD 1810. Conversely, ‘impacted’ Lake Nyungu indicates a significant shift in the diatom assemblage data in the last c. 50 years, with a change in habitat from a planktonic to a benthic dominated system. The major changes in the diatom flora are coincident with an increase in the flux of sediment to the lake system. Even in Lake Kamunzuka, there is evidence for an increase in sediment delivery to the system in the last 20 years of the core record. The increases in sediment flux to the lakes over the last 20-50 years is not unique to the two systems presented here (e.g. Mills, 2009; Mills et al., 2014; Mills et al., 2018). The near simultaneous increase in sediment delivery to the two lakes suggests that there is a regional driver for changes in the recent record, and this is likely related to major human disturbance of the lake catchments (e.g. clearance of natural vegetation for agriculture). The increase in the dry mass accumulation, inferred to mark an increase in the amount of organic and minerogenic material being delivered to the lake system, is coincident with increases in benthic, periphytic and aerophilous diatom taxa in Lake Nyungu, suggesting a causal link between diatom response and catchment disturbance. Although in many instances sediment influx has decreased in the most recent period (late 1990s), the relative abundance of benthic and periphytic taxa remain high. This could be the result of the crossing of a threshold within the lakes.

There is evidence of increasing human impacts over the last 150 years in the region of western Uganda, with changes in catchment vegetation due to the replacement of forest with agriculture (Ssemmanda et al., 2005). Vegetation changes affect catchment hydrology, and it is likely that the diatom assemblage changes are driven by nutrient enrichment and/or changes in the turbidity of water, and hence light availability (Battarbee, 2000; Verschuren, 2003). The removal of catchment vegetation for small-scale agriculture and plantations could have a large effect on the amount of sediments delivered to the lake and the rates of sediment delivery to the system in the last 50 years is unprecedented when compared to the preceding decades.

The increase in the delivery of sediments to the lake systems is also likely to have caused an increase in the amount of nutrients delivered to the lake system. Increasing nutrients can lead to the deterioration of lake water quality, largely through eutrophication. Cultural eutrophication of lake waters occurs as a result of human activity within the lake's catchment that increases the nutrient input to the aquatic ecosystem, which can in turn increase algal productivity and can lead to water quality issues and deep-water anoxia (Smith, 1998). Whilst many studies have shown that early societies have modified catchments (e.g. removal of vegetation for agricultural purposes) and therefore water chemistries of lakes in Europe (Fritz, 1989), tropical America (Anselmetti et al., 2007) and North America (Ekdahl et al., 2004), the study of human impacts on lacustrine ecosystems and the onset of cultural eutrophication in eastern Africa, has been limited to the larger lakes, such as lake Victoria (Verschuren et al., 2002) and Malawi (Hecky, 2000). The only exception to this is a comparative study of data over a 30-year span (1971-2000) at Lake Saaka, near Fort Portal, which suggested that eutrophication had occurred over the time period in question. Although this study was based on one dataset collected in 1971 (Melack, 1978) and compared to data collected during monthly monitoring between 1995 and 1998, it indicated that the lake had been undergoing cultural eutrophication since the 1970s. This eutrophication was attributed the enlargement of a prison farm and agricultural expansion on the flanks of the crater as well as the introduction of Nile perch in the 1970s which would have caused alterations to the food web, leading to the observed increase in trophic state (Crisman et al., 2001).

It is likely that changes in catchment hydrology (both natural and/or anthropogenic) and the increase in nutrient inputs since the early 1900s has fundamentally, and perhaps permanently, modified the lake ecosystems under investigation. Similar studies from Uganda show enhanced phytoplankton production since AD 1950 and AD 1970 in Lakes Kanyanmukali and Chibwera (Bessems et al., 2008), though only the change in Kanyanmukali is attributed to cultural eutrophication as a result of subsistence agriculture within the lake's catchment.

4.5. Palaeolimnology and lake management

Palaeolimnology is a valuable tool which can be used to provide long term records of ecological and environmental change in lakes, and, therefore, as an evidence-base to inform the future management of lake systems (Sayer et al., 2012). Its use has been proposed to assist with large scale water quality monitoring and restoration projects such as the EU Water

Framework Directive (Bennion and Battarbee, 2007). Palaeolimnological studies from the Ugandan crater such as those described here are a promising, but currently underutilised, tool for informing the management of these systems.

Palaeolimnological datasets are a cost-effective way of adding to and extending datasets back in time, which improves our ability to understand the range of drivers of environmental changes (Bennion and Battarbee, 2007) and identify which are particularly important in a given system (Moorhouse et al., 2018). Multi-proxy studies in particular, and their integration with modern limnological and catchment datasets, can establish the relative importance of such drivers (Davidson and Jeppesen, 2013). Furthermore, core data complement monitoring data in terms of temporal scale. While monitoring data is highly sensitive to short term variability, the time integrated nature of palaeolimnological datasets means that the 'noise' associated with high frequency data is smoothed and is therefore can be easier to interpret with regards to long term change (Bennion and Battarbee, 2007).

Palaeolimnology is also able to provide a 'baseline' of conditions for a lake or region prior to catchment disturbance and recent climate changes, as lake monitoring often post-dates these (Bennion et al., 2010). This multi decadal, or centennial perspective is often a far more appropriate baseline with which to compare current lake water conditions to, and for setting management targets in relation to (Bennion and Battarbee, 2007; Bennion et al., 2010).

5. Conclusions

The variability of lakes, both physically and chemically, is well known and has been intensively studied in temperate regions, with many long-term monitoring stations in place. In comparison, tropical lakes are under-studied, with many of the published studies based on just a single sample per lake (Escobar et al., 2020). The lack of knowledge regarding the functioning of these lake systems in tropical regions can lead to generalisations (Hutchinson, 1957, Talling and Lemoalle, 1998) which have consequences in terms of our ability to successfully manage these systems.

The results presented here show a clear regional pattern of lake change in western Uganda over recent decades but highlight the numerous drivers that could drive these changes and that, despite some general patterns, not all lake systems behave in the same way. The importance of a co-ordinated monitoring approach is therefore clear, with palaeolimnology able to provide a much-needed longer term perspective, and a baseline to these recently observed trends. The importance of understanding each lake on its own merits, from a monitoring or palaeolimnological perspective is also highlighted.

Palaeolimnology provides a potentially logistically and economically friendly way of retrospectively monitoring lakes through time, especially when combined with targeted shorter-term monitoring programmes. Combined they provide the potential to inform management decisions to sustain lake ecosystems in a healthy state, for the benefit of all users.

The work described and discussed in this paper leads to a number of specific recommendations for future academic and policy driven research projects for east African lakes:

- A co-ordinated, ongoing monitoring of multiple lakes across the region, including standardisation of field and laboratory practises to allow comparison and amalgamation of datasets.
- Clear protocols for access (for uploading and downloading data) to databases.
- Multiproxy core studies to capture potential drivers and lake responses and to provide benchmarks for management targets.

- A landscape palaeolimnological approach i.e. using multiple sites to understand how different lake systems may respond to common drivers.

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References

Anderson, N.J. (1995) Using the past to predict the future: lake sediments and the modelling of limnological disturbance, Ecological Modelling 78: 149-172

Anselmetti, F.S., Hodell, D.A., Ariztegui, D., Brenner, M., Rosenmeier, M.F. (2007) Quantification of soil erosion rates related to ancient Maya deforestation, Geology 35: 915-918

Appleby, P.G. (2001) Chronostratigraphic techniques in recent sediments. In: Last, M.L., Smol, J.P. (eds.) Tracking Environmental Change Using Lake Sediments: Basin Analysis, Coring, and Chronological Techniques, Kluwer Academic Publishers, Dordrecht, The Netherlands, p 171-203

Appleby, P.G., Oldfield, F. (1978) The calculation of 210Pb dates assuming a constant rate of supply of unsupported 210Pb to the sediment, Catena 5:1-8

Appleby, P.G., Nolan, P.J., Gifford, D.W., Godfrey, M.J., Oldfield, F., Anderson, N.J., Battarbee, R.W. (1986) ^{210}Pb dating by low background gamma counting, Hydrobiologia 141:21-27

Battarbee, R.W., Jones, R.V., Flower, R., Cameron, N.G., Bennion, H., Carvalho, L., Juggins, S. (2001) Diatoms. In: Smol, J.P., Birks, H.J.B., Last, W.M. (Eds) Tracking Environmental Change Using Lake Sediments: Terrestrial, Algal, and Siliceous Indicators, Kluwer Academic Publishers, Dordrecht, The Netherlands. p. 155-202

Battarbee, R.W. (2000) Palaeolimnological approaches to climate change, with special regard to the biological record, Quaternary Science Reviews 19:107-124, doi 10.1016/S0277-37991(99)00057-8

Bennion, H., Battarbee, R. (2007) The European Union Water Framework Directive: opportunities for palaeolimnology Journal of Paleolimnology 38:285-295, doi 10.1007/s10933-007-9108-z

Bennion, H., Battarbee, R., Sayer, C.D., Simpson, G.L. (2010) Defining Reference Conditions and Restoration Targets for Lake Ecosystems Using Palaeolimnology: A Synthesis, Journal of Paleolimnology 45(4):533-544, doi 10.1007/s10933-010-9419-3

Bessems, I., Verschuren, D., Russell, J.M., Hus, J., Mees, F., Cumming, B.F. (2008) Palaeolimnological evidence for widespread late 18th century drought across equatorial East Africa, Palaeogeography Palaeoclimatology Palaeoecology 259:107-120, doi 10.1016/j.palaeo.2007.10.002

Birks, H.H., Birks, H.J.B. (2006) Multi-proxy studies in palaeolimnology, Vegetation History and Archaeobotany 15:235-251, doi 10.1007/s00334-006-0066-6

Beadle, L.C. (1932) The waters of some East African Lakes in relation to their fauna and flora, Journal of the Linnean Society (Zoology) 38: 157-211, doi 10.1111/j.10963642.1932.tb00699.x

Borman, F.H., Likens, G.E. (1970) The nutrient cycles of an ecosystem, Scientific American 223: 92-101

Chapman, L.J., Chapman, C.A., Crisman, T.L., Nordlie, F.G. (1998) Dissolved oxygen and thermal regimes of a Ugandan crater lake. Hydrobiologia 385: 201-211 doi 10.1023/A:1003527016384

Cocquyt, C. (1998) Diatoms from the Northern Basin of Lake Tanganyika, Bibliotheca Diatomologica 39, Crammer, Berlin/Stuttgart

Colombaroli, D., Ssemmanda, I., Gelorini, V., Verschuren, D. (2014) Contrasting long term records of biomass burning in wet and dry savannas of equatorial East Africa, Global Change Biology 20(9) doi 10.1111/gcb.12583

Crisman, T.L., Chapman, L.J., Chapman, C.A., Prenger, J. (2001) Cultural eutrophication of a Ugandan highland crater lake: a 25-year comparison of limnological parameters, Verhandlungen Internationale Vereinigung für Limnologie 27:3574-3578

Dalton, C., Taylor, D., Jennings, E. (2009) The role of palaeolimnology in implementing the water framework directive in Ireland, Biology and Environment: Proceedings of the Royal Irish Academy 109 (B):161-174, doi 10.3318/ BIOE.2009.109.3.161

Davidson, T.A., Jeppesen, E. (2013) The role of palaeolimnology in assessing eutrophication and its impact on lakes, Journal of Palaeolimnology 49:391–410, doi 10.1007/s10933-012-9651-0

Dean, W.E. (1974) Determination of carbonate and organic matter in calcareous sediments and sedimentary rocks by loss on ignition: Comparison with other methods, Journal of Sedimentary Petrology 44: 242–248

Dubois, N., Saulnier-Talbot, E., Mills, K., Gell, P., Battarbee, R., Bennion, H., Chawchai, S., Dong, X.H., Francus, P., Flower, R., Gome, D.F., Gregory-Eaves, I., Humane, S., Kattel, G., Jenny, J.,Langdon, P., Massaferro, J., McGowan, S., Mikomagi, A., Ngoc, N.T.M., Ratnayake, A.S., Reid, M., Rose, N., Saros, J., Schillereff, D., Tolotti, M., Valero-Garces, B. (2018) First human impacts and responses of aquatic systems: A review of palaeolimnological records from around the world, Anthropocene Review 5:28-68, doi 10.1177/2053019617740365

Eggermont, H., Heiri, O., Verschuren, D. (2006) Fossil Chironomidae (Insecta : Diptera) as quantitative indicators of past salinity in African lakes, Quaternary Science Reviews 25:1966-1994

Ekdahl, E.J., Teranes, J.L., Guilderson, T.P., Turton, C.L., McAndrews, J.H., Wittkop, C.A, Stoermer, E.F. (2004) Prehistorical record of cultural eutrophication from Crawford Lake, Canada, Geology 32: 745-748

Escobar, J., Serna, Y., Hoyos, N., Velez, M.I., Correa-Metrio, A. (2020) Why we need more paleolimnology studies in the tropics, Journal of Paleolimnology 64:47-53, doi:10.1007/ s10933-02000120-6

Fritz, S.C. (1989) Lake development and limnological response to prehistoric and historic land-use in Diss, Norfolk, U.K, Journal of Ecology 77: 182–202

Fritz, S.C. (2008) Deciphering climatic history from lake sediments, Journal of Paleolimnology 39:5-16, doi 10.1007/s10933-007-9134-x

Gasse, F. (1986) East African diatoms; Taxonomy, ecological distribution, Bibliotheca Diatomologica 11, Crammer, Berlin/Stuttgart.

Gasse, F., Talling, J.F., Kilham, P. (1983) Diatom assemblages in East Africa: classification, distribution and ecology, Review Hydrobiology Tropical 116: 3-34

Gasse, F., Juggins, S., Ben Khelifa, L. (1995) Diatom-based transfer functions for inferring past hydrochemical characteristics of African lakes, Palaeogeography, Palaeoclimatology, Palaeoecology 117: 31-54

Gelorini, V., Verbeken, A., van Geel, B., Cocquyt, C., Verschuren, D. (2011) Modern non-pollen palynomorphs from East African lake sediments Review of Palaeobotany and Palynology 164:143-173, doi 10.1016/j.revpalbo.2010.12.002

Gill, J.C., Mankelow, J., Mills, K. (2019) The Role of Earth and Environmental Science in Addressing Sustainable Development Priorities in Eastern Africa, Environmental Development 30:3-20 doi 10.1016/j.envdev.2019.03.003

Hecky, R.E. (2000) A biogeochemical comparison of Lakes Superior and Malawi and the limnological consequences of an endless summer, Aquatic Ecosystem Health and Management 3: 23-33

Hecky, R.E., Kilham, P. (1973). Diatoms in alkaline, saline lakes: Ecology and geochemical implications, Limnology and Oceanography 18: 53-71

Ho, J.C., Michalak, A., Pahlevan, N. (2019) Widespread global increase in intense lake phytoplankton blooms since the 1980s, Nature 547:667-670, doi 10.1038/s41586-019-1648-7

Hutchison, G.E. (1957) A treatise on limnology. John Wiley & Sons, New York.

Jones, M.N. (1984) Nitrate reduction by shaking with cadmium, alternative to cadmium columns, Water Research 18: 643–646

Juggins, S. (2003) C2User Guide; Software for Ecological and Palaeoecological Data Analysis and Visualisation, https://www.staff.ncl.ac.uk/stephen.juggins/software/code/C2.pdf.

Kalff, J. (1983) Phosphorus limitation in some tropical African lakes, Hydrobiologia 100:101-112

Kalff, J. (2003) Limnology. Prentice Hall Inc., New Jersey

Kelly, M.G., Bennion, H., Cox, E.J., Goldsmith, B., Jamieson, J., Juggins, S., Mann, D.G., Telford, R.J. (2005) Common freshwater diatoms of Britain and Ireland: an interactive Key, Environment Agency, Bristol

Kilham, P. (1971) Biogeochemistry of African lakes and rivers. Ph.D. thesis, Duke University, Durham, N.C.

Kizito, Y., Nauwerck, A., Chapman, L.J., Koste, W. (1993) A limnological survey of western Uganda crater lakes, Limnologica **23**: 335-347

Krammer, K., Lange-Bertalot, H. (1986) Bacillariophyceae. 1. Teil: Naviculaceae. In: Ettl H, Gerloff J, Heynig H, Mollenhauer D (eds.) Süßwasserflora von Mitteleuropa, Band 2/1, Gustav Fischer Verlag, Suttgart, New York.

Krammer, K., Lange-Bertalot, H. (1988) Bacillariophyceae. 2. Teil: Bacillariaceae, Epithemiaceae, Surirellaceae. In: Ettl H, Gerloff J, Heynig H, Mollenhauer D (eds.) Süßwasserflora von Mitteleuropa, Band 2/2, Gustav Fischer Verlag, Jena.

Krammer, K., Lange-Bertalot, H. (1991a) Bacillariophyceae. 3. Teil: Centrales, Fragilariaceae, Eunotiaceae. In: Ettl H, Gerloff J, Heynig H, Mollenhauer D (eds.) Süßwasserflora von Mitteleuropa, Band 2/3, Gustav Fischer Verlag, Stuttgart, Jena.

Krammer, K., Lange-Bertalot, H. (1991b) Bacillariophyceae. 4. Teil: Achnanthaceae, kritsche erganzungen zu Navicula (Lineolatae) und Gomphonema Gesamliteraturverzeichnis. In: Ettl H, Gerloff J, Heynig H, Mollenhauer D (eds.) Süßwasserflora von Mitteleuropa, Band 2/4, Gustav Fischer Verlag, Stuttgart, Jena.

Leland, H.V., Brown, L.R., Mueller, D.K. (2001). Distribution of algae in the San Joaquin River, California, in relation to nutrient supply, salinity and other environmental factors, Freshwater Biology 46: 1139-1167

Lewis, W.M. (1987) Tropical Limnology, Annual Review of Ecology, Evolution, and Systematics 18:159-84.

Mackereth, F.J.H., Heron, J., Talling, J.F. (1978) Water analysis: some revised methods for limnologists. Freshwater Biollogical Association, Ambleside, United Kingdom.

Magnuson, J.J., Benson, B.J., Kratz, T.K. (2004) Patterns of coherent dynamics within and between lake districts at local to intercontinental scales, Boreal Environment Research 9:359-369

Melack, J.M. 1978. Morphometric, physical and chemical features of the volcanic crater lakes of western Uganda. Archiv Fur Hydrobiologie 84, 430-453.

Mills, K. (2009) Ugandan Crater Lakes: Limnology, Palaeolimnology, Palaeoenvironmental History. PhD Thesis, Loughborough University

Mills, K., Ryves, D.B. (2012) Diatom-based models for inferring past water chemistry in western Ugandan crater lakes, Journal of Palaeolimnology 48:383–399, doi 10.1007/s10933-012-9609-2

Mills, K., Ryves, D.B., Anderson, N.J., Bryant, C.L., Tyler, J.J. (2014) Expressions of climate perturbations in western Ugandan crater lake sediment records during the last 1000 years, Climate of the Past 10:1581-1601, doi 10.5194/cp-10-1581-2014

Mills, K., Schillereff, D., Saulnier-Talbot, E., Gell, P., Anderson, N.J., Arnaud, F., Dong, X.H., Jones, M., McGowan, S., Massaferro, J., Moorhouse, H., Perez, L., Ryves, D.B. (2017) Deciphering long-term records of natural variability and human impact as recorded in lake sediments: a palaeolimnological puzzle, Wiley Interdisciplinary Reviews - Water 4:e1195, doi 10.1002/wat2.1195

Mills, K., Vane, C.H., dos Santos, R.A.L., Ssemmanda, I., Leng, M.J., Ryves, D.B. (2018) Linking land and lake: Using novel geochemical techniques to understand biological response to environmental change, Quaternary Science Reviews 202:122-138, doi 10.1016/j.quascirev.2018.09.038

Moorhouse, H.L., McGowan, S., Taranu, Z.E., Gregory-Eaves, I., Leavitt, P.R., Jones, M.D., Barker, P., Brayshaw, S.A. (2018) Regional versus local drivers of water quality in the Windermere catchment, Lake District, United Kingdom: The dominant influence of wastewater pollution over the past 200 years. Global Change Biology 24: 4009-4022, doi 10.1111/gcb.14299

Nankabirwa, A., De Crop, W., Van der Meeren, T., Cocquyt, C., Plisnier, P.D., Balirwa, J., Verschuren, D. 2019. Phytoplankton communities in the crater lakes of western Uganda, and their indicator species in relation to lake trophic status. Ecological Indicators 107: 105563, doi 10.1016/j.ecolind.2019.105563

Ndebele-Murisa, M.R., Musil, C.F., Raitt, L. (2010) A review of phytoplankton dynamics in tropical African lakes, South African Journal of Science 106(1/2):13-18, doi 10.4102/sajs.v106i1/2.64

Patrick, R., Reimer, C.W. (1975) The diatoms of the United States. Vol. 2, Part 1, Monographs of the Academy of Natural Sciences of Philadelphia, Number 13

Rumes, B., Eggermont, H., Verschuren, D. (2005) Representation of aquatic invertebrate communities in subfossil death assemblages sampled along a salinity gradient of western Uganda crater lakes, Hydrobiologia 542:297-314, doi 10.1007/s10750-004-1873-3

Renberg, I. (1990) A procedure for preparing large sets of diatom slides from sediment cores, Journal of Paleolimnology 4: 87-90, doi 10.1007/BF00208301

Richards, F.A., Thompson, T.G. (1952) The estimation and characterisation of plankton populations by pigment analyses. II. A spectrophotometric method for the estimation of plankton pigments, Journal of Marine Research 11:156-172

Rumes, B., Eggermont, H., Verschuren, D. (2011) Distribution and faunal richness of Cladocera in western Uganda crater lakes, Hydrobiologia 676:39-56, doi 10.1007/s10750-011-0829-7

Ryves, D.B., Mills, K., Bennike, O., Brodersen, K.P., Lamb, A.L., Leng, M.J., Russell, J.M., Ssemmanda, I. (2011) Environmental change over the last millennium recorded in two contrasting crater lakes in western Uganda, eastern Africa (Lakes Kasenda and Wandakara), Quaternary Science Reviews 30:555-569 doi 10.1016/j.quascirev.2010.11.011

Sabater, S. (2000) Diatom communities as indicators of environmental stress in the Guadiamar River, S-W Spain, following a major mine tailings spill, Journal of Applied Phycology 12: 113-124

Saulnier-Talbot, E., Gregory-Eaves, I., Simpson, K.G., Efitre, J., Nowlan, T.E., Taranu, Z.E., Chapman, L.J. (2014) Small Changes in Climate Can Profoundly Alter the Dynamics and Ecosystem Services of Tropical Crater Lakes, Plos One 9(1): e86561, doi 10.1371/journal.pone.0086561

Sayer, C.D., Bennion, H., Davidson, T.A., Burgess, A., Clarke, G., Hoare, D., Frings, P., Hatton-Ellis, T. (2012) The application of palaeolimnology to evidence based lake management and conservation: examples from UK lakes, Aquatic Conservation: Marine and Freshwater Ecosystems 22(2):165-180 , doi 10.1002/aqc.2221

Smith, V.H. (1998) Cultural eutrophication of inland, estuarine and coastal waters. In: Pace ML, Groffman PM (Eds) Successes, limitations and frontiers in ecosystem Science, Springer, New York

Ssemmanda, I., Ryves, D.B., Bennike, O., Appleby, P.G. (2005) Vegetation history in western Uganda during the last 1200 years: a sediment-based reconstruction from two crater lakes, Holocene 15:119-132, doi 10.1191/0959683605hl774rp

Stoermer, E.F., Smol, J.P. (1999) The Diatoms: Applications for the Environmental and Earth Sciences, Cambridge University Press

Talling, J.F., Talling, I.B. (1965) The chemical composition of African Lake waters, International Revue gesamten Hydrobiologie 50: 421-463

Talling, J.F., Lemoalle, J. (1998) Ecological dynamics of tropical inland waters. Cambridge University Press.

Taylor, D., Robertshaw, P. (2001) Sedimentary sequences in western Uganda as records of human environmental impacts, Palaeoecology of Africa 27: 63-76

Temple, P.H. (1971) The Lakes of Uganda. In: Ominde SH (ed) Studies in East African Geography and Development. Heinneman, London. p. 86-99.

Ter Braak, C.J.F., Šmilauer P (2002) CANOCO reference manual and CanoDraw for Windows user's guide: software for canonical community ordination (version 4.5). Microcomputer Power, Ithaca, New York.

Uganda Government Department of Land and Surveys (1962) Atlas of Uganda. Government Printer, Entebbe, Uganda.

United Nations Water (2006) Gender, water and sanitation: A policy brief, https://www.unwater.org/publications/gender-water-sanitation-policy-brief. Cited 28 July 2020.

Van Dam, H., Mertens, A., Sinkeldam, J. (1994) A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. Netherlands Journal of Aquatic Ecology 28: 117-133

Verschuren D (2003) Lake-based climate reconstruction in Africa: progress and challenges, Hydrobiologia 500: 315–330, doi 10.1023/A:1024686229778

Verschuren, D., Johnson, T.C., Kling, H.J., Edgington, D.N., Leavitt, P.R., Brown, E.T., Talbot, M.R., Hecky, R.E. (2002) History and timing of human impact on Lake Victoria, East Africa, Proceedings of the Royal Society of London (B) 269: 289-294

Vollenweider R A and Kerekes J (1982) Eutrophication of Waters, Monitoring, Assessment and Control. OECD, Paris

World Bank Group (2020) Historical Climate Data - Uganda, Climate Change Knowledge Portal, https://climateknowledgeportal.worldbank.org/country/Uganda. Cited 26 October 2020

The Impact of Water Insecurity on Female Youths in Africa: A Review

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Abstract

Water security is a term used to describe the availability of clean water concerning its sustainability. Recently, water security has gained more prominence among researchers and international organizations as it is identified as an essential concept of United Nations Sustainable Development Goal 6 (SDG 6). The aim and objective of this paper are to analyze the impact of water security on female youth in Africa. Searches for relevant medical literature published since 2010 in biomedical databases like Google Scholar and PubMed were conducted using the key terms. Papers were selected by reviewing their abstracts and titles and also using supplementary references gotten from the list of references for the paper. Rural women are vulnerable to several dangers that threaten their physical security due to their performance of fetching water's daily activity. Water insecurities in school environments affect the menstrual health of female youth negatively. Water insecurity is also linked to increased mortality and morbidity caused by waterborne diseases from inadequate sanitation and hygiene. As a result of the long period that women spend on fetching water for drinking, cooking, and sanitation, women and girls' time to engage in productive activities is greatly reduced. Unequal rights in water access and use continue to exist in Africa. Studies however, show that policy reform and local initiatives can bring positive changes on issues that relate to female youths and water security in Africa.

Keywords: Water insecurity; Africa; Women; Females; Girls.

1. Introduction

Access to clean and drinkable water is an essential human need and right for good health and smooth economic and industrial activities. Due to its necessity for survival, global water security is ranked among the top five most significant societal impacts (Global Risk Report, 2019). Water security is a term used to describe the availability of clean water concerning its sustainability. There are different definitions of 'water security depending on the discipline and water needs. One of the broad definitions of water security was developed by Geere and Cortobius. They defined water security as 'the availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems, and production, coupled with an acceptable or tolerable level of water-related risks to people, environments, and economies'(Geere et al., 2017). Recently, water security has gained more prominence among researchers and international organizations. It is identified as an essential concept of United Nations Sustainable Development Goal 6 (SDG 6) and plays a key role in achieving other SDGs, including SDG 3 (Wateraid, 2018). Zeitoun (2011) described six water security elements that contribute to its availability globally: human/community security; national security; climate security; energy security; food security; and water resources security. The interactions between these external securities contribute to the availability of sustainable water in the community. Water security in countries of Sub-Saharan Africa is low compared to that of developed countries. Nine out of ten countries with the lowest access to water are African and constitute the bulk of the 60% of the world's population reported to be experiencing water stress (Zeitoun, 2011). Most Africans, especially those in rural areas, walk several miles to get access to water which sometimes, may be unclean or even unavailable. Climate change is one of the most significant challenges to water security globally. However, poverty, lack of infrastructure, poor government policies, rapid population growth, poor hygiene and sanitation are other important factors that threaten water security in Africa (Water security framework, 2012).

Water security is required to promote agriculture and food security, foster personal hygiene, and alleviate poverty (Sinyolo et al., 2014). Irrigation is an innovative way to of managing available water in agriculture. It is necessary to maintain food production throughout the year in most African countries that experience drought and high spatial and temporal variability in rainfall. Besides, water security plays a crucial role in improving personal hygiene in Africa. Menstrual hygiene, oral hygiene, bathing, handwashing, and proper waste disposal are personal hygiene practices and require access to clean water. Therefore, poor personal hygiene in Africa may be attributed to a lack of water security in most continent areas. For example, an estimated 100 million and 63 million Nigerians still lack basic sanitation facilities and improved source of drinking water, respectively (UNICEF & WHO, 2015). In Uganda, only 38% of the population has access to clean water close to home (UNICEF & WHO, 2015). Poor personal hygiene increases the spread of infectious diseases and mortality rate in Africa. Hence, water insecurity in Africa has continued to hinder efforts to improve Africans' health and well-being. However, children and women are the most vulnerable population affected by water insecurity. They are culturally responsible for fetching water for cooking, and other household uses in most African countries.

Fetching water over a long distance exposes female youth to sexual harassment and injuries, including fractures and dislocations (Venkataramanan et al., 2015). Moreover, female youths require water to maintain menstrual hygiene, which is essential for their health and well-being. The aim and objective of this paper are to analyze the impact of water security on female youths in Africa. The female gender was chosen because the lack of access to safe water affects them more than the male gender, as revealed by our literature review.

2. Methods

A review of published articles on the impact of water security on female youths in Africa was conducted. Searches for relevant medical literature in biomedical databases like Google Scholar and PubMed were conducted using the following key terms: "Water Security," "Female," "Africa," "Youth," and "Menstrual hygiene". Papers were selected by reviewing their abstracts and titles and also using supplementary references obtained from the list of references on the paper. The time span for the literature search was set from 1st January, 2010 to 30th June, 2020. Relevant diagrams gotten from reviews to further buttress findings and conclusions further.

3. Result and Discussion

3.1. Prevalence of water insecurity in Africa

According to Ritchie and Roser (2019), people living in Africa are among the most disadvantaged with respect to access to safe and sufficient water supply. Recent findings on this issue are illustrated in figure 1 (Ritchie and Roser, 2019), which depicts that the percentage of access to and sufficient supply of safe water for most urban and rural areas in sub-Saharan Africa is 50-60 % (Fleifel et al. 2019, Pommells et al. 2018, Ritchie et al 2019). It was also discovered that people living in rural areas suffer more than those in urban areas in terms of water insecurity. To back up this study, a peer-reviewed publication on access to water, sanitation, and hygiene in Sub-Saharan Africa shows that access to water, sanitation, and hygiene across 25 countries in Africa is less than 20% (Figure 2) (Fleifel et al 2019, Pommells et al 2018, Ritchie et al 2019).

While the burden of water insecurity affects those in rural areas than urban areas, it also weighs disproportionately on the grounds of gender (Fleifel et al. 2019, Pommells et al. 2018, Ritchie and Roser, 2019). In relation to gender disparity, female youths are at a disadvantage in meeting their basic water needs from the dangers and health risks in fetching water to meeting sanitation needs. In most African countries, it is the responsibility of the females to fetch water. The joint monitoring program highlighted this burden on African women by stating that women and girls are bearing the main responsibility for collecting water in 71% of households (Fleifel et al. 2019, Joint Monitoring Programme For Water Supply, Sanitation & Hygiene, 2015).

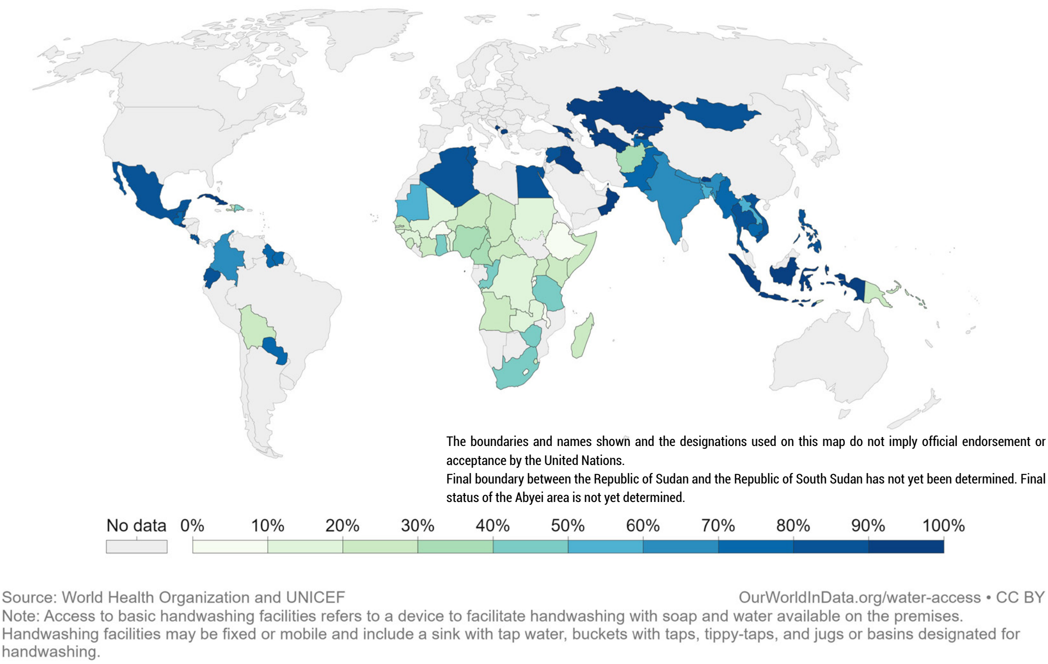

Figure 1. Share of population with access to basic handwashing facilities, 2017 (Adapted from Ritchie & Roser, 2019)

3.2. Security threat and vulnerabilities

Existing research studies suggest that poor access to WASH services can lead to social vulnerability, rape, and assaults. That fear from these can prevent women and children from using sanitary facilities out at night like they normally would. Violence against women and girls (VAWG) is a violation of fundamental human rights and a growing public health concern. A study conducted by Sommer & Cruso (2015) explained that experiences women and girls have regarding access to water and sanitation include vulnerability to violence, putting them at risk for negative psychosocial outcomes. Besides, a cross-sectional study by Wateraid (2011), identified various forms of violence faced by Dalit women when collecting water or defecating in the open.

Furthermore, it was found out that in a society where women are responsible for fetching water, their daily routine offers perpetrators the opportunity as well as constant access and dependable access to vulnerable women and girls (Fleifel et al. 2019, Joint Monitoring Programme For Water Supply, Sanitation & Hygiene,2015). It was also evident that traveling long distances coupled with the high level of predictability of community women's water fetching routines allows assailants to attack women who are isolated, alone, and ultimately overtly vulnerable. Animal attack was also reported as another form of physical attack women and girls encounter (Fleifel et al. 2019, Joint Monitoring Programme For Water Supply, Sanitation & Hygiene,2015).

3.3. Health impact

Water insecurities in school environments affect the menstrual health of female youths negatively. A study carried out on the water, sanitation, and hygiene conditions in Kenyan rural schools indicated that menstruating girls in most rural primary schools have struggled to access appropriate materials for managing their menstruation, including water for cleaning hands washing due to leakage (Mason et al., 2013). Sub-optimal water security programs in schools may hinder girls' ability to concentrate in class or attend school when menstruating (Somme et al., 2012; McMahon et al., 2011; Mahon et al., 2010). From their results, although 66% of schools had water (for hand washing), only 13% of schools were observed to have provided water in or very near the girls' latrines. A possible explanation for the results was that the Government of Kenya does not provide schools with sufficient resources for constructing water, sanitation, and hygiene (WASH) facilities being that funds given to schools are mainly for repairing existing infrastructure (Gallo et al., 2012). While WASH facilities are important for everyone, they are particularly vital for women and girls because WASH is essential for menstrual hygiene management (Haver et al., 2013). Also, in a study conducted in primary schools in a rural area in Uganda involving 205 menstruating schoolgirls (10-19years), the majority of the girls (90.5%) were found to have inadequate menstrual hygiene management (MHM) and about 44.2% of these girls do not have regular access to water at school which resorted to washing their stained absorbents at home rather than at school (Hennnegan et al., 2016). Some of the consequences of poor menstrual hygiene include shame, discomfort, odor, inability to stand up to answer questions in class, and even absence from school. Water insecurity is also linked to increased mortality and morbidity caused by waterborne diseases from inadequate sanitation and hygiene (Fleifel et al., 2019, Joint Monitoring Programme For Water Supply, Sanitation & Hygiene,2015). Some of these diseases include typhoid, cholera, worm infestations, and eye infections (Stevenson et al., 2012).

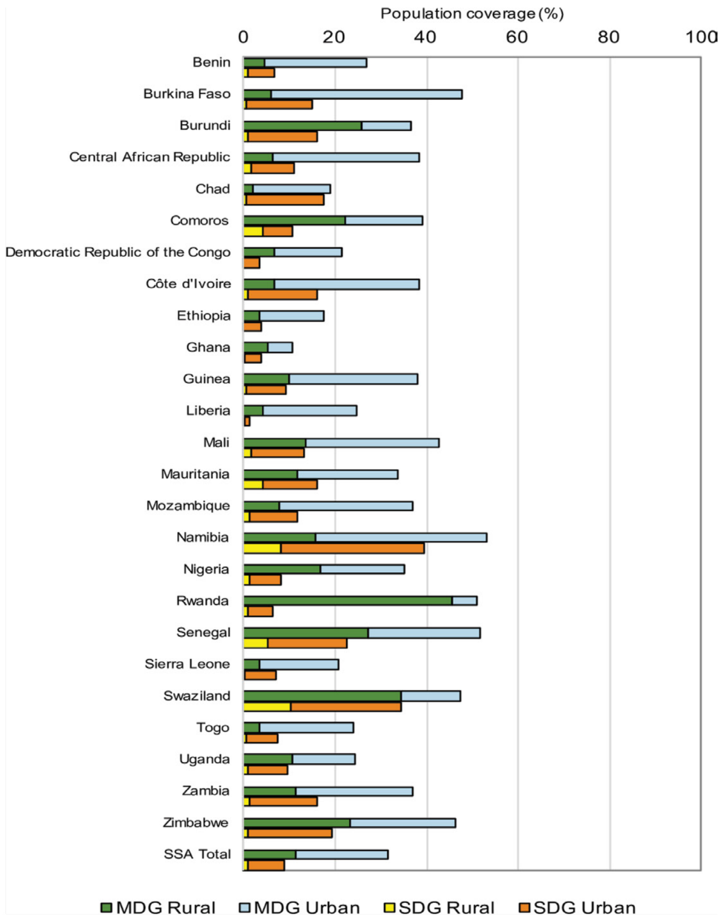

Figure 2. Estimates of Combined Water, Sanitation and Hygiene Coverage for 25 Sub-Saharan African Countries © 2017 Roche et al., CC BY 4.0

In Lesotho, where women are primarily concerned with fetching water for the household, similar to other African countries, water insecurity is significantly associated with depression and anxiety among the women in the study (Workman et al., 2017). In another study in Ethiopia, water insecurity contributed to psychosocial distress in women (Stevenson et al., 2012). Water cleanliness and scarcity are major contributory factors to stress by females in Lesotho. There, they increase the risk of various mental disorders, notably anxiety and depression, and the high rate of HIV/AIDs recorded in the country (Workman et al., 2017). Women are obliged to walk miles to acquire water for their households, even in late pregnancy and after delivery, while their husbands often provide only instrumental support like money and may also suffer physical injuries like bruises, fracture, and dislocation, and may drown and be attacked and injured by animals or hoodlums while walking to water sources (Collins et al., 2019).

Water insecurity also significantly affects the female Africans indirectly through their children. Water insecurity exposes children to infections due to poor hygiene and sanitation, poor infant feeding, undernutrition, and poor personal hygiene (Schuster et al., 2020).

3.4. Energy and time loss

Gathering water for hygiene, cooking, drinking, cleaning, and other basic activities is not a waste of time but how millions of rural women in sub-Saharan Africa gather and fetch the resources results in great time loss and in certain areas, more than the others, with respect to geographical location and extent on in - access to the water resources, women spend long hours making the journey to fetch water every day (Fleifel et al., 2019). Time poverty due to the need for fetching water, firewood, and domestic chores cause trade-offs putting food security, child nutrition, health, and education at risk (Sorenson et al., 2011). With respect to time, it's important to note that the level of energy expelled to carry out on both long and short commutes leaves little energy to complete other productive activities in the remaining daylight hours.

4. Conclusions

Water insecurity exposes vulnerable groups – women and girls to security threats, negative health impacts, and more. Water remains an essential resource for both men and women. However, unequal rights in water security and its use continue to exist in Africa. Studies, however, show that policy reform and local initiatives can bring positive changes on issues relating to female youths and water security in Africa.

Funding Information and Conflicts of Interest

No external funding was received. The authors declare no competing interest.

References

Collins, S.M., Owuor, P.M., Miller, J.D. et al, (2019). 'I know how stressful it is to lack water!' Exploring the lived experiences of household water insecurity among pregnant and postpartum women in western Kenya., *Global Public Health,* 14:5, 649-662. https://doi.org/10.1080/17441692.2018.1521861

Fleifel, E., Martin, J., and Khalid, A. (2019). Gender specific vulnerabilities to water insecurity. University of Waterloo, faculty of environment, School of environment, Canada, 1-8. Accessed online at : https://ic-sd.org/wp-content/uploads/2019/11/eliana-fleifel.pdf

Gallo, K., Mwaki, A., Caruso, B., Ochari, I., Freeman, M., Saboori, S., Dreibelbis, R., and Rheingans, R. (2001). An Evaluation of the Financial Mangement of Wash Programs in SWASH + Primary Schools. Kenyan Water Organization. Available online: https://www.washinschoolsindex.com/document/113

Geere, J. and, Cortobius, M. (2017). Who Carries the Weight of Water ? Fetching Water in Rural and Urban Areas and the Implications for Water Security. Water Alternatives,10(2), 513–540. Available online : https://www.researchgate.net/publication/317509689

Haver, J., Caruso, B.A., Ellis, A., Sahin, M., Villasenor, J.M., Aandes, K.L., and Freeman, M.Cc. (2013) WASH in Schools Empowers Girls' Education in Masbate Province and Metro Manila, Philippines: An Assessment of Menstrual Hygiene Management in Schools. UNICEF. Available online : : https://www.researchgate.net/publication/259033543

Hennegan, J., Dolan, C., Wu, M., Scott, L., and Montgomery, P. (2016). Measuring the prevalence and impact of poor menstrual hygiene management: a quantitative survey of schoolgirls in rural Uganda. BMJ Open, 6(12). http://dx.doi.org/10.1136/bmjopen-2016-012596

Joint Monitoring Programme for Water Supply, Sanitation and Hygiene. (2015). A snapshot of Drinking Water, Sanitation and Hygiene in Africa (pp. 2-6). Retrieved from https://washdata.org/sites/default/files/documents/reports/2018-01/JMP-2017-Regional-snapshot-Africa.pdf

Mahon, T. and; Fernandes, M. (2010). Menstrual hygiene in South Asia: a neglected issue for WASH (water, sanitation and hygiene) programmes. Gender & Development, 18(1), 99-113. https://doi.org/10.1080/13552071003600083

Mason, L., Nyothach, E., Alexander, K., Odhiambo, F.O., Eleveld, A., Vulule, J., Rheingans, R., Laserson, K.F., Mohammed, A., and Phillips-Howard, P.A. (2013). We keep it secret so no one should know—A qualitative study to explore young schoolgirls attitudes and experiences with menstruation in rural western Kenya. *PLoS ONEE* 2013, 8. https://doi.org/10.1371/journal.pone.0079132

McMahon, S., Winch, P., Caruso, B., Obure, A., Oguti, E., Ochari, I. and Rheingans, R. (2011). The girl with her period is the one to hang her head Reflections on menstrual management among schoolgirls in rural Kenya. *Int. Health Hum. Rights* 2011, 11, 1–10. Available online: https://doi.org/10.1186/1472-698X-11-7

Pommells, M., Schuster-Wallace, C., Watt, S., and& Mulawa, Z. (2018). Gender as a Water, Sanitation, and Hygiene Risk: Uncovering Violence Against Women and Girls as It Pertains to Poor WaSH Access. *Violence Against Women,* 24(15), pp. 1851-1862. https://doi.org/10.1177/1077801218754410

Ritchie, H., & Roser, M. (2017). Water Use and Sanitation. Our world in Data. Retrieved from https://ourworldindata.org/hygiene

Roche, R., Bain, R. and Cumming, O. (2017). A Long Way to Go – Estimates of Combined Water, Sanitation and Hygiene Coverage for 25 Sub-Saharan African Countries. PLOS ONE, 12(2), pp.1-24. https://doi.org/10.1371/journal.pone.0171783

Schuster, R.C., Butler, M.S., Wutich, A., Miller, J.D., Young, S.L. (2020). Household Water Insecurity Experiences-Research Coordination Network (HWISE-RCN). "If there is no water, we cannot feed our children": The far-reaching consequences of water insecurity on infant feeding practices and infant health across 16 low- and middle-income countries. *Am J Hum Biol.*, 2020; 32:e23357. https://doi.org/10.1002/ajhb.23357

Sinyolo, S., Mudhara, M. and, Wale, E. (2014). Water security and rural household food security : empirical evidence from the Mzinyathi district in South Africa. *Springer Sci.,* 2014;6, :483–99. https://doi.org/10.1007/s12571-014-0358-0

Sommer, M. (2012). Structural factors influencing menstruating school girls' health and well-being in Tanzania. *Comp. J. Comp. Int. Educ. 2*012, 43, 323–345. https://doi.org/10.1080/03057925.2012.693280

Sommer, M. and, Caruso, B. (2015). Menstrual hygiene management and WASH. In J. Bartram J (eEd.) Routledge Handbook of Water and Health.(Part 6, Chapter 52). Routledge. https://doi.org/10.4324/9781315693606.ch52

Sorenson, S., Morssink, C., and & Campos, P. (2011). Safe Access to Safe Water in Low Income Countries: *Water Fetching in Current Times. Social Science & Medicine,* 72(9), pp. 1522-1526. https://doi.org/10.1016/j.socscimed.2011.03.010

Stevenson, E.G.J., Greene, L.E., Maes, K.C. et al. (2012). Water insecurity in 3 dimensions: An anthropological perspective on water and women's psycho social distress in. *Social Science & Medicine*, 75 (2012), 392e400. https://doi.org/10.1016/j.socscimed.2012.03.022

WHO/UNICEF. (2014). Progress on Drinking-Water and Sanitation – Joint Monitoring Programme Update. Retrieved from https://www.who.int/water_sanitation_health/publications/2014/jmp-report/en/ Cited 1 October 2020

UNICEF and World Health Organization. (2015). Progress on Sanitation and Drinking Water. Retrieved from 2015. Access: http://www.unicef.org/publications/files/Progress_on_Sanitation_and_Drinking_Water_2015_Update_.pdf). Cited 1 October 2020

Venkataramanan, V., Geere, J.-AL., Thomae B, et al. (2020). In pursuit of 'safe' water: the burden of personal injury from water fetching in 21 low-income and middle-income countries. BMJ Global Health, 2020;5, :e003328. http://dx.doi.org/10.1136/bmjgh-2020-003328

WaterAid. (2011). What the global report on disability means for the WASH sector. Retrieved from Available at: http://www.wateraid.org/~/media/Publications/what-global-report-disability-means-for-WASH-sector.ashx

WaterAid. (2012). Water security framework. London. Available at: https://washmatters.wateraid.org/publications/water-security-framework

Wheeler, C. (2018). The Water Gap - The State of the World's Water, London; https://doi.org/APO-137041

Workman, C.L., Ureksoy, H. (2017). Water insecurity in a syndemic context: Understanding the psychoemotional stress of water insecurity in Lesotho, Africa. *Social Science & Medicine*, 179. https://doi.org/10.1016/j.socscimed.2017.02.026

World Economic Forum (2019). Global Risks Report, 14th edn. ;World Economic Forum: Geneva, Switzerland; ISBN 9781944835156. https://doi.org/10.3390/w11122491

Zeitoun, M. (2011). The Global Web of National Water Security. Global Policy, 2: 286-296. Wiley Online; https://doi.org/10.1111/j.1758-5899.2011.00097.x

Youth for Water Security: Water Centric Empowerment Framework for African Youth

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Abstract

Water is inextricably linked with the welfare of African youth as water scarcity creates poor health and living conditions, malnutrition, lack of opportunities for education and employment which challenge the quality of life of youth. Whilst African youth are highly vulnerable to water scarcity, involving them in water sector is the ideal strategy towards achieving African water security. For effective engagement, three types of empowerment, namely educational, financial and organizational empowerment are proposed in this paper. With the aim of engaging African youth in water issues, a novel empowerment framework is designed to fit internationally recommended standards.

Keywords: Water security, African youth, Gender mainstreaming, Social entrepreneurship, Youth engagement strategy.

1. Introduction

With a projected contribution of 42% to the global youth population by 2030, the African continent is increasingly facing the challenges of youth unemployment and low literacy (UNDESA, 2015). Out of 420 million African youth aged 15 to 35, one third are unemployed and African youth are twice as likely to be unemployed as adults (UNEP, 2019). Due to the problems such as poor education, poverty, unemployment, lack of social protection, health and migration factors, many African youth have decided to take up petty jobs to survive and engage in informal economy (ILO, 2020). The potential of transforming employment challenges into opportunities, particularly in water sector, will expand economies, promote social inclusion and lead to the creation of more decent jobs (UNESCO, 2016). Thus, this paper tries to provide a common solution for water scarcity and youth unemployment in Africa by connecting the increasing youth population with depleting water resource.

Youth are facing great challenges, including life-threatening hazards that are experienced disproportionately by young women with intersecting marginalization and underrepresentation (UN, 2020). Commonly, African girls and women take the burden of carrying water and spend more than half an hour for one round trip in many regions of Sub-Saharan Africa (UNICEF, 2016). A steady increase in youth population has aggravated many socio-economical hazards in Africa, particularly, unemployment and shortage of decent work (UNECA, 2012). The UN Youth Strategy 2030 clearly indicates that engaging youth, working with them, supporting them and creating the condition that allows them to progress and play an active role in the international community will enable the achievement of sustainable development for all. UNESCO's youth strategy aims at "empowering young people, fostering and supporting their action, promoting partnership and ensuring their recognition and visibility". The main objective of this paper is to propose a new thematic framework for empowering African young females and males on water security through water-focused educational and research engagement in academia; financial empowerment for social entrepreneurship by financial and technical assistance through governmental bodies; organizational empowerment for youth-led water organizations through nonprofit and training institutes.

Youth are the greatest asset of Africa but their potential remains untapped due to unemployment and underemployment (AFDB, 2016). Africa faces critical challenges related to decent work deficits where 53.9% of workers live in poverty (ILO, 2020). Climate change affects the availability of jobs for youth who live in arid and semi-arid regions which cover 67% of Africa (UNESCO, 2017). The same report indicates that water resources are highly affected by increasing climate variability. Water availability and quality has impact on youth employment in Africa. Also, it must be noted that Africa suffers from acute water scarcity (Naik, 2016) both in terms of physical and economical water scarcity that may worsen youth in job and health dimensions. Since African youth are affected by both unemployment and water crisis, employing youth in water sector is the key strategy to achieve a win-win situation. Water and jobs are inseparably linked at various levels, and when people are empowered with water, it provides health and job opportunities to break the cycle of poverty in Africa (UNESCO, 2016). The report also indicates that water is a vibrant tool for empowerment of women and youth as their involvement in water management and water infrastructure can improve efficiency and increase output.

The African water sector faces many challenges and needs more contributions by stakeholders and has the potential of engagement of youth in the development of solutions. Youth are not limited by existing solutions as 80% of Africans choose entrepreneurship as viable career opportunity (UNEP, 2019). Access to financing for youth education, entrepreneurship and innovation is a constraint (AMCOW, 2013), and many educated African youth lack entrepreneurial skills to facilitate their self-employment (UNECA, 2017). In every region, except Sub-Saharan Africa, social entrepreneurs tend to have relatively high levels of education (UN, 2020). This demonstrates the importance of educational empowerment. UNESCO (2016) recommends more investments in education, access to technology, and opportunity to enhance the talents of African youth. "Agenda 2063: The Africa We Want" focuses on financing entrepreneurship, as it is the catalyst for growth and technological development. It also adds creativity, energy and innovation of African youth to enhance the driving force behind the continent's transformation. No society can reach its full potential unless it empowers its women and youth (African Union, 2015). Therefore educational empowerment for enhanced awareness and water enthusiasm; financial empowerment for financing water entrepreneurship or enterprise; and organizational empowerment to strengthen youth-led water organizations are essential for African youth to make positive and significant impacts in the water sector. In general, any type of empowerment and policy implication should be "gender equitable, disability-inclusive, conflict sensitive and promote safe youth participation" (UNICEF, 2020). This paper addresses 'water empowerment for unreachable and inaccessible African youth' in line with the UN's motto-"Leaving no one behind" for achieving 2030 agenda for sustainable development.

2. Methodology

This paper provides a novel theoretical framework with the idea of water-centric youth empowerment and to support "Youth-Water-Education-Employment" nexus in the African context. An ideal and creative framework is developed based on the vision of better African youth engagement in water sector. For the purpose of structuring the conceptual framework, the *logic model* is used. A 7-E strategy is designed with reference to approaches recommended by global organizations. Three types of empowerments are herein explained in detail. This paper culminates in the proposal of framework with the analyses of the means of achieving a meaningful youth empowerment and assessing whether youth empowerment should be the same or divergent for different groups of African youth. These factors are discussed in section 2.4. The importance and suitability of the proposed types of youth empowerment in addressing African water scarcity are discussed in section 2.6.

2.1. Conceptual Framework

Figure 1 is a map of the conceptual framework herein proposed for African youth empowerment in water domain. It is designed based on *logic model* approach which is a visual representation of relationship between program activities and intended impact (CDC, 2006). The components of the proposed logic model include input, activities, output, outcomes and impacts. Per its name, the model helps to construct a logical sequence of steps to effectively achieve the goal

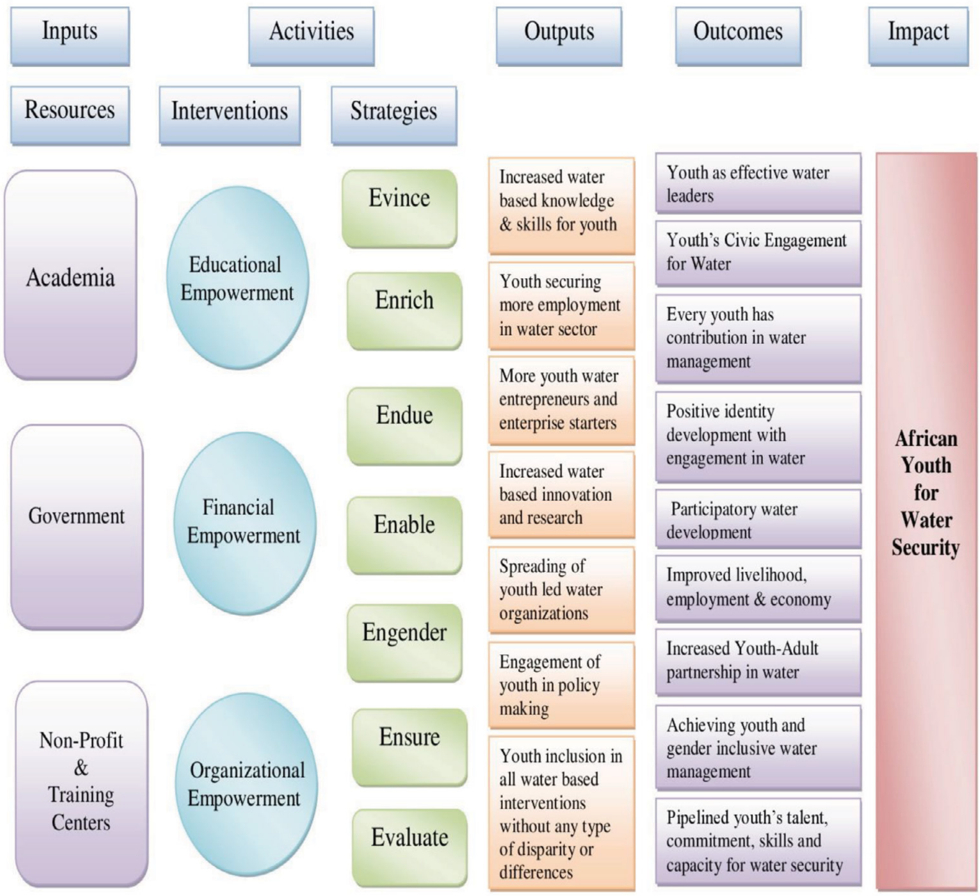

Figure 1. Conceptual framework for water-youth empowerment

of the program. In the proposed logical model, inputs are the resources or partners in the intervention; activities are the events necessary to produce desired outcomes; outputs are direct tangible results of activities; outcomes are desired results of the program; and impact is the ultimate goal of the intervention (CDC, 2006). In this paper, by fixing 'African youth for water security' as impact and empowerment as activity, the framework is made logical. The resources (per Figure 1) such as academia, government and non-profit institutes act as the media for empowering youth in water security.

2.2 7-E Strategy

The conceptualization of the 7-E strategy is based on the scholarly frameworks and evidence based approaches proposed by international agencies in the field of youth development and empowerment. These seven strategies, namely, Evince, Enrich, Endue, Enable, Engender, Ensure and Evaluate are designed to accomplish the empowerment cycle starting from providing information to youth about water to making them lead in water-based policy interventions. Being that access to power is the real meaning of empowerment, strategies do not stop with just educating or supporting African youth in as required. The goal of the strategies is to empower African youth in all dimensions and involve them in all facets of the water sector. In addition to strategies, three key attributes viz., supporting policy, political will and financial and relevant resources are identified as deciding factors on the strategies that get shaped and implemented.

Evince: Sharing the opportunities and career paths in water sector as well as informing all the possible ways through which African youth can contribute to water security. World Youth Report (UN, 2011) states that 'Even when the resources and job options exist, the lack of information about them prevents students and youth from accessing them'. For uneducated, less educated and unemployed youth, indicating the water-based empowerment options suitable for them like vocational training, rural entrepreneurship, starting NGO for water, etc., will sensitize the youth who are not educationally empowered and informed in schools. Not only showing the career options but by creating awareness, youth in other sectors can be stimulated to contribute in water conservation and management through simple and effective ways as introducing them to 'water footprint calculation', 'water ethics', etc.,

Enrich: Education and capacity-building are the key means of empowerment (UNESCO, 2015). Providing skill development and training required for water-based jobs through academia (schools and colleges) and non-profit institutions to the African youth. Improving water governance requires a concerned program of education and skill development with a focus on youth and women (UNESCO, 2016). The key intention of this stage is creating water enthusiasm and developing relevant knowledge systems among the children, students and youth via water-centric education and training, and making them professionally ready to take water-based jobs and services.

Endue: Supporting the water-based interventions of trained African youth by providing financial and technical guidance. For starting and sustaining water entrepreneurship, enterprise or youth water organization, assistance in financial and organizational empowerment is required. UNESCO (2016) recommends the provision of reliable financial support, improved market linkages, and quality technical assistance for successful entrepreneurship in the water sector.

Enable: Enabling environment relates to programs and governance (Mabiso and Benfica, 2019) that are inevitable in creating effective space for African youth in implementing their expertise, knowledge and interests that are gained through water-based empowerment in the earlier stage. UNESCO's Operational Strategy on Youth indicates that decision makers create and sustain an enabling environment for youth to be 'engaged and valued as social actors and knowledge holders in the specialized field as it is the key to unleashing their potential'.

Engender: Engendering youth involvement in all water-based interventions and at all levels along with the provision of decision making roles without any difference or disparity. The UN Youth Strategy 2030 fixes youth involvement as the first priority out of 5 strategic priorities areas for youth development. 'Meaningful participation' of youth is necessary rather than tokenistic involvement in order to harness youth potential for accomplishing African water security targets.

Ensure: Corroborating the participation of African youth in water-based interventions and programs. It is important for follow-up activities and taking necessary steps when youth inclusion is improper in water domain. The Commonwealth Youth Program (CYP) has defined '*ensuring*' as one of three main functions that are central to practice of youth development in projects. CYP's strategic goal mentions 'ensuring youth are provided with and have access to opportunities that enable them to achieve sustainable livelihoods, and for them to participate in, contribute to, and benefit from good governance and development processes at national, regional and international levels' (CYP, 1974).

Evaluate: The last strategic component *evaluate* is to appraise the effectiveness of policies, regulations and programs that pertain to youth empowerment in water. Examining the strengths and potential challenges in youth-water centered policy interventions will be helpful in refinement and sharpening of the approaches to achieving youth-inclusive water governance. Per the guidance of UNESCO Operational Strategy on Youth, policies that affect the youth need to be formulated and reviewed or evaluated with the participation of youth. Complete involvement of youth in all the stages of policy-making, including in review process, will make the intervention more successful and shape a better world (UN, 2018).

Key Attributes: Key attributes decide the extent of success of strategies. Political will and financial resources are important for upscaling youth-based programs in the water sector (ILO, 2019). To enhance the water-based opportunities for youth, Political commitment and planning engagement, sustainable investment and other supporting resources are primarily essential (UNESCO, 2016). For any intervention, policy appropriateness plays a vital role in successful implementation. In order to achieve youth empowerment through the above-mentioned strategies, 'supporting policies, political will and relevant resources' are necessary. Resources include financial resource, human resource, etc., which are required to accomplish the goal of strategies.

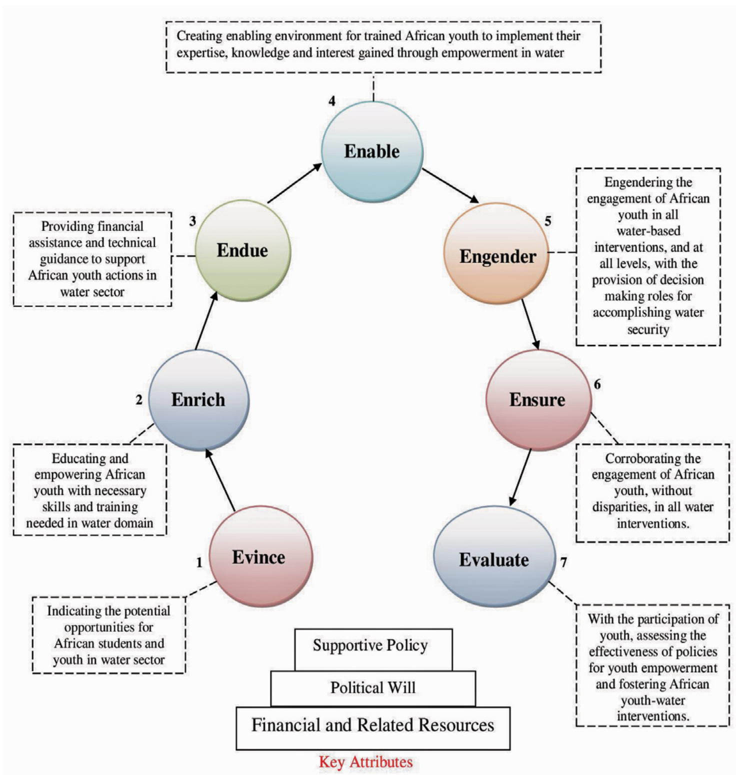

Figure 2. 7-E Strategy

2.3. Empowerment

The vision statement of UN's youth strategy visualizes a youth transformative future by aiming to ensure that youth is empowered to achieve their full potential and get recognized as agents of change for their positive contribution (UN, 2020). UNESCO Operational Strategy on Youth (2014-2021) insists 'young women and men to engage in policies and programs that affect them'. It further states that youth empowerment and capacity development are vital to train youth with skills and competencies as well as helpful to effectively move through 'four interconnected life transitions such as continuing to learn; starting to work; exercising citizenship; and developing a healthy lifestyle'. Accordingly, three types of empowerment: educational empowerment, financial empowerment and organizational empowerment are proposed for African youth to achieve water security.

2.3.1. Educational Empowerment

One of the major issues in African youth unemployment is the prevailing gap between educational output and actual skills required for business, which could be alleviated by building capacity and focused educational empowerment of youth (UNECA, 2012). Water education is essential at all levels for achievement of the goal of water security and sustainable development (UNESCO, 2015). When it comes to educating youth in water, it should not limited to school or college curriculum but extended with the aim of creating water wisdom, to all African youth irrespective of their literacy status. Hence the requirement is the provision of water education at all dimensions. The ranges should extend from school training to tertiary and professional development; and from formal education to informal, vocational, technical and skill training, for policy makers and community dwellers, there is a need for education in water. It is critical for handling the challenges in water domain (UNESCO, 2015).

With the aim of providing water education and skill development to all African youth, Figure 3 is structurized as conceptual building blocks for educational empowerment. The figure is primarily divided into four parts, namely, school-based water empowerment, empowerment of youth in water field, empowerment of job seeking-youths and empowerment of youth in other fields. In school-based water education, apart from the curriculum, extra-curricular activities are vital in educating youth about water. For youth already working in water field, professional development and training are important. Despite the increasing demand for the water professionals, especially in developing nations, there is a lack of clear vision on water education and capacity-building (UNESCO, 2015). Thus, job-seeking youth can be potentially involved in water sector through their enrollment in specialized courses and skill development coaching. As water education is a significant *empowerment tool* for youth and women in Africa (UNESCO, 2015), each and every African youth needs to be involved in water security activities. Youth from other fields can be sensitized in basic water subjects using unconventional teaching methods such as educative videos, arts, films, music, etc.

UNESCO's Proceedings on Water Education and Capacity Building (2015) distinctly enunciated the challenges and requirements in water education. The enumerated list prescribes the provision of water education to everyone as a priority. One highlighted point in the report is the difficulty of involving youth in the water sector due to the lack of interest in water issues. This is considered to be a threat to water security as youth are the future impact bearers as regards water scarcity. For overcoming these challenges, the report prescribes tailored youth empowerment and water development programs with focus on youth engagement in water security issues. Youth engagement is crucial for attaining sustainable development in the water sector. Next the report recommends the use of current technologies in water education to attract the new generation, develop mandatory fieldworks, integrate games into subject, and provide financial support for students for effective and implementable education in water domain.

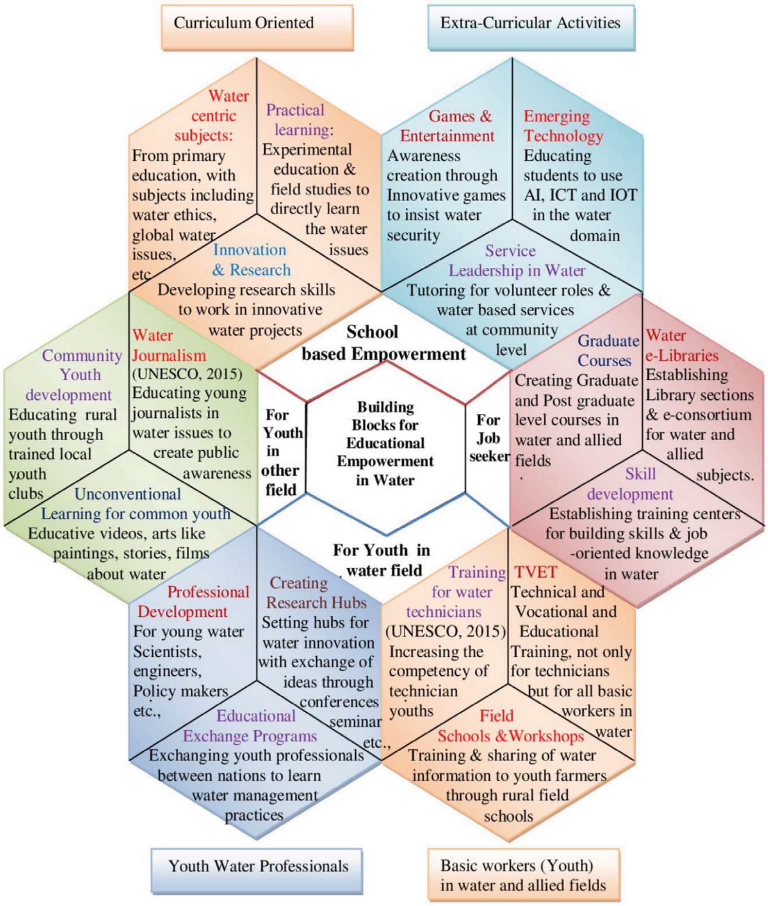

Figure 3. Educational empowerment of youth for water security

Thus, the ultimate aim of educational empowerment is to create water enthusiasm among all African youth, along with providing knowledge, information and skills to them to understand and take decisions on water issues, and finally to harness their contribution in useful form, to achievement of Africa's water security.

2.3.2. Financial Empowerment

Poverty coupled with scarcity of employment, escalates the everyday challenges of youth in Africa (UNECA, 2012). Around 80% of young Africans are in vulnerable employment and over 11 million youths are entering the labor market ever year (Ude, 2020). The creation of 18 million jobs per year until 2035 in the regions of Sub-Saharan Africa is estimated as required to sustain the growing employment needs (IMF, 2015). But this gap remains wider and job sector is developing in slower pace (Ude, 2020). The increasing youth population, fast growing need for employment, poor education, and weak financial conditions urge the demand for decent jobs in Africa. In the same way, African Economic Outlook (AFDB, et, al., 2015) recommends entrepreneurship as a potential career path for African youth as self-employment can counteract joblessness. The unemployment and poverty risks of youth can be seen as opportunity when they spur innovation and development at the individual, household, community and national levels (Ude, 2020). The UN Youth 2030 Strategy recognizes economic empowerment of youth as one of the five priority areas. Introduction of entrepreneur skills in higher education and provision of entrepreneurship training to youth are essential for developing an economy through positive youth engagement (UNESCO, 2014).

New markets for water innovation are emerging due to increasing population and industrialization. These circumstances drive the necessity for inventive ideas, products and measures in the water sector (ILO, 2019). UNESCO (2015) states that 'Africa needs to increase by at least 300% its number of water professions to achieve future water development'. This statement itself explains the stake for African youth and water managers as well as the potential scope for water related jobs in Africa which are less aware.

UNESCO (2016) suggests empowering low income youth in ecosystem-based entrepreneurship schemes such as Payment for Ecosystem Services (PES), to increase their income while implementing environmental conservation practices. Financial empowerment is essential for different forms of small and medium scale entrepreneurship, including scalable startups, social enterprise and innovation based water projects, for both handling unemployment crisis as well as solving community level water issues. Apart from financial assistance, technical and skill guidance are needed for youth aspirants to effectively engage in water entrepreneurship. Thus, skill development centers and non-profit training institutes are critical in technically empowering the African youth. In RIFC Global Social Franchising Index 2019 rankings, top 10 countries are in Africa where social entrepreneurship or social franchising needs to be improved. Out of top 10 African countries, 7 are in Western Africa. Hence for western Africa, it is viable to promote financial empowerment in Water.

2.3.3. Organizational Empowerment-'Empowerment with Equity'

Encouraging start-ups as well as strengthening youth water structures like youth water organizations, youth water councils, etc., are essential to achievement of the goal of African water security with youth action. In Figure 4, the scale for African youth engagement in water gives the clear picture of the required collective youth engagement in water security issues. Youth water organizations can be helpful in disseminating scientific knowledge and innovative water practices to the field as they work at the grass root level. Thus, organizational empowerment can be achieved by providing training through non-profit institutions for skill development and catering for the financial needs through government's assistance. Special funds and grants will help in the establishment and spread of youth water organizations in Africa. The net result would be the creation of opportunities for African youth to develop community-based careers, engage in collaborative actions with other youth, achieving positive identity and civic engagement in the water sector.

Business, technical and life skills are the basic requisites for young people, particularly, in the rural areas for sustaining their income. This is especially so, where it is appropriate to engage Public-Private Partnerships (PPP) to foster skill development and training programs, as it addresses both the needs of social enterprise and aspirations of rural youth (G 20, 2017). Making local and rural organizations partners in disseminating water knowledge and as empowering media for rural youth helps in 'decentralizing the youth empowerment' and is effective in reaching marginalized and underrepresented rural youth. In Youth engagement toolkit published by Pan Canadian Joint Consortium for School Health (JCSH, 2018), linking youth to the local organizations is identified as a crucial strategy and recommended for the effective youth engagement in a community. As the curricula and postures of non-profit and training institutes may not cover and empower each and every youth on water issues, encouraging youth water organizations in catalyzing the basic water wisdom in rural communities is essential, especially for uneducated youth. The idea of engaging youth in empowering other youth, viz. '*Youth-Youth Partnership*' is appropriate to empower unreachable youth and in bridging the empowerment gap, exactly to achieve '*empowerment with equity*'.

As discussed in Figure 4, partnership and connectivity between youth water organizations at regional, national and international level is exhorted by experts for sharing water-based success stories and raising strong voice for policy change. Special support and recognition for youth-led water organizations is required to facilitate a wide youth engagement in water conservation and management (UNICEF, 2020). Thus, empowering youth water organization is equal to empowering the whole community where the organization works. Sensitizing rural or local community becomes easy when youth water organization is started, strengthened or empowered. Table 1 helps design strategies and suitable empowerment for African youth in the water sector. It suggests the type of empowerment required by analyzing the difficulties in youth engagement and proposes strategies to engage youth for water security.

2.4. Leaving No Youth Behind - Challenges in African Youth Empowerment

The success of any youth engagement and empowerment strategy relies on the fundamental understanding and acknowledging the heterogeneity of youth along with youth vulnerabilities and entrenched exclusions which are not only limited to 'age, gender, ethnicity, socio-economic status, migration and language but also serious in the *rural-urban divide*, poverty, lack of resources, etc.,' (UNICEF, 2020). UN firmly advocates adoption of appropriate approaches to youth engagement and empowerment by considering all forms of diversity that exist among the youth community (UN, 2020). Leaving no youth behind is the requisite for meaningful African youth transformation. However, a number of challenges are identified in terms of urban-rural divide and its cross-cutting impacts on education, resource availability, job etc., Accordingly in the youth development, special attention to young rural people especially women from the developing nations, is required. There is also a need to focus efforts on the creation of income-generating opportunities as well as harnessing of the potential of rural youth through targeted policies and approaches (G 20, 2017). At the same time, urban poor youth are equally disadvantaged in access to skill development, resources, etc., Thus Figure 5.illustrates the challenges found in schemes of African youth empowerment for water security. There are several factors that act as common threats to both African urban and

Table 1. Engagement strategies and empowerment of African youth in water

Reasons to engage African youth in water sector	Difficulties in youth engagement	Strategies to engage	Type of empowerment
Youth are both present and future sufferers of water scarcity in Africa	Lack of motivation and common attitude as water is a state's responsibility	Awareness creation on youth's role in achieving water security	Educational empowerment
Youth are Critical Thinkers (UN, 2016) Youth are dynamic and capable of creating solutions	Lack of basic water knowledge, low literacy and unawareness on water issues	Water-centric educational curriculum from primary education in Africa	Educational empowerment
Youth are Innovators (UN, 2016) Youth are vital for better economy, innovation and development	Lack of awareness on social entrepreneurship opportunities in water sector.	Creating an 'enabling environment' for young entrepreneurs in water sector by providing funds and technical assistance	Economic empowerment

Reasons to engage African youth in water sector	Difficulties in youth engagement	Strategies to engage	Type of empowerment
Youth are Change Makers (UN, 2016) Involving youth can be most transformative for society. (Cava, et al., 2004)	Lack of leadership skills and organizational knowledge	Providing organizational skills and encouraging to start and strengthen youth-led initiatives and organizations	Organizational empowerment
Youth are Leaders (UN, 2016) Youth engagement is important for addressing water scarcity, especially at the rural level.	Elders domination in managing water and lack of indigenous water knowledge	Developing youth leadership for community management and educating them on traditional water practices of the community.	Organizational empowerment
Investing in youth and women is significant for African development (UNDP, 2016)	Barriers in inclusion, especially women globally. African women and youth, are more vulnerable to water scarcity, lack of sanitation, and poor water quality (UNICEF, 2016).	Special empowerment schemes for young female in water sector	Educational, Economic and Organizational empowerment for women
Mobilizing youth energy and enthusiasm for social and economic productivity (AMCOW, 2013)	Unemployment , poor health and migration	Increasing water literacy and investments in water-based sectors like agriculture, fisheries, etc.,	Educational and Economic empowerment
Youth are Communicators (UN, 2016) Tapping the digital skills of youth such as information sharing, online volunteerism, etc., for water management	Unawareness on utilizing digital skills and ICT activities for water management	Capacity building and engaging youth from various sectors as water management need a multidisciplinary approach.	Educational and Organizational empowerment
African youth are central to the successful implementation of transformative actions and development projects (UNECA, 2017)	Less inclusion of youth in decision- making and policy-making roles.	Providing decisive roles for youth in policymaking and developmental activities	Educational and Organizational empowerment

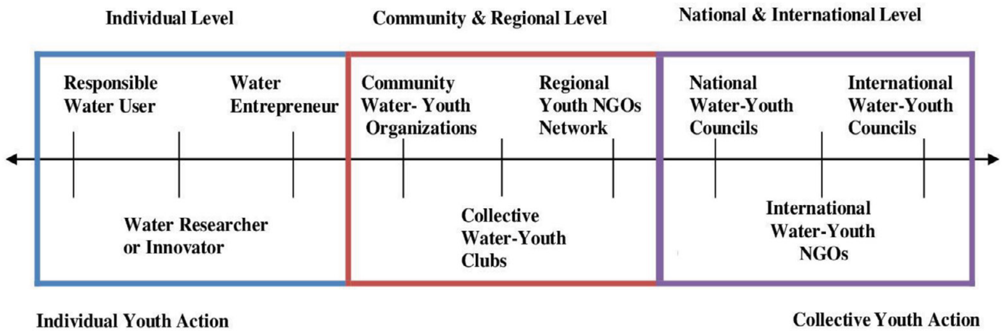

Figure 4. Scale for individual and collective youth engagement in water sector

rural youth as regards access to support systems. Irrespective of their locations, poverty and illiteracy widely affect the youths of Africa. Social disparity, economic inequity, resource and geographical differences make rural and urban poor youth even more vulnerable. UNESCO'S Youth Operational Strategy mentioned *rural youth and poor urban youth* needs greater focus in empowerment and skill development programs, as they are major part of marginalized groups. Thus Systematic strategies and endeavors are needed for youth engagement and empowerment in challenging and averting all forms of discrimination and inequity (UNICEF, 2020).

2.4.1. African Urban Youth and Empowerment

Rapidly increasing urban population marks Africa as the fastest urbanizing continent. It is predicted that Africa will account for quarter of the world's urban population by 2050 when more than half of the Africa will be urban (UNECA, 2012). Despite the 'urban' status, poor youth in urban areas are severely affected in many dimensions, including access to water. Poor and marginalized urban youth "are a demographic majority seen as an outcast minority" (Sommers, 2007). Alienation of poor youth with the underrepresentation of young women was noted in many urban areas of Africa since the chance of accessing youth development programs are very less in the outskirts of cities, which are the living places of poor urban youth (Sommers, 2007). Albeit the developing facilities in cities, fast urbanization results in unplanned habitat and infrastructure deficit towns where access to basic facilities is even difficult (UNECA, 2012). Thus, initiating a development or empowerment program for urban African youth needs an understanding of their social conditions (Sommers, 2007). There are more positive opportunities in urban areas such as better education facilities and infrastructure compared to rural areas, but it is hard for the poor urban youth due to less affordability of amenities and services. Instead of diverse career opportunities, 76% of African urban workforce is in informal jobs and globally Africa stands highest in the informal employment in cities (Chen and Beard, 2018). They are the working poor who are highly vulnerable to lack of basic services including water, sanitation, education, etc., due to the evictions and relocations (Chen and Beard, 2018). As water has significant impacts on health, hygiene, education, livelihood, etc., of African urban poor and socially marginalized youth, they need extra attention in water-based empowerment and engagement interventions.

2.4.2. Empowerment for African Rural Youth

In spite of migration and rapid urbanization, Africa is overwhelmingly rural. Half of the Africa's population resides in rural areas (Mabiso & Benfica, 2019). In spite Africa has a large youth population in rural areas, there is a limited understanding of issues experienced by different segments of Africa youth (Mabiso & Benfica, 2019). Rural youth are the key drivers of inclusive rural transformation. Yet, the limited entrepreneurship and decent jobs for them in rural areas have adverse impacts on the 'socio-economic stability, and resilience of these areas and contribution to food insecurity, malnutrition, rural underdevelopment, inequalities, poverty, rapid urbanization and migration' (G 20, 2017). Additional social challenges in rural African areas are underemployment and low-paying jobs, particularly in rural informal sectors (Mabiso & Benfica, 2019).

Lack of education and training in rural areas creates skill mismatch in the water-based sector (ILO, 2019). In Sub-Saharan Africa, rural youth are more excluded from education than youth in urban areas (World Bank, 2015). Lack of training and skill development has increased job uncertainty for rural youth in Africa which signs the importance of increased investment in education and training (Mabiso & Benfica, 2019). Rural African youth were experiencing the challenges of lack of access to better infrastructure, education and they consider Water scarcity as a major threat to their livelihood and daily life (Giuliani, et. al., 2017). Apart from increasing education facilities for rural youth, International Labour Organization (ILO) (2019), recommends *re-skilling and up-skilling* processes for rural youth engaged in water sector to achieve better results in associated objectives like 'reducing poverty& hunger, protecting livelihood, increased health and wellbeing, improving education and innovation, combating climate change and conflict'. FAO (2014) insists that *rural entrepreneurship* and *green jobs* are effective options for African rural youth, and that provision of informal education as well as skill development, will improve the capacity of rural youth to take jobs that are more relevant to rural areas.

As rural youth are the 'future for food security', agriculture is an asset to the African rural youth to sustain their livelihood and to deal with increasing unemployment (FAO, 2014). Rural African youth are primarily employed in agriculture, and the number is expected to rise in future (Mabiso & Benfica, 2019). Thus, more attention is needed on African rural youth and young farmers for empowerment in water, as agriculture is the largest consumer of freshwater and nearly 70% of all freshwater withdrawals are used for irrigation (UNESCO, 2016). Albeit the improvement of accessibility to mobile phones and digital devices, information and communication technology (ICT) is still beyond the reach of a lot of rural youth and young farmers in villages of Africa (Lohento and Ajilore, 2015). One of the challenges for rural youth is lack of proper internet connection and ICT facility. ICT such as online radio, social media, web applications, online videos, blogs and other internet based communication actives are predominantly used in developing nations to sensitize rural youth farmers in water conservation, agricultural water management, precision agriculture, etc., (Lohento and Ajilore, 2015) whereas it is a challenge for many African rural youth in access to ICT since half of the world's population without access to internet connection lives in Sub-Saharan Africa that to majority in rural Africa (GSMA, 2020). Sub-Saharan Africa recorded the largest rural-urban gap in access to mobile internet in the world as the gap remains 60% in 2020, 40% coverage in urban Africa whereas it is just 16% in rural Africa (GSMA, 2020).

Thus, the provision of youth empowerment through education including informal education, skill development, training, covering internet facilities, assistance for entrepreneurship, facilitating market linkages, etc., are likely to provide rural youth's socio-economic satisfaction and development.

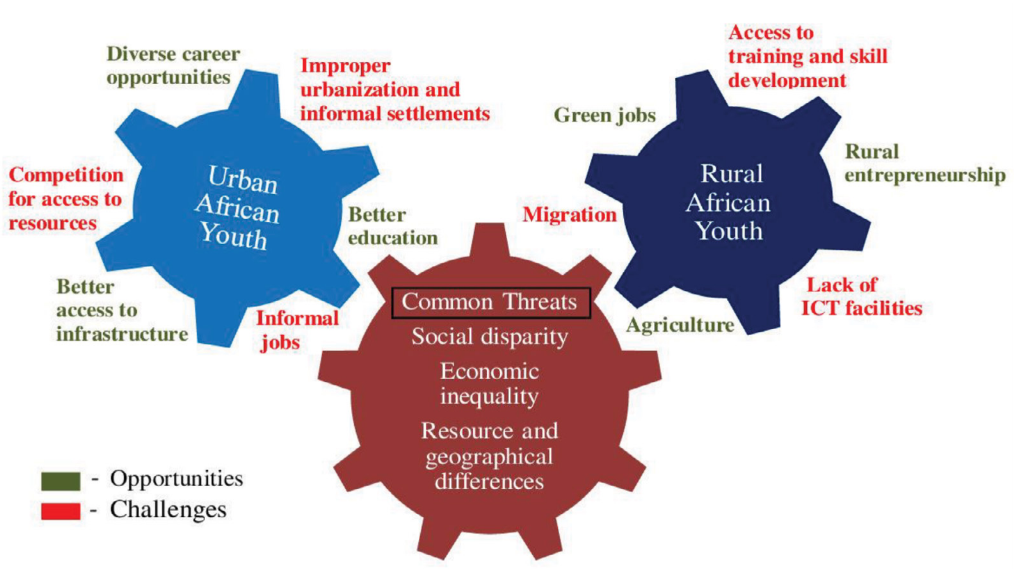

Figure 5. Challenges in African youth empowerment

2.4.3. Engagement-Empowerment nexus

The UN emphasizes the importance of youth empowerment by recognizing as 'its mission cannot be achieved without collaborating with youth and ensure *not only engaged but empowered*' (UN, 2020). The two terms widely used in the youth development literatures are 'engagement' and 'empowerment'. As per oxford dictionary, the definition for engagement is 'to become involved with and try to understand something' and empowerment is defined as 'the act of giving somebody power or authority to do something or more control over their own life'. Accordingly, the ultimate goal of empowerment is to make decisions and control something which is affecting their life. This paper promotes engaging African youth in water since they are directly affected (in terms of education, job, livelihood, health and other linked factors) due to the water scarcity in Africa. In order to involve them in water sector, empowerment such as education and capacity building, financial and organizational empowerment are proposed to enrich their knowledge, and support in all ways to promote youth's contribution as well as to train them to make effective decisions in water-related issues. Therefore, the final target of empowerment of African students and youth is for their '*effective engagement*' in water sector. On this account, it is 'empowerment to engage' the African youth in water sector. In general, youth empowerment frameworks are primarily designed to empower students and youth who aspire to get involved in certain fields. It is necessary to review the needs of African youth who are already engaged in water-related fields, many of whom have little or no access to water-based empowerment. Uneducated or less educated youth, including poor and rural young farmers, basic youth workers in water supply and sanitation, grass-root youth employers in water-based energy production and processing sectors, young fishermen, youth forest workers, youth in water-intensive manufacturing and recycling industries (UNESCO, 2016) etc., are engaged in the water and its allied sectors but may not be reached by the current empowerment cycle. Intensification of schemes is important for their productive involvement and improving their skills for better contribution to the water field. More than just engagement, empowerment promotes them to effectively engage and take initiatives in their own water-related domain. In this case, it is empowerment for the already engaged African youth in the water field.

In Figure 6, the empowerment-engagement nexus is visualized. 'Empowerment to engage' process is prepared for non-water engagers like children, students and job seekers who need empowerment to involve in water field. The youth are provided with skills, education and training to get expertise and raise aspirations for their own intervention in water domain. Trained youth are needed to partner with all water-based initiatives. They would apply their knowledge and create spheres to make their own contributions where youth could be influencers. The last stage creates the real meaning of youth empowerment when youth are given decision-making roles for them to become African water leaders. In the 'empowerment for the engaged' process, youth who work in water and allied fields are empowered through informal water education systems like field schools, workshops, social media platforms, etc. With the knowledge gained on their working fields, they practically become effective water managers. When implementing and sharing the gained knowledge, they are revitalized with enhanced vision, to set off as mentors in their professional fields. Encouragement should not only confined to their working sphere but to other fields and activities that enable them to elevate themselves as pioneers and leaders of innovation.

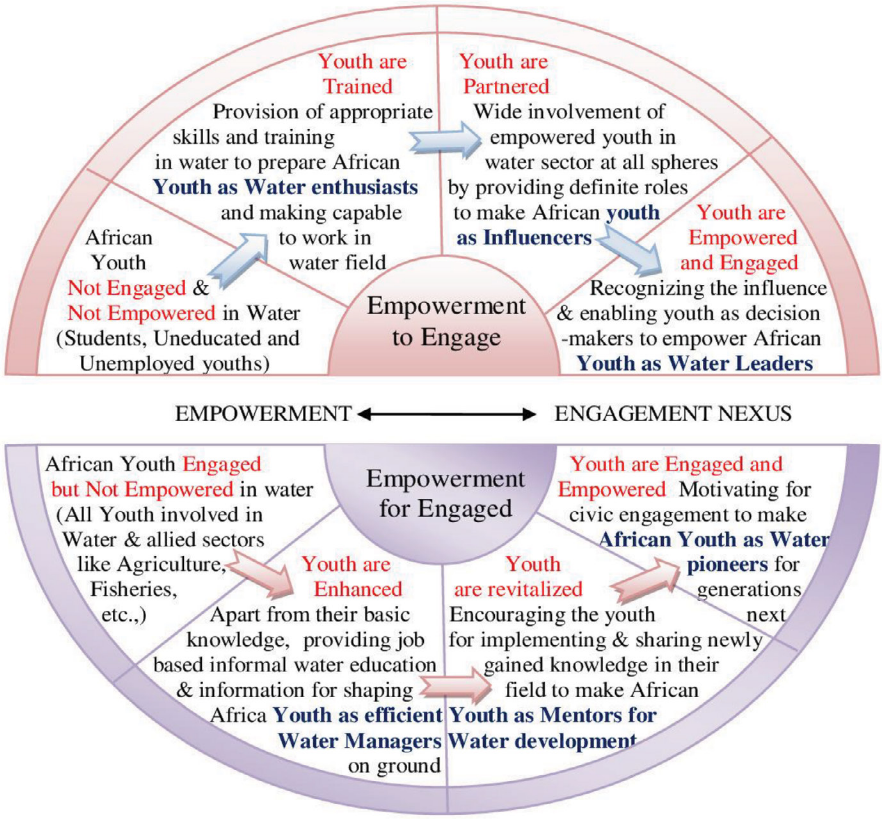

Figure 6. Empowerment-Engagement Nexus

2.5 Stakeholders in African Youth-Water Empowerment

In Figure 7, a possible way of connecting stakeholders for African youth empowerment is visualized. Youth bridges academia, government, and non-profit or training institutes in the empowerment cycle.

In Figure 8, an interaction for African water security is mapped. The figure integrates African youth and water with government, as the role of government is indispensable in youth empowerment, youth inclusion in policy-making and developmental projects, funding and technical guidance.

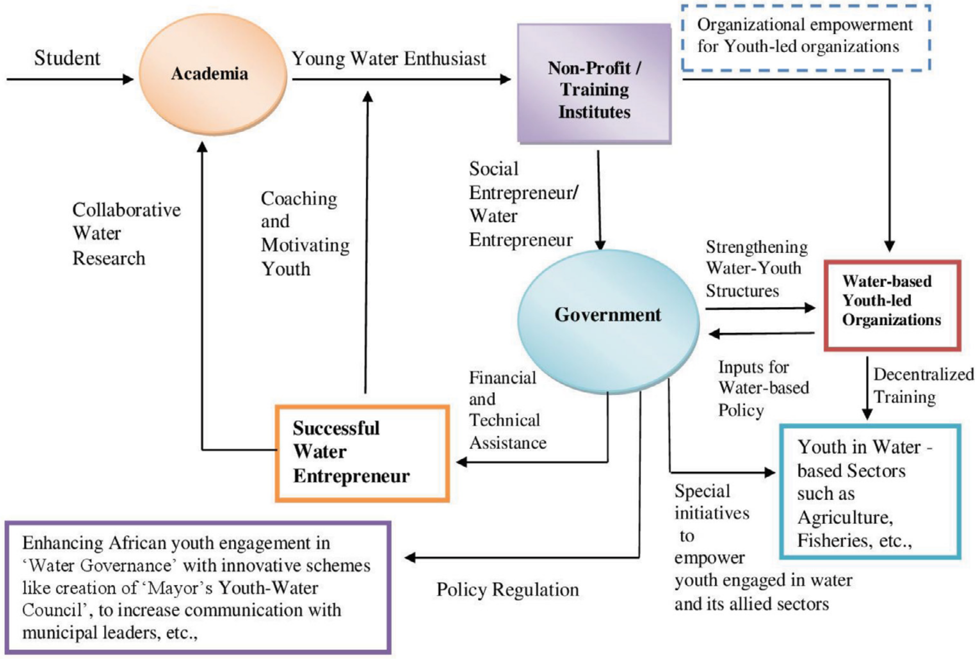

Figure 7. Bridging the stakeholders for water security

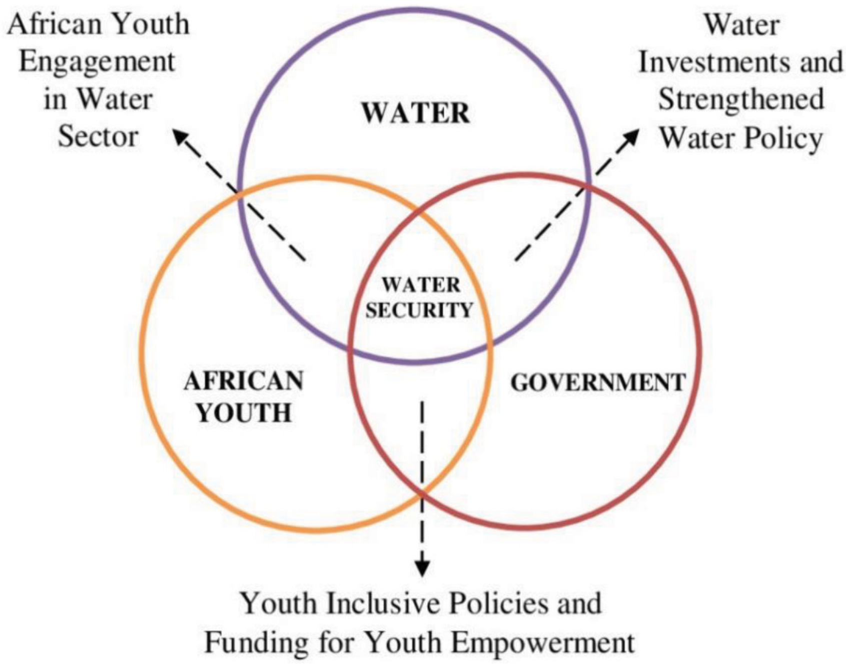

Figure 8. Interactions for water security

2.6. African Water Scarcity and Youth Empowerment:

Sub-Saharan Africa faces severe water scarcity and has the 'largest number of water-stressed countries of any region in the world' (UN, 2014). Lack of human capacities for managing water is one of the primary factors for the situation of water scarcity in Africa (UNESCO, 2012). Empowering African youth to combat water scarcity is imperative to achieve water security. The proposed empowerment cycle fulfills when the youth are particularly trained to tackle the prevailing water scarcity in Africa. Table 2 analyses the suitability of three types of youth empowerment in addressing African water scarcity.

3. Results and Discussion

The primary objective of proposing an effective water-youth empowerment framework is conceptualized with the logical model in this paper. The framework presents a clear picture of the factors influencing youth empowerment, such as relevant stakeholders, resources needed, types of empowerment, process in empowerment cycle and desired outcomes. Each of the factors is analyzed in detail with relevance to African youth and water scarcity. In addition to the framework, a study on challenges in African youth empowerment and effective ways of addressing the issues during empowerment cycle are discussed. Without just proposing a framework for students and aspiring youth, the paper attempts research on empowering youth who already engaged in water and allied fields. At last, the empowerment framework is fit into the context of African water scarcity, to analyze the applicability of the framework to practically achieve water security with the actions of African youth.

4. Conclusion

The paper is intended in making the sense of water conservation as a moral responsibility of every African youth. Respectively the framework and strategies are designed to engage African youth in the water sector. Thus, this study has compiled scholarly resources and evidence-based frameworks in the youth development field and incorporated them into the contexts of water and African youth. The main outcome of this paper is to widen the knowledge of 'youth engagement and empowerment' in the water sector. With the vision of permuting youth challenges into opportunities, the framework is evoked for sustainable engagement of African youth in water sector. It is concluded that investing in youth and water is investing in Africa's future.

Acknowledgement

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Table 2. African youth empowerment and water scarcity

Type of Water Scarcity	Cause of Water Scarcity		Educational Empowerment	Financial Empowerment	Organizational Empowerment
Physical Water Scarcity	Nature Induced	Drought	Education and exchange of knowledge are the important strategies to train youth in drought management. (Farsani., et al., 2017)	Supporting youth entrepreneurs helps to develop tackling technologies for climate change impacts on water resources such as drought, etc., (UNFCC, 2018)	Training youth organizations about drought resilience strategies help to transfer it to farmers and relevant stakeholders at the grass-root level.
		Spatial and temporal variability of Rainfall and shrinkage of water bodies	Educating on rainwater harvesting, climate change impacts on rainfall variability, and the role of water bodies in water security will enable youth to protect and secure local water bodies from shrinkage	Empowering entrepreneurs for developing cost-effective, innovative technologies and mechanisms for restoring and maintaining water bodies.	Involving youth organizations in planning and restoring water bodies for better youth engagement and success of the project
	Human Induced	Over usage or Over consumption	Youth can be empowered as "water ethics promoters" by informing them about water values, responsible water usage, and ill effects of over-consumption practices.	Promoting digital entrepreneurship for technological solutions, to limit the usage or wastage of water in water-intensive fields like agriculture, industries, etc.,	Youth organizations can create awareness among communities and may carry the scientific solutions to the grass-root level. Example: Educating farmers on efficient irrigation practices.
		Pollution (Water Quality Issues)	Educating youth on source, and cause of water pollution with its effect on water quality, health and ecosystem.	Enterprising the nature-based and cost-effective solutions for wastewater treatment like Biofilters and finding new technologies for monitoring and controlling water pollution.	Youth organization may mobilize the community for collective wastewater treatment initiatives and pollution control practices.

Type of Water Scarcity	Cause of Water Scarcity	Educational Empowerment	Financial Empowerment	Organizational Empowerment
Economic Water Scarcity	Lack of water infrastructure and financial capital	Educating and researching on water conservation methods at the household and community level.	Social enterprise for water supply and treatment. Public-Private partnership to improve water supply for the poor and economically inaccessible group	Mobilizing the community for participatory water conservation and management
	Lack of proper water institutions, policy and management approaches	Involving youth females and males in water policy formulation and research.	Promoting schemes and policies for the collaboration of social enterprises and private actors with public water institutions for better service	Youth organizations need to be included in policy making and in public water institutions, to raise concerns and address the issues at the grass-root level.

References

AFDB, OCED, UNDP. (2015). African Economic Outlook, Regional development and Spatial Inclusion. https://www.oecd-ilibrary.org/development/african-economic-outlook-2015_aeo-2015-en. Cited 12 August 2020.

AFDB. (2016). Bank Group Strategy for Jobs for Youth in Africa, 2016-2025, Revised Version, OSHD Department, https://www.tralac.org/images/docs/9843/afdb-strategy-for-jobs-for-youth-in-africa-2016-2025.pdf. Cited 12 August 2020.

African Union. (2015). Agenda 2063: The Africa We Want. https://www.un.org/en/africa/osaa/pdf/au/agenda2063.pdf. Cited 17 August 2020.

AMCOW. (2013). Policy and Strategy for Youth in the Water and Sanitation sector in Africa. https://nottawasagainstitute.files.wordpress.com/2015/11/amcow-youth-english0807201603.pdf. Cited 20 August 2020.

Cava, G., Cler, C., Lytle, P. (2004). Investing in Youth Empowerment and Inclusion: A Social Development Approach, Insights from the ECA and LAC regions. World Bank. https://www.semanticscholar.org/paper/Investing-in-Youth-Empowerment-and-Inclusion%3A-A-the-Cava-Clert/6e3dd9b5521336e793bba22a6d361fbb2e5edca7. Cited 3 September 2020.

CDC. (2006). Evaluation Guide, Developing and Using a Logic Model. https://www.cdc.gov/dhdsp/docs/logic_model.pdf. Cited 20 August 2020.

Chen, M.A., and Beard, V.A. (2018). Including the Excluded: Supporting Informal Workers for More Equal and Productive Cities in the Global South. Working Paper. World Resources Institute. Washington, DC. https://files.wri.org/s3fs-public/towards-more-equal-city-including-the-excluded_2.pdf. Cited 20 August 2020.

CYP. (1974). Common Wealth Youth Program: Mission Statement. Four Strategic Goals http://www.colelearning.net/cyp/unit1/page6d1.html. Cited 24 August 2020.

FAO. (2014). Youth and Agriculture: Key challenges and concrete solutions. http://www.fao.org/3/a-i3947e.pdf. Cited 3 September 2020.

Farsani, N.T., De Carvalho, C.N., Eslamian, S. (2017). Education Program for Drought, Handbook for Drought and Water scarcity. In Eslamin, S., and Eslamin, F. (ed.) Handbook of Drought and Water Scarcity: Environmental Impacts of Drought and Water Scarcity, CRC Press. 551-556. https://www.researchgate.net/publication/317175626_Chapter_27_-_Education_Program_for_Drought

G 20. (2017). Initiative for Rural Youth Employment. Supporting the "Next Generation" in Rural Development, Agriculture and Food Security in developing countries. https://www.consilium.europa.eu/media/23551/2017-g20-rural-youth-employment-en.pdf. Cited 3 September 2020.

Giuliani, A., Mengel, S., Paisley, C., Perkins, N., Flink, I., Oliveros, O., and Wongtschowski, M. (2017). Realities, Perceptions, Challenges and Aspirations of Rural Youth in Dryland Agriculture in the Midelt Province, Morocco. *Sustainability*, (9)6, 1-23. doi: 10.3390/su9060871.

GSMA. (2020). The State of Mobile Internet Connectivity, Connected Society. https://www.gsma.com/r/wp-content/uploads/2020/09/GSMA-State-of-Mobile-Internet-Connectivity-Report-2020.pdf. Cited 7 September 2020.

ILO. (2019). Water for rural livelihood. https://www.ilo.org/wcmsp5/groups/public/---ed_dialogue/---sector/documents/publication/wcms_729058.pdf. Cited 7 September 2020.

ILO. (2020). World Employment and Social Outlook and Global Employment Trends for Youth 2020: Africa. https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/documents/briefingnote/wcms_737670.pdf. Cited 7 September 2020.

IMF. (2015). Regional Economic Outlook: Sub-Saharan Africa, Dealing with the Gathering Clouds, World Economic and Financial Surveys. https://www.imf.org/external/pubs/ft/reo/2015/afr/eng/sreo1015.htm?hootPostID=2329f9881e105022a10dc7a98a241527. Cited 10 September 2020.

JCSH. (2018). Pan Canadian joint consortium for school health's Youth engagement tool kit. http://www.gov.pe.ca/photos/original/eecd_YETOOL_E.pdf. Cited 26 August 2020.

Lohento, K., and Ajilore, O.D. (2015). ICT and Youth in Agriculture. In Koira, A.K., et. al., (ed.) Africa Agriculture Status Report 2015, AGRA.118-142. https://www.researchgate.net/publication/308968253_ICT_and_Youth_in_Agriculture. Cited 26 August 2020.

Mabiso, A., and Benfica, R. (2019). The Narrative on rural youth and economic opportunities in Africa: facts, myths and gaps. IFAD. https://www.ifad.org/documents/38714170/41187395/21_Mabiso+and+Benfica_2019+RDR+BACKGROUND+PAPER.pdf/f741a15a-49c1-93ae-5155-5b0ef7bdf733. Cited 7 September 2020.

Naik, N.P. (2016). Water Crisis in Africa, Myth or Reality? International Journal of Water Resources Development. 326-339. doi:10.1080/07900627.2016.1188266.

Sommers, M. (2007). Creating programs for Africa's Urban Youth: The Challenges of Marginalization, *Journal of International Cooperation in Education,* (10)1, 19-31.

Ude, D.M. (2020). Youth Employment Challenge and Rural Transformation in Africa. The Palgrave Handbook of Agriculture and Rural Development in Africa. https://doi.org/10.1007/978-3-030-41513-6_3. Cited 24 August 2020.

UN. (2011). World Youth Report, Youth Employment: Youth Perspectives on the Pursuit of Decent Work in Changing Times. https://www.un.org/esa/socdev/unyin/wyr/2011/report.pdf. Cited 10 September 2020.

UN. (2014). Water Scarcity. https://www.un.org/waterforlifedecade/scarcity.shtml. Cited 7 September 2020.

UN. (2016). Roles of Youth and the SDG. https://www.un.org/sustainabledevelopment/youth/. Cited 12 August 2020.

UN. (2018). Youth 2030 Strategy, Working With and For Young People. https://www.un.org/youthenvoy/wp-content/uploads/2018/09/18-00080_UN-Youth-Strategy_Web.pdf. Cited 12 August 2020.

UN. (2020). World Youth Report, Youth Social Entrepreneurship and 2030 Agenda, https://www.un.org/development/desa/youth/wp-content/uploads/sites/21/2020/07/2020-World-Youth-Report-FULL-FINAL.pdf. Cited 24 August 2020.

UNDESA. (2015). Population Facts, No 2015/1, https://www.un.org/en/development/desa/population/publications/pdf/popfacts/PopFacts_2015-1.pdf. Cited 17 August 2020.

UNDP. (2016). Investing in Youth and Women critical to Africa's development. https://www.undp.org/content/undp/en/home/news-centre/news/2016/08/27/investment-in-youth-and-women-critical-to-africa-s-development-says-un-development-chief/. Cited 17 August 2020.

UNECA. (2012). New and Emerging Challenges in Africa, Summary Report. https://sustainabledevelopment.un.org/index php?page=view&type=400&nr=502&menu=35. Cited 26 August 2020.

UNECA. (2017). Africa's Youth and Prospects for Inclusive development, Regional Situation analysis report. https://www.ohchr.org/Documents/Issues/Youth/UNEconomicCommissionAfrica.pdf. Cited 24 August 2020.

UNEP. (2019). Global Environmental Outlook (GEO)-6 for Youth, Africa, A wealth of Green opportunities. https://wedocs.unep.org/handle/20.500.11822/30673. Cited 20 August 2020.

UNESCO. (2012). Managing Water under Uncertainty and Risk. United Nations Water Development Report, World Water Development Report (WWAP). Volume 1. http://www.unesco.org/new/fileadmin/MULTIMEDIA/HQ/SC/pdf/WWDR4%20Volume%201-Managing%20Water%20under%20Uncertainty%20and%20Risk.pdf. Cited 7 September 2020.

UNESCO. (2014). Operational Strategy on Youth 2014-2020, https://unesdoc.unesco.org/ark:/48223/pf0000227150. Cited 12 August 2020.

UNESCO. (2015). Proceedings on Water Education and Capacity Building, Key for Water Security and Sustainable Development, 7th World Water Forum. https://unesdoc.unesco.org/ark:/48223/pf0000233579.%20Cited%2026%20August%202020. Cited 26 August 2020.

UNESCO. (2016). Water and Jobs. United Nations Water Development Report, World Water Development Report (WWAP). http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2016-water-and-jobs/. Cited 24 August 2020.

UNESCO. (2017). Waste Water, the Untapped Resource. United Nations Water Development Report – World Water Development Report (WWAP). http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2017-wastewater-the-untapped-resource/. Cited 24 August 2020.

UNFCC. (2018). Report on Energizing entrepreneurs to tackle climate change, Addressing Climate through Innovation, Technology executive committee- TEC brief. https://unfccc.int/ttclear/misc_/StaticFiles/gnwoerk_static/brief12/bd80d2dd55e64d8ebdbc07752108c52c/af75fb524aa042e2a4f795ba6f29196f.pdf. Cited 20 August 2020.

UNICEF. (2016). Collecting water is often a colossal waste of time for women and girls. https://www.unicef.org/press-releases/unicef-collecting-water-often-colossal-waste-time-women-and-girls. Cited 24 August 2020.

UNICEF. (2020). Engaged and Heard, Guidelines on Adolescence Participation and Civil Engagement. https://www.unicef.org/sites/default/files/2020-07/ADAP-Guidelines-for-adolescent-participation-and-civic-engagement.pdf. Cited 20 August 2020.

University of New Hampshire. (2019). RIFC Global Social Franchise Index. https://www.unh.edu/rosenbergcenter/. Cited 3 September 2020.

World Bank. (2015). Youth in Sub-Saharan Africa are out if School. https://www.worldbank.org/en/topic/education/publication/out-of-school-youth-in-sub-saharan-africa. Cited 7 September 2020.

Gender Inequality as a Driver of Institutional Water Scarcity: A Case Study of Kenya and Uganda

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Abstract

Water scarcity is a gendered issue. With the increasing effects of climate change, water scarcity is becoming one of the most imminent threats to humanity. In many parts of the world, however, particularly under developmental contexts, the physical lack of water resources is not the only barrier to water access and use. Social, economic, cultural and political dimensions play an important role in creating institutional water scarcity, by creating structures of inequality. One of the most prominent and salient of these structures is gender inequality. Thus, this paper examines the relation between gender inequality and institutional water scarcity in the two nations of Kenya and Uganda, as well as the government responses to address this issue. For each case, a three-part analysis was conducted, examining (i) the current state of (institutional) water scarcity, (ii) the mutually reinforcing relation between gender inequality and water scarcity, and finally (iii) the government response in dealing with the issue at hand. An in-depth review of relevant literature, related projects and programmes, as well as government legislations, strategies, and plans, demonstrates that gender norms, power relations and division of labor all lead to exacerbated experiences of water scarcity for women in Kenya and Uganda.

Keywords: Institutional water scarcity; gender; Kenya; Uganda

1. Introduction

In the age of climate change, water security is becoming an ever-more important issue. From water scarcity to water "wars," the world is facing a tremendous responsibility for resolving the complex issue of water security, climate change, and sustainable development (Biswas & Tortajada, 2016; Farinosi et al., 2018; Myrttinen et al., 2018). However, scientific analyses and public policies on climate change often undermine the human component, mainly focusing on technical and economic solutions (Jerneck, 2018). This tendency is especially detrimental in the context of the water sector, as water is directly related to human livelihoods, through food security, public health, sanitation, and more (UNESCO & UN Water, 2020).

Water is deeply entrenched within every economic and social aspect of human life, and as a result, its scarcity and insecurity hold the potential of completely changing our social, economic, and political structures (Jerneck, 2018; UNESCO & UN Water 2020; World Bank, 2017b). Especially within the developing world, climate change and water security will inevitably interact with nations' socioeconomic development trajectories (Jerneck, 2018; Sultana, 2018). Thus, water needs to be seen not only as a hydrological concept or an economic resource, but also a humanitarian issue that requires human-focused perspectives for its management (Jemmali, 2016).

Water scarcity is one of the biggest threats to humanity in the modern day, already threatening four out of every 10 people, and expected to affect roughly two-thirds of the world's population by 2050 (UNESCO & UN Water, 2020; UN Water, 2018; Wutich, 2012). The concept of water scarcity is not straightforward, however, which complicates scopes of research and policy making. Although physical (hydrological) lack of water resources is the dominant aspect of scarcity discussed, previous research has expansively demonstrated that there are social, economic, cultural, and political facets of water scarcity as well (FAO, 2012a; Kamya et al., 2020; Mdee, 2017; Savenije, 2000; WWAP, 2016). For this reason, regions such as Sub-Saharan Africa experience severe levels of institutional water scarcity despite the fact that much of the region does not have a physical lack of water resources (WWAP, 2016).

One of the important drivers of this institutional water scarcity is gender inequality. Gender, as one of the most powerful and deeply embedded institutions of our day, is inseparable from power relations and societal value systems (Myrttinen et al., 2018). Gender structures, therefore, both shape and are shaped by other power structures, including the environment (Sen & Durano, 2014). The relation between gender and water has gained increasing recognition through both policy and research. Much of this research, however, has been focused around three main areas: (i) the gendered division of labor related to water, whereby women and girls carry an 'unequal burden' for collecting water (e.g., Dometita, 2017; Gambe, 2019; Graham et al., 2016), (ii) the gender inequality of representation, decision-making, and rights in the water sector, such as the underrepresentation of women in community water management (e.g., Andajani-Sutajahjo et al., 2015; Charles K. & Kindiki, 2015; Sinyolo et al., 2018), and (iii) the disproportionate vulnerabilities of women and girls in face of limited access to WASH facilities (e.g., Mitra & Rao, 2019; Morgan et al., 2017; Wali et al., 2020). While these are important and necessary discussions for the sensitization of the water sector, research and policy on more specific sub-sectors of water and sanitation remain relatively under-researched. Particularly, the gender dimensions of water scarcity, and their implications for policy, remain a big gap in the literature (Bennett et al., 2008; Crow & Sultana, 2002; Wutich, 2012).

Gender and water scarcity are intersecting and relational concepts. Gendered power structures and systems create structural inequality in water access, control, and use (Bennett et al., 2008; Sultana, 2018), threatening to exacerbate institutional water scarcity. Particularly in sub-Saharan Africa, where many countries have high disparities in water access across regions, and where the political geography remains salient from colonial influences, the gendered implications of water scarcity are more important. Therefore, it is imperative that any research or policy regarding water scarcity address the gender dimension, especially when dealing with developmental contexts. With this understanding, this paper examined the relation between gender inequality and institutional water scarcity in the context of the two East African nations of Kenya and Uganda, as well as the current government responses to addressing the issue at hand.

2. Methodology

A comparative case study of the two East African nations of Kenya and Uganda was conducted. The two countries were chosen for their struggle with water scarcity, and particularly with institutional water scarcity. For each case, a three-part analysis was conducted, explaining (i) the current state of (institutional) water scarcity, (ii) the mutually reinforcing relation between gender inequality and water scarcity, and finally (iii) the government response in dealing with this issue at hand. For the first two parts, an in-depth literature review was conducted, and statistics and data were collected from open database sources such as the UN-Water SDG 6 Data Portal (UN Water, n.d.) and the WHO/UNICEF Joint Monitoring Programme on WASH (WHO/UNICEF JMP, 2018). Lastly, the government response was analyzed through a systematic review of the legislations, strategies, and plans established by the two nations' Ministries responsible for water management (the Kenyan Ministry of Water & Sanitation and Irrigation, and the Ugandan Ministry of Water and Environment).

3. A Case Study of Kenya and Uganda

Many studies have previously demonstrated that although Kenya and Uganda are not faced with imminent and absolute physical lack of water resources, a large portion of their population, especially in rural areas, struggle with water scarcity (Kamya et al., 2020; World Bank, 2019; WWAP, 2016). According to the FAO (2018), Kenya is experiencing water stress of around 14%, and Uganda of 1%. However, the levels of basic and safe drinking water coverage in Kenya rest at roughly 59% in Kenya and 49% in Uganda, both of which are lower when only looking at rural areas (WHO/UNICEF JMP, 2018). This indicates that the available water resources are not being distributed efficiently nor equitably, resulting in institutional water scarcity for a substantial potion of the population. The following part outlines each specific case in more detail, particularly looking at the role of gender inequality in fueling this institutional water scarcity, as well as the government measures that are being taken to address the issue.

3.1. The Case of Kenya

Despite the fact that Kenya is "endowed with both surface and groundwater resources," (Republic of Kenya, 2020) the nation is classified as a "chronically water-scarce" country (FAO, 2019). The scarcity of the nation's renewable water resources is sharply increasing with rising competition and demand, caused by population growth, urbanization, and climate change (Republic of Kenya, 2020). However, Kenya's water scarcity is also fueled by institutional factors such as lack of government investment and unequal socioeconomic as well as political structures (Dometita, 2017; Kameri-Mbote & Kariuki, 2015). For instance, urban-rural disparities are quite significant (World Bank, 2013), with uneven distribution both spatially and temporally. Water resource conflicts and ineffective control and regulation of water resources are other serious issues (Republic of Kenya, 2020). These institutional dimensions of water scarcity play a central role in causing inefficient allocation and use of water, as well as in shaping structural inequalities that impact the poorest and most vulnerable sections of the population the hardest (Kameri-Mbote & Kariuki, 2015; World Bank, 2013). Consequently, Kenya's institutional water scarcity is a strong threat to both the nation's developmental progress as well as the livelihoods and well-being of its people, through health complications and food insecurity (Dometita, 2017; Mogaka et al., 2005; World Bank, 2017a).

Within this context, the gender relations and structures within the nation create harsher realities for women and girls. According to Kenya's cultural practices and norms, there is a general understanding that men or husbands hold higher status over women or wives within the household (Dometita, 2017). Also, there is a common belief that men own not only physical resources, but also the women and children themselves (Dometita, 2017; GCF, 2019). It is no surprise, therefore, that women have much lower levels of decision-making power, and have relatively little ownership of resources (Dometita, 2017; World Bank 2003 as cited in GCF, 2019). This leads to direct impacts in women's experiences of water scarcity. For instance, access to water and sanitation services in Kenya are directly linked to land tenure, meaning that women face systematic inequality in gaining access to and use of water (Kameri-Mbote & Kariuki, 2015). Decision-making regarding water management is also skewed in favor of male representation (Charles K. & Kindiki, 2015; Speranza & Biketti, 2018), leading to community decisions that continue to reinforce the systematic marginalization of women's needs and ideas. Furthermore, the existing power inequalities lead to a chain reaction of marginalization in the face of water scarcity, for instance through food insecurity, threats to physical safety, and loss of socioeconomic opportunities. Dometita (2017) found, for example, that when water scarcity aggravates food insecurity, women are affected the fastest and the hardest, as they give up their food for their husbands and children (Dometita, 2017). Finally, the gendered division of labor also creates different experiences and burdens for Kenyan men and women. Men dominate productive labor, while women are responsible for reproductive labor (Dometita, 2017; GCF, 2019). Particularly, collecting water is one of the most burdening and significant aspects of women's unpaid labor (GCF, 2019), with some women having to fetch water even during their last month of pregnancy (Collins et al., 2018). As a result of this responsibility, water scarcity burdens women and girls with prolonged hours for collecting water, which also leads to lost socioeconomic opportunities such as schooling or economic activity (Dometita, 2017).

The Kenyan government has recognized these problematic issues that emerge at the intersections of gender and water. The state has demonstrated their dedication to resolving both gender inequality and water scarcity, starting with their Constitution ratified in 2010, which guarantees both gender equality as well as the unanimous right to adequate quantities and safe quality of water (GCF, 2019; Kameri-Mbote & Kariuki, 2015; Republic of Kenya, 2010; Speranza & Biketti, 2018). According to Speranza & Biketti (2018), who conducted a systematic review of the Kenyan government's water-related policies and plans for their engagement with gender issues, gender mainstreaming in government policy and practice demonstrates much progress and potential. For instance, while the Water Act of 2002 "…did not address gender at all…" it has now been replaced by the Water Act of 2016, which does include references to gender-equal rights and opportunities, in line with the Constitution (Speranza & Biketti, 2018). Furthermore, government plan documents such as Kenya's Water Sector Strategic Plan 2010-2015 and the Integrated Water Resources Management and Efficiency Plan for Kenya also demonstrate efforts to mainstream gender into the water sector (Speranza & Biketti, 2018).

However, a closer look at the latest government documents reveals that these aforementioned advances remain largely in rhetoric, only. The Republic of Kenya's Third Medium Plan (2018-2022) for the Kenya Vision 2030 includes development strategies for both water and sanitation as well as gender equality, separately, but the two sections indicate no points of convergence between each other (Republic of Kenya, 2018b). It appears that while the oil and gas sub-sector has developed gender assessment guidelines, the same cannot be said about the water and sanitation sector (Republic of Kenya, 2018b). The Ministry of Water and Sanitation's Strategic Plan for 2018-2022, on the other hand, does mention gender a few times. For instance, the first of the eight 'Key Result Areas,' "Policy, Legal and Institutional Framework," indicates that cross-cutting issues will be mainstreamed, including "gender policy" (Republic of Kenya, 2018a). However, the document does not contain any explanation as to what this gender policy entails. Other mentions of gender appear in the monitoring and evaluation section, which indicates that Ministry projects will be evaluated for their sensitivity to factors such as "age, gender, disabilities, ethnicity, etc.," as well as for setting affirmative action policies (Republic of Kenya, 2018a). Finally, the Water Services Regulatory Board Strategic Plan 2018-2022 and the Water Act of 2016 also mention gender only once per each document (Republic of Kenya, 2016; WAREB, 2018). In the WASREB Strategic Plan, the situation analysis section mentions that there is "inadequate gender mainstreaming in water decision making" (WASREB, 2018). Once again, however, there is no detailed explanation detailing this aforementioned inadequacy. Lastly, the Water Act mentions gender for promoting gender representation within boards or committees only (Republic of Kenya, 2016).

As can be seen, Kenya's government policies and strategies demonstrate that there is still little understanding about the intersections of water resources management and gender. While there is increased attention to the importance of representing women, there is still a large gap in recognizing the *why* and *how*. Thus, there is a need to develop more specific strategies, with concrete, realistic, and achievable goals. This is particularly more important as Kenya is experiencing sharp increases in water scarcity, expected to aggravate the gender-based burdens and risks. The following case study of Uganda, in this regard, can serve as an important frame of reference.

3.2. The Case of Uganda

Uganda is, relatively speaking, one of the "well-watered" countries in Africa (World Bank 2011). Around one third of the nation's surface is covered by freshwater resources (Alabaster & Kruckova, 2015; GoU, 2013). The country is, however, experiencing rapid decreases in water resource availability as a result of climate change impacts, high population growth, and degradation of water catchment areas (GIZ, 2020). This rising water scarcity threatens the rural population the most, with roughly 10% of the population affected each year (World Bank, 2019). The major challenges of Uganda's institutional water scarcity result from both physical as well as sociopolitical issues. Inequalities in water access are caused, on the first instance, by a widespread geographical distribution of water points and population densities (Kamya et al., 2020). Additionally, political motivations also create great variations between counties in their level of access, as some receive more preferential treatment (Kamya et al., 2020). Furthermore, lack of capacity for effective water management and lack of public investment in water infrastructure and services are also exacerbating the public's experience of water scarcity (World Bank, 2011).

The relationship between gender inequality and water scarcity in Uganda is resemblant of that of Kenya. The active discrimination against women in access, control, and ownership of resources restricts their adaptive capacities for climate change issues like water scarcity (GoU, 2017b; Kabaseke, 2020). Women are pushed out of stable and economic activities, and into vulnerable and unpaid activities such as water collection (GoU, 2017b). Furthermore, while women and children are almost fully responsible for collecting water (Sugita, 2006), men dominate the majority of decision-making (Magala, 2017). The power disparities are also apparent. While men and women both play important roles in Uganda's water management through water user groups, men are entitled to financial and productive water use while women are responsible for reproductive and unpaid labor (Magala, 2017; Naiga et al., 2017). These household level differences in gender roles and power dynamics influence the experiences of institutional scarcity (Magala et al., 2015).

Cognizant of these issues, the Governent of Uganda has taken several steps to address the gendered dimensions of water resource management. A review of key legal documents revealed that like Kenya, Uganda's Constitution guarantees equality between women and men, as well as "prescribes temporary affirmative action in favor of women for purposes of redressing imbalances created by history, tradition and other factors (GoU, 2016). Also, like Kenya, the government's main development plans and strategies such as the Uganda Vision 2040 and the National Development Plan unfortunately demonstrate no understanding or emphasis on the link between gender and water resource management (GoU, 2013; GoU 2020). However, a key difference exists between Kenya and Uganda, which is that since 2003, the Ugandan government has published an explicit strategy to increase gender sensitivity into its water policies, and is now implementing the third of this strategy from 2018 to 2022 (Gender and Water Alliance, n. d.; GoU, 2009; GoU, 2017b).

The first and second Water and Sanitation Gender Strategy (WSGS), released by the Republic of Uganda's Ministry of Water and Environment, covered the years 2003-2008 and 2010-2015. A Gender Impact Study conducted in 2017 revealed that these strategies were effective in mainstreaming gender concerns into Ministry policies such as guidelines and manuals, and even trickling into the development plans of some districts and sub-counties (GoU, 2017a).

Persisting challenges, on the other hand, included gender imbalance in leadership and management, and collecting gender-disaggregated data on all levels and sub-sectors (GoU, 2017a; GoU, 2017b). Based on this study, the third WSGS (or WSGS III) was released in 2017, addressing a wide range of issues such as gender mainstreaming in policy, capacity building, economic empowerment, and more (GoU, 2017b).

An examination of the WSGS III revealed that the Ugandan Government demonstrates a high level of recognition and interaction with the gendered dimensions of water resource management. For instance, the strategy states from its very beginning that “women and children are the most affected by (…) inadequate water supply” because of their unpaid labor as well as lost socioeconomic opportunities (GoU, 2017b). Additionally, the document also recognizes that commitments to gender equality are remaining largely “only on paper,” emphasizing the need for translating these into actual implementation (GoU, 2017b). This is distinct to the case of Kenya, where the same reality seems to exist but the recognition of it is missing. Other notable parts of the WSGS III include: (1) recognition of the social and cultural inequalities that reinforces water sector inequalities for women and girls, (2) emphasis on capacity building and the need for gender focal points (“Gender Champions”), and (3) identification of facilities and tools that need to become more gender-sensitive, such as washrooms within the workplace and handpumps (“Install hand pumps which are easy to repair…”) (GoU, 2017b).

All in all, Uganda’s Water and Sanitation Gender Strategy demonstrates an impressive level of gender awareness and sensitivity. While the strategy is ambitious, it also outlines concrete and short-term plans for action that demonstrate great potential. It is also worth noting that the WSGS III also attempts to address the larger structures of gender inequality such as cultural norms and socioeconomic opportunities. The one downfall, however, is that this impressive strategy is not reflected in the more mainstream and higher-order development strategies of the state at large, such as the Vision 2040 or the National Development Plan. It is important to advocate these issues into the higher political realm, in order to gain practical and/or institutional support (such as funding).

4. Discussion and Conclusion

Kenya and Uganda are both sub-Saharan African countries that are experiencing rapidly rising levels of water scarcity (FAO, 2019; GIZ, 2020; World Bank, 2019). While their experiences of scarcity result in large part due to hydrological causes related to climate change or population change, sociopolitical factors also play an important role, especially in exacerbating the lived experiences of scarcity for vulnerable populations (GCF, 2019; Kamya et al., 2020; World Bank, 2013; World Bank, 2019). Gender structures and power relations, expressed in gender-based division of labor, levels of rights, and traditional roles, play an especially central role in exacerbating the experiences and burdens of water scarcity for women and girls (Dometita, 2017; Kameri-Mbote & Kariuki, 2015; Magala et al., 2015). Therefore, it is imperative that water sector policies and strategies reflect an understanding of this interrelation.

The Kenyan and Ugandan states have both begun their efforts to sensitize their water sectors towards gender issues. Both governments have fully recognized the important role that women play in the collection, management, and use of water, which is an important starting point. The strategic objectives and action plans established to address the different experiences of women, however, are less visible in Kenya’s policies. Uganda’s Water and Sanitation Gender Strategy demonstrates higher levels of specificity in providing directions, guidelines, and goal-oriented actions for local governments or other lower-level administrations to implement.

Hence, as Uganda's gender mainstreaming efforts are one step ahead, their policies may offer useful guidance for Kenya's and other nations' development of gender-sensitive water policies. At the same time, Uganda's policies have room for improvement as well, particularly in reflecting the strategic directions of the WSGS into the larger state legislations and policies.

What this paper attempted to illustrate, through its comparative case study, is the gendered implications of water scarcity and water (in)security at large. With increasing water stress worldwide, it is becoming even more important to address the intersections of sustainability, equity, and security. However, most research and international interventions in the water sector still remain highly concentrated on economic and/or technical aspects only, with social development goals receiving insufficient attention. Additionally, even as research and policy on the intersections of gender and water are becoming increasingly visible, the gendered dimensions of specific sub-sectors of water are still largely absent. Therefore, suggestions for future research include: (1) examining the effectiveness of water sector gender policies or strategies in improving the equality and security experienced by women, (2) assessing the specific ways in which water scarcity affects men and women differently, and (3) comparative analyses of the intersections of gender inequality and water scarcity in other nations and regions.

References

Alabaster, R. A., & Kruckova, L. (2015). Uganda Country Mapping: The status of implementation and monitoring of the human right to water and sanitation. WaterLex, Geneva. ISBN 978-2-940-526-04-8.

Andajani-Sutajahjo, S., Chirawatkul, S., & Saito, E. (2015). Gender and Water in Northeast Thailand: Inequalities and Women's Realities. *Journal of International Women's Studies, 16*(2), pp. 200-212.

Bennett, V., Davila-Poblete, S., & Rico, M. N. (2008). Water and Gender: The Unexpected Connection That Really Matters. *Journal of International Affairs, 61*(2), pp. 107-126.

Biswas, A. K., & Tortajada, C. (2018). Water Security, Climate Change and Sustainable Development: An Introduction. In A. K. Biswas, C. Tortajada (Eds.), *Water Security, Climate Change and Sustainable Development* (pp. 1-5). Springer International Publishing.

Charles K., W., & Kindiki, M. (2015). Gender Disparities in Water Resource Management Projects in Njoro Sub-County, Kenya. *International Journal of Social Science Studies, 3*(2).

Collins, S. M., Owuor, P. M., Miller, J. D., Boateng, G. O., Wekesa, P., Onono, M., & Young, S. L. (2018). 'I know how stressful it is to lack water!' Exploring the lived experiences of household water insecurity among pregnant and postpartum women in western Kenya. *Global Public Health, 14*(5), pp. 649-662.

Crow, B., & Sultana, F. (2002). Gender, Class, and Access to Water: Three Cases in a Poor and Crowded Delta. *Society and Natural Resources, 15,* pp. 709-724.

Dometita, M. L. M. (2017). *Beneath the Dryland: Kenya Drought Gender Analysis.* Oxfam Research Reports. ISBN 978-1-78748-154-1.

Farinosi, F., Giupponi, C., Reynaud, A., Ceccherini, G., Carmona-Moreno, C., De Roo, A., Gonzalez-Sanchez, D., & Bidoglio, G. (2018). An innovative approach to the assessment of hydro-political risk: A spatially explicit, data driven indicator of hydro-political issues. *Global Environmental Change, 52,* pp. 286-313. https://doi.org/10.1016/j.gloenvcha.2018.07.001

Food and Agriculture Organization of the United Nations [FAO]. (2012). Coping with water scarcity: An action framework for agriculture and food security. ISBN 978-92-5-107304-9.

Food and Agriculture Organization of the United Nations [FAO]. (2018). Progress on level of water stress – Global baseline for SDG 6 indicator 6.4.2 2018. Rome. FAO/UN-Water. ISBN 978-92-5-130988-9.

Food and Agriculture Organization of the United Nations [FAO]. (2019). Total renewable water resources per inhabitant [image]. Retrieved from: http://www.fao.org/aquastat/en/geospatial-information/maps.

Gambe, T. R. (2019). The Gender Dimensions of Water Poverty: Exploring Water Shortages in Chitungwiza. *Journal of Poverty, 23*(2), pp. 105-122.

Gender and Water Alliance [GWA]. (n. d.) Uganda: Mainstreaming Gender into Policy: Examining Uganda's Gender Water strategy.

GIZ. (2020, December 18). Enhanced water security and sanitation. Retrieved from: https://www.giz.de/en/worldwide/19263.html.

Government of Uganda [GoU]. (2009). Water and Sanitation Sub-Sector Gender Strategy (2010-2015).

Government of Uganda [GoU]. (2013). Uganda Vision 2040. http://www.npa.go.ug/uganda-vision-2040/. Accessed: March 28, 2021.

Government of Uganda [GoU]. (2016). Environment and Natural Resources Sub-Sector Gender Mainstreaming Strategy 2016-2021. https://www.mwe.go.ug/library/enr-gender-strategy-2016-2021. Accessed: March 28, 2021.

Government of Uganda [GoU]. (2017a). A Gender Impact Study of the Water and Sanitation Sub-Sector. https://www.mwe.go.ug/library/gender-impact-study-report-2017. Accessed: March 28, 2021.

Government of Uganda [GoU]. (2017b). Water and Sanitation Gender Strategy: 2018-2022. https://www.mwe.go.ug/library/water-and-sanitation-gender-strategy-2018-2022. Accessed: March 28, 2021.

Government of Uganda [GoU]. (2020). Third National Development Plan (NDPIII) 2020/21-2024/25. http://www.npa.go.ug/development-plans/national-development-plan-ndp/. Accessed: March 28, 2021.

Graham, J. P., Hirai, M., & Kim, S. (2016). An Analysis of Water Collection Labor among Women and Children in 24 Sub-Saharan African Countries. *PLoS ONE, 11*(6). https://doi.org/10.1371/journal.pone.0155981

Green Climate Fund [GCF]. (2019). FP 113: Towards ending drought emergencies: Ecosystem-based Adaptation in Kenya's arid and semi-arid rangelands (TWENDE). Gender Assessment. Green Climate Fund.

Jemmali, H. (2016). Mapping water poverty in Africa using the improved Multidimensional Index of Water Poverty. *International Journal of Water Resources Development.*

Jerneck, A. (2018). What about Gender in Climate Change? Twelve Feminist Lessons from Development. *Sustainability, 10.* https://doi.org/10.3390/su10030627

Kabaseke, C. (2020). Climate change adaptation and women's land rights in Uganda and Kenya: Creating legal pathways for building the resilience of women. *Gender & Behaviour, 18*(2).

Kameri-Mbote, P., & Kariuki, F. (2015). Human Rights, Gender and Water in Kenya: Law, Prospects and Challenges. In A. Hellum, & P. Kameri-Mbote (Eds.), *Water is Life: Women's Human Rights in National and Local Water Governance in Southern and Eastern Africa* (pp. 81-214). Weaver Press.

Kamya, I. R., Asingwire, N., & Waiswa, D. B. (2020). Besides Physical Scarcity: An Analysis of Domestic Water Access in Rural Rakai, Uganda. *Eastern Africa Social Science Research Review, 36*(2), pp. 115-131.

Magala, J. M. (2017). Community Water Management in Rural Uganda: A Woman's Predicament. *wH2O: The Journal of Gender and Water, 4*(1).

Magala, J. M., Kabonesa, C., & Staines, A. (2015). Lived experiences of women as principal gatekeepers of water management in rural Uganda. In G. H. Fagan, S. Linnane, . G. McGuigan, A. Rugumayo (Eds.), *Water is Life: Progress to secure water provision in rural Uganda.* ISBN 9781853398902

Mdee, A. (2017). Disaggregating Orders of Water Scarcity – The Politics of Nexus in the Wami-Ruvu River Basin, Tanzania. *Water Alternatives, 10*(1), pp. 100-115.

Mitra, A., & Rao, N. (2019). Gender, Water, and Nutrition in India: An Intersectional Perspective. *Water Alternatives, 12*(3), pp. 930-952.

Mogaka, H., Gichere, S., Davis, R., & Hirji, R. (2005). Climate variability and water resources degradation in Kenya. *World Bank Working Papers*.

Morgan, C., Bowling, M., Bartram, J., & Kayser, G. L. (2017). Water, sanitation, and hygiene in schools: Status and implications of low coverage in Ethiopia, Kenya, Mozambique, Rwanda, Uganda, and Zambia. *International Journal of Hygiene and Environmental Health, 220*(6), pp. 950-959.

Myrttinen, H., Cremades, R., Fröhlich, C., & Gioli, G. (2018). Bridging Troubled Waters: Water Security Across the Gender Divide. In C. Fröhlich, G. Gioli, R. Cremades, & H. Myrttinen (Eds.), *Water Security Across the Gender Divide* (pp. 3-14). Springer International Publishing.

Naiga, R., Penker, M., & Hogi, K. (2017). Women's Crucial Role in Collective Operation and Maintenance of Drinking Water Infrastructure in Rural Uganda. *Society & Natural Resources, 30*(4), pp. 506-520.

Republic of Kenya. (2010). *The Consitution of Kenya. 2010.* http://www.kenyalaw.org:8181/exist/kenyalex/actview.xql?actid=Const2010. Accessed: June 21, 2020.

Republic of Kenya (2018a). Ministry of Water and Sanitation Strategic Plan 2018-2022. https://www.water.go.ke/downloads/. Accessed: March 28, 2021.

Republic of Kenya. (2018b). Third Medium Term Plan (2018-2022) Kenya Vision 2030. https://vision2030.go.ke/publication/third-medium-term-plan-2018-2022/. Accessed: March 28, 2021.

Republic of Kenya. (2020). Ministry of Water, Sanitation and Irrigation Annual Status Report on Water, Sanitation and Irrigation. https://www.water.go.ke/downloads/. Accessed: March 28, 2021.

Savenije, H. H. G. (2000). Water Scarcity Indicators; the Deception of the Numbers. *Physics and Chemistry of the Earth, 25*(3), pp. 199-204.

Sen, G., & Durano, M. (2014). Social contracts revisited: the promise of human rights. In G. Sen, & M. Durano (Eds.), *The Reamking of Social Contracts: Feminists in a Fierce New World.* Zed Books.

Sinyolo, S. A., Sinyolo, S., Mudhara, M., & Ndinda, C. (2018). Gender Differences in Water Access and Household Welfare among Smallholder Irrigators in Msinga Local Municipality, South Afirca. *Journal of International Women's Studies,* 19(5), pp. 129-146.

Speranza, C. I., & Biketti, E. (2018). Engaging with Gender in Water Governance and Practice in Kenya. In C. Fröhlich, G. Gioli, R. Cremades, & H. Myrttinen (Eds.), *Water Security Across the Gender Divide* (pp. 17-33). Springer International Publishing.

Sugita, E. W. (2006). Increasing quantity of water: perspectives from rural households in Uganda. *Water Policy,* 8, pp. 529-537.

Sultana, F. (2018). Gender and Water in a Changing Climate: Challenges and Opportunities. In C. Fröhlich, G. Gioli, R. Cremades, & H. Myrttinen (Eds.), Water *Security Across the Gender Divide* (pp. 17-33). Springer International Publishing.

UNESCO & UN Water. (2020). U*nited Nations World Water Development Report 2020: Water and Climate Change.* https://en.unesco.org/themes/water-security/wwap/wwdr/2020

United Nations World Water Assessment Programme [WWAP]. (2016). *The United Nations World Water Development Report 2016: Water and Jobs*. Paris, UNESCO.

UN Water. (2018). *Water and Climate Change.* https://www.unwater.org/publications/un-water-policy-brief-on-climate-change-and-water/

UN Water. (n.d.) SDG 6 Data Portal. https://www.sdg6data.org/data-lab. Accessed: March 28, 2021.

Wali, N., Georgeou, N., Simmons, O., Gautam, M. S., & Gurung, S. (2019). Women and WASH in Nepal: a scoping review of existing literature. *Water International*, 45(3), pp. 222-245.

Water Services Regulatory Board [WASREB]. (2018). WASREB Strategic Plan 2018-2022. https://wasreb.go.ke/downloads/WASREB-Strategic-Plan-2018-2022-Draft.pdf

World Bank. (2011). Uganda: Water Assistance Strategy. Washington DC: The World Bank.

World Bank. (2013). *Kenya- Water Security and Climate Resilience Project* (English). Washington DC, World Bank. http://documents.worldbank.org/curated/en/660001468045533836/Kenya-Water-Security-and-Climate-Resilience-Project

World Bank. (2017a). Kenya - Water and Sanitation Development Project (English). Washington DC: World Bank Group.

World Bank. (2017b). *The Rising Tide: A New Look at Water and Gender.* http://documents.worldbank.org/curated/en/901081503580065581/The-rising-tide-a-new-look-at-water-and-gender

World Bank. (2019). Disaster Risk Profile: Uganda. Washington DC: The World Bank Group.

World Health Organization & UNICEF Joint Monitoring Programme for Water Supply, Sanitation and Hygiene [WHO/UNICEF JMP]. (2018). "Data." https://washdata.org/

Wutich, A. (2012). Gender, Water Scarcity, and the Management of Sustainability Tradeoffs in Cochamba, Bolivia. In M. L. Cruz-Torres, & P. McElwee (Eds.), *Gender and Sustainability* (pp. 97-120). University of Arizona Press. http://www.jstor.com/stable/j.ctt181hxh7.9

Yerian, S., Hennink, M., Greene, L. E., Kiptugen, D., Buri, J., & Freeman, M. C. (2014). The Role of Women in Water Management and Conflict Resolution in Marsabit, Kenya. *Environmental Management,* 54, pp. 1320-1330. https://doi.org/10.1007/s00267-014-0356-1

Rethinking Water Governance in Fluorosis Affected Communities Using the Mt. Longonot Sharity Concept, Naivasha – Kenya

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Abstract

This paper explores deeper dimensions of fluorosis and seeks to develop a clear community-driven policy framework around fluorosis. It aims at redistributive policies that will lead to resource benefits to the local residents. The work will provide the foundation necessary to lobby for the implementation of policies that favor rainwater harvesting at household level. Exploitation of water for energy production needs to be redefined and readdressed properly. Naivasha geothermal exploration and fluorosis is used as the case study. Mount Longonot's previous volcanic events were a blessing and a curse to the geographical area in that, it is the reason for geothermal potential and is also the generator of observed high fluoride aquifers of the area. Geothermal energy production has always required water in the form of steam to produce energy and therefore, legislation should be able to induce good quality and affordable consumption water as well as wastewater treatment in Naivasha.

Keywords: fluorosis; geothermal energy; groundwater; Kenya; rainwater harvesting

1. Introduction

The population of Naivasha sub-county of Kenya is expected to outgrow its drinking water supply due to the anticipated developments that are indicated in the County Integrated Development Plan (CIDP) 2018-2022 (CGN, 2018). Some of the proposed large projects are inland container park and development of housing units in Naivasha town (CGN, 2018; World Bank, 2018; Kengen, 2021). Naivasha water and sanitation company (NAIVAWASCO) is a state-owned company that provides drinking water to communities in Naivasha sub-county with a coverage of 84% (Borda/Sanivation, 2019). In Africa, groundwater is the main source of raw water supply, but this is beset with high levels of fluoride (Table 1) and in Naivasha sub-county is located in the Kenya Rift Valley (Gevera, 2017). Alternative raw water sources are being developed such as Kinja dam, Malewa dam and drilling of more boreholes and proposed desalination/defluoridation projects (World Bank, 2018). The studies of Gevera (2017) and Wagatua (2019) showed that the groundwater quality was poor due to high levels of fluoride and this contributed to dental and skeletal fluorosis among the communities in Naivasha sub-county. Fluorosis does affect the vulnerable groups the most, due to lack of affordable defluoridation technology, the insufficient awareness on water safety, high poverty rate and the lack of water safety coping strategies (Ndé-Tchoupé, Nanseu-Njiki, et al., 2019). Data on the quality of water in Naivasha is not readily available and the local population do not have knowledge nor control of the fluoride concentrations in the water they consume. The paper explores potential mutually beneficial relationship between United Nations Sustainable Development Goal (SDG) 6 on water and sanitation for all and SDG 7 on energy in the case of Naivasha. This will in turn achieve SDG 17 on multi-stakeholder partnerships, SDG 3 on healthy lives and healthy ecosystems and SDG 1 on ending poverty and building the resilience of fluorosis affected communities.

Unsafe levels of fluoride in drinking and cooking water is a major problem across the globe, with health hazards such as dental and skeletal fluorosis (Shakir et al., 2016). Mental fluorosis leads to neurodegeneration, triggering diseases such as Alzheimer's and other neurodegenerative and vascular diseases (Fluoride and Mental Decay, n.d.), depending on the dosage of the fluoride consumed.

Table 1. **The natural occurrence of fluoride in water resources in selected countries in Africa**

Country	Range Levels of fluoride (mg/L)	Reference
Algeria	0.79 to 2.01	(Baouia & Messaitfa, 2015)
Benin	1.53 to 4.3	(Avocefohoun et al., 2017)
Cameroon	0.01 to 0.87	(Fantong et al., 2009)
Chad	0.05 to 1.1	(Sorlini et al., 2013)
Ethiopia	1 to 264	(Tekle-Haimanot et al, 2006)
Eritrea	1.07 to 3.73	(Srikanth et al, 2002
Egypt	0.113 to 0.452	(Ahmed, 2014)
Ghana	0.01 to 11.6	(Salifu, 2017)
Libya	0.8 to 11	(Aldeghaither, 2018)
Malawi	0.51 to 7.25	(Sajidu et al., 2008)
Senegal	0.4 to 2.85	(Kane et al., 2012)
Morocco	0.28 to 2.97	(El Jaoudi et al., 2012)
Nigeria	0.48 to 1.84	(Emenike et al., 2018)
South Africa	0.1 to 8.2	(Malago et al., 2017)
Sudan	0.01 to 2.07	(Mustafa & Younis, 2018)
Uganda	0.3 to 3	(Elumalai et al., 2019)
Kenya	0.5 to 72	(Gevera, 2017)
Tanzania	0.5 to 1402	(Makoba, 2020)

In their study, Alkurdi et al. (2019) notes that the concentration of fluoride in groundwater resources depends on the geographical location and is largely associated with the presence of nearby volcanic activities. The local geology and climatic conditions allow for the adaptation of Fluoride concentration above 1.5 mg/l (WASREB, 2016).

Historically, public health policies have focused on mortality, with death rates and burden of diseases (WHO, 2009a). This approach looks at the effect and impact of infections of pathogens and their ability to result in deaths. On the other hand, the effect of fluorosis is a long-term impact on human health. Hence, the World Health Organization (WHO) does not classify fluorosis to be among the preventable health risks that are as a result of absent, inadequate, or inappropriately managed water services. The outdated and inadequate WHO's building capacity tools on fluoride and the global prevalence rate of fluorosis indicates how poorly understood chronic fluoride induced conditions are (WHO, 2009b; WHO, 2005; WHO, n.d.) . The fact that these conditions are none communicable, and not life threatening, has made it less of a priority for the medical and the public health practitioners and at the policy level.

The African Union's Agenda 2063 targets a water secure Africa (DeGhetto et al., 2016). Despite high fluoride levels being observed in most African countries and the Great Rift Valley belt having been termed as the world's most severe fluoride belt (Lukiko et al., 2016), the Africa Water Vision for 2025 (Africa, 2003) does not mention fluorosis to be among the natural threats on the sustainability of the African water resources. The Kenya Water Act No. 43 of 2016 (Water Act, 2016) and the county water governing blueprints (Gazette, 2014) particularly on fluorosis, are inadequately put in writing, hence the gap is very clear when it comes to guidance for fluorosis eradication interventions.

Olkaria geothermal power station is a series of compacts units (Olkaria I to V) that have been constructed and installed to generate electricity to the tune of 699MW (Kengen, 2021). The natural heat and steam from the vicinity of Mount Longonot has been harnessed to provide electricity. This is clean form of electricity as opposed to the fossil powered systems.

The 2018 SDGs report indicates that many people still lack access to safely managed water supplies and sanitation facilities and this hinders social and economic development and in order to attain SDG6, everyone's needs must be addressed, leaving no one behind (WHO, 2019). The UN World Water Development (WWDR 2018) report demonstrates potential contribution of nature-based solutions (NBS) in order to meet SDG 6 targets across all sectors in addressing contemporary water management challenges such as on improving water quality.

Mount Longonot sharity concept aims to rectify inequitable harvest of resources by integrating the management of water and energy. This is so as to balance energy with the resilience of good quality water supply provision and investments in sanitation facilities in Nakuru County.

This paper provides the entrusted policy makers and practitioners with useful insight into water and energy in Naivasha with the hope to transform old patterns of water governance. Construction of a defluoridation plant and implementation of other safe water solutions will achieve an economic solid ground for the women and youth in the area through the anticipated employment opportunities that will be as a result of the project.

2. Materials and methods

Naivasha is a good case-study because of its geographical location and geology (Naivasha, n.d.). The area has a freshwater lake but the catchment community suffers from fluorosis. As water continues to be the blood system of geothermal energy production in Naivasha, energy has never been committed to neither ensuring good quality and affordable community water provision nor construction of a waste water treatment plant. Unimproved community water projects still pay overwhelming electricity bills that translate to the water supply tariff being considerably high to the local consumer. There is a small aircraft from the local flower farms that has been blamed by the residents of Hells Gate ward, Naivasha, of air spraying targeting rain bearing clouds hence modifying the local climate, threatening the only rainwater solution they rely on. These are the water challenges in Naivasha where policy needs to be developed around.

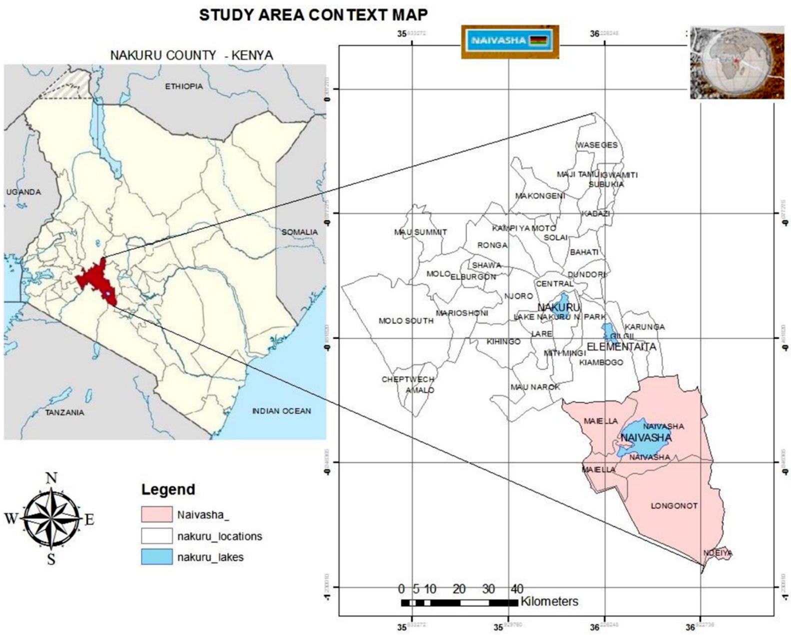

Figure 1. Context Map showing the study site; Naivasha in Nakuru County, Kenya

To obtain data from the selected Naivasha sub-county wards, this study employed a mixed method approach. Action research method was employed by building relations with all stakeholders as co-researchers and exploration of the topic based on the stakeholders' understanding of their own actions and experiences. Quantitative and observational data were collected from the wards using household surveys, observations and questionnaires. Key informants comprised of water experts. Questionnaires were administered to 193 households and 10 local water suppliers. Detailed questionnaires were distributed from 8th-22nd May, 2019 and the questions focused on; the adequacy of the available water, education on fluoride and how people would take rain water harvesting or a defluoridation plant for the whole community. Photos were taken while observable data recorded on the surveyCTO platform. Secondary data were obtained based on the policies of the County and national government, and 95 relevant literature works searched from the available global databases for water policy like Scopus database and Google scholar. Grey literature from company and government websites were also considered. To find out the quality of the drinking water sources in Naivasha Sub County, data was officially requested from the water resources authority office in Naivasha. Questionnaire and water quality data was summarized using descriptive statistics. Interpretation of results was done in comparison to past findings and discussed, compared with existing literature on similar or related works.

3. Results

Most of the domestic water requirements were met using unimproved groundwater sources, especially by those living in rural fluoritic areas (Table 1). Thus, borehole water within Naivasha has exposed the residents to higher fluoride levels (Figure 2).

Table 2: Total, Mean, Min and Max for parameters measured at selected sampling sites

Parameter	Source category	N	Mean	Standard deviation (±)	Min	Max	WHO
Calcium (mg/L)	Borehole	57	102.07	20.97	0	112	250
Chloride (mg/L)	Borehole	57	65.81	9.08	7	350	250
Conductivity (µS/cm)	Borehole	57	576.74	77.6	0.077	2,900	2500
Fluoride (mg/L)	Borehole	57	6.47	1.31	0.2	23.3	1.5
Iron (mg/L)	Borehole	57	0.32	0.05	0	1.35	0.3
Manganese (mg/L)	Borehole	57	0.34	0.47	0	3.0	0.1
Nitrate (mg/L)	Borehole	57	2.11	0.31	0	41.3	10
Nitrite (mg/L)	Borehole	57	0.26	0.52	0	4.2	10
Orthosphate (mg/L)	Borehole	57	0.02	0.004	0	0.33	NS
Sulphate (mg/L)	Borehole	57	39.45	7.841	0	295	490
Temperature (°C)	Borehole	57	5.65	1.123	0	25.6	30
Phosphate (mg/L)	Borehole	57	0.06	0.12	0	0.53	0.1
Alkalinity (mg/L)	Borehole	57	348.9	39.53	0	1,260	500
TDS (mg/L)	Borehole	57	385.08	73.07	0	1,798	500
THO (°f)	Borehole	57	56.97	7.31	0	223	5.0
Turbidity (NTU)	Borehole	57	4.6	0.739	0	33	5.0
WRL	Borehole	57	0.02	0.03	0	1	NS
pH (pH Scale)	Borehole	57	7.35	1.23	0	8.8	6.5 – 8.5

Key Where, NS- Not Specified, TDS-Total Dissolved Solids, THO-Total Hardness Observation and WRL-Water Rest Level.

Figure 2. A photograph showing a victim of dental fluorosis in Hells Gate Ward, Naivasha Sub County, Kenya © Ruth Wagatua

The percentage of women who participated in this research was significantly high (60.1%). The piping system for water supply to Rapland in Olkaria Ward, Naivasha, via the geothermal exploration grounds, is very rusty and very small in diameter when compared to the steam piping installation for energy exploration with is colorful and adequate in diameter. A small aircraft from the local flower farms was witnessed in the Hells Gate ward airspace interfering with the rainfall.

4. Discussion

The educational system in these communities has not been able to create awareness on fluorosis. The difference between the steam piping installation for energy exploration and the piping system for consumption supply indicates how much water supply for consumption has been neglected. There is a need for formulation of policies that protect the local residents against their rainfall pattern being interfered with. Women being the primary caregivers and having participated significantly high in this study, need to be empowered to develop community social enterprises that will take action towards ending fluorosis in Naivasha. These enterprises will be utilized as channels through which implementation of initiatives aimed at educating the people on water and capacity building is made a reality, ensuring fluorosis eradication in Naivasha. Through this, households will also be trained on how to come up with home policies that ensure water safety. The enterprises will serve as platforms that ensures that women are present where public policy that touches on them and theirs is being implemented for successful processes and projects. (Wagatua R. Graduate student, Pan African University - PAUWES, unpublished data, 2019).

The water governance structure that is currently in place, has approaches that focus on money-making for the county and the national government without this reflecting on the thriving capacity of the local population in terms of good quality water and wastewater treatment plant provision. The government engages more with businesses at the expense of the communities and sustainability of resources available (Wagatua R. Graduate student, Pan African University - PAUWES, personal communication, 2020). There's a need to design a unique water governance model that ensures that pollution and water abstraction costs cast on the principles in place, towards Lake Naivasha, and collected in the form of revenues, as well as the water sector trust fund and Hell'sGate National Park proceeds are ring-fenced to ensure the local community benefits from it by construction of safe water solutions and water treatment plants that serve the catchment community. There is the need for formulation of corporate accountability policies that will ensure the multimillion horticultural industry, conference tourism, fishing, and geothermal exploitation in Naivasha reflect on the thriving capacity of the local population in terms of good quality and affordable water provision as well as investments in sanitation facilities. (Wagatua R. Graduate student, Pan African University - PAUWES, unpublished data, 2019).

Mount Longonot sharity concept was discovered by observing the true meaning behind the high fluoride aquifers in Naivasha. The phrase sharity means "sharing equally between resources". There's a need to share resources equally for social benefit. Mount Longonot's previous volcanic activities was a blessing as well as a curse to Naivasha and all the volcanic emission radius in that, it being the reason behind the geothermal potential is also the reason behind the high fluoride aquifers in the area. The blessing that is geothermal potential is the curse that is high fluoride aquifers (Wagatua R. Graduate student, Pan African University - PAUWES, personal communication, 2020). Geothermal exploration in Naivasha is a major economic contributor and the biggest geothermal project in Africa (The Independent, 2018). Besides water in the form of steam being the blood system of the energy exploration, geothermal energy exploration has not given back in terms of good quality water provision and wastewater treatment facilitation. Community water projects still generate overwhelming electricity bills that translate to the water supply tariff being considerably high. Water and energy resources are imbalanced and out of sync in Naivasha. The concept aims to hold water and energy to the same standard and as the state-owned Algerian energy company takes up the role of handling water privatization in Algeria (WaterWorld, 2014), geothermal energy exploration in Naivasha should be able to partner in the investment of good quality water provision and wastewater treatment facilities in Naivasha and the whole of Nakuru County.

5. Conclusion

In order to create a new water governance paradigm away from the dormant limiting patterns, genuine policy conversations from the community, energy and water resource perspectives need to be considered. This dialogue is capable of addressing the community and ecosystem health issues within Nakuru County. The County government of Nakuru should ensure policy coherence between the county water governing laws and the reality on the ground. The legislative should formulate and implement comprehensive community driven policies on water that address resource equity in the case of water and energy in Naivasha, because per unit charge of water should be equal to per unit charge of energy hence balanced resources use towards a more inclusive and resilient County. Other policy interventions that are needed include; policies that favor rainwater harvesting at household level in resolution of consumption water challenges, policies that protect the local residents against their rainfall pattern being interfered with by selfish flower farmers, policies on Lake Naivasha integrated water resource management (IWRM). There should be a balance between government, business and the community interest and welfare in Naivasha, for a future where people and nature are able to thrive. Policies that encourage stewardship partnerships in the implementation of safe water initiatives should also be introduced, hence a shift in the governance of rainwater, surface water and groundwater resources.

This paper further recommends that more extensive research be done, on the geology of the Great Rift Valley basin in relation to geothermal potential. There's another whole world to discover in terms of water and energy where volcanic eruptions may have occurred, that would lead to a sustainable water and energy governance model thus further advancing the path towards accomplishing the Sustainable Development Goals and therefore, this possibility should be explored.

References

Africa, U. W. (2003). The Africa water vision for 2025: Equitable and sustainable use of water for socioeconomic development. Addis Ababa, Ethiopia: Economic Commission for Africa

Ahmed, A. A. (2014). Fluoride in Quaternary groundwater aquifer, Nile Valley, Luxor, Egypt. *Arabian Journal of Geosciences*, August, 7(8), 3069-3083.

Alkurdi, S. S., Al-Juboori, R. A., Bundschuh, J., & Hamawand, I. (2019). Bone char as a green sorbent for removing health threatening fluoride from drinking water. Environment international, 127, 704-719. https://doi.org/10.1016/j.envint.2019.03.065

Aldeghaither, F. K. A. (2018). *Fluoride in the Greater Middle East and Its Source: A Literature Review* (Doctoral dissertation, UCLA).

Avocefohoun, A. S., Gbaguidi, B. A., Sina, H., Biaou, O., Houssou, C. S., & Baba-Moussa, L. (2017). Fluoride in water intake and prevalence of dental fluorosis stains among children in Central Benin. International Journal of Medical Research & Health Sciences, 6(12), 71-77.

Baouia, K., & Messaitfa, A. (2015). Distribution and removal of fluoride ions in the drinking waters in the Algerian South (Ouargla as a showcase). *Energy Procedia*, August, *74*, 294-300.

Borda/Sanivation (2019). Naivasha sub-county vision. County wide inclusive sanitation plan for Naivasha sub-county, ensuring sanitation for all https://programme.worldwaterweek.org/Content/ProposalResources/PDF/2019/pdf-2019-8564-1-CWISP_Publication_Naivasha_A_Vision_For_Change-compressed.pdf (date of access March 21, 2021)

CGN (2018). Nakuru County Integrated Development Plan (CDIP 2018-2022). https://nakuru.go.ke/wp-content/uploads/2018/11/Nakuru-County-CIDP-2018-2022-FINAL..pdf (date of access June 13, 2019)

DeGhetto, K., Gray, J. R., & Kiggundu, M. N. (2016). The African Union's agenda 2063: aspirations, challenges, and opportunities for management research. Africa Journal of Management, 2(1), 93-116.

El Jaoudi, R., Mamouch, F., El Cadi, M. A., Bousliman, Y., Cherrah, Y., & Bouklouze, A. (2012). Determination of fluoride in tap water in Morocco using a direct electrochemical method. *Bulletin of environmental contamination and toxicology*, August, *89*(2), 390-394.

Elumalai, V., Nwabisa, D. P., & Rajmohan, N. (2019). Evaluation of high fluoride contaminated fractured rock aquifer in South Africa–Geochemical and *chemometric* approaches. *Chemosphere*, November, *235*, 1-11.

Emenike, C. P., Tenebe, I. T., & Jarvis, P. (2018). Fluoride contamination in groundwater sources in Southwestern Nigeria: Assessment using multivariate statistical approach and human health risk. *Ecotoxicology and environmental safety*, July, *156*, 391-402.

Fantong, W. Y., Satake, H., Ayonghe, S. N., Aka, F. T., & Asai, K. (2009). Hydrogeochemical controls and usability of groundwater in the semi-arid Mayo Tsanaga River Basin: far north province, Cameroon. *Environmental geology*, September, *58*(6), 1281-1293.

Fluoride and Mental Decay. (n.d.). 2019 & 2020Research Updates, https://pregnancyandfluoridedonotmix.com/mentalfluorosis/2019research.html. (date of access November 6, 2020)

Gazette, N. C. (2014). Republic of Kenya Nakuru County Gazette Supplement, 14(13). http://kenyalaw.org/kl/fileadmin/pdfdownloads/bills/2014/NakuruCountyWaterBill2014.pdf (date of access June 20, 2020)

Gevera, P. K. (2017). The occurrence of high fluoride in groundwater and its health implications in Nakuru County in the Kenyan Rift Valley (unpublished Doctoral dissertation, University of Johannesburg, South Africa).

Kane, C.H., Diene, M., Fall, M., Sarr, B., & Thiam, A., (2012). Reassessment of the Resources of a Deep Aquifer System under Physical and Chemical Constraints: The Maastrichtian Aquifer. *Journal of Water Resource and Protection*, April, *2012*.

Kengen (2021). Geothermal http://www.kengen.co.ke/index.php/business/power-generation/geothermal.html. Cited 21 March 2021

Makoba, E.E., (2020). Geological and hydro-geochemical assessment of fluorine around Mount Meru, northern Tanzania. Unpublished PhD dissertation. Nelson Mandela African Institution of Science and Technology, Tanzania

Mustafa, D. E., & Younis, U. M. (2018). The relationship between the fluoride levels in drinking water and the schooling performance of children in rural areas of Khartoum state, Sudan. *Fluoride*, April, *51*(2), 102-113.

Naivasha. (n.d.). Naivasha, http://www.naivasha.info/drinking-water/. Cited 1 September 2019

Ndé-Tchoupé, A. I., Nanseu-Njiki, C. P., Hu, R., Nassi, A., Noubactep, C., & Licha, T. (2019). Characterizing the reactivity of metallic iron for water defluoridation in batch studies. Chemosphere, 219, 855-863. https://doi.org/10.1016/j.chemosphere.2018.12.065

Sajidu, S. M. I., Masamba, W. R. L., Thole, B., & Mwatseteza, J. F. (2008). Groundwater fluoride levels in villages of Southern Malawi and removal studies using bauxite. International Journal of Physical Sciences Vol. 3 (1), pp. 001-011, January, 2008

Salifu, A. (2017). Fluoride Removal from Groundwater by Adsorption Technology. CRC Press.

Shakir A. K & Thakur, Sachin & Sarkar, Aditya & Shekhar, Shashank. (2016). Worldwide contamination of water by fluoride. Environmental Chemistry Letters. 10.1007/s10311-016-0563-5.

Sorlini, S., Palazzini, D., Sieliechi, J. M., & Ngassoum, M. B. (2013). Assessment of physical-chemical drinking water quality in the Logone Valley (Chad-Cameroon). *Sustainability*, July, *5*(7), 3060-3076.

Srikanth, R., Viswanatham, K. S., Kahsai, F., Fisahatsion, A., & Asmellash, M. (2002). Fluoride in groundwater in selected villages in Eritrea (North East Africa). *Environmental monitoring and assessment*, April, *75*(2), 169-177.

The Independent. (2018). How Kenya is harnessing geothermal energy to power its growing economy, https://www.independent.co.uk/news/long_reads/geothermal-kenya-africa-green-energy-environmentally-friendly-un-development-expansion-a8228821.html. (date of access November 22, 2020)

Tekle-Haimanot, R., Melaku, Z., Kloos, H., Reimann, C., Fantaye, W., Zerihun, L., & Bjorvatn, K. (2006). The geographic distribution of fluoride in surface and groundwater in Ethiopia with an emphasis on the Rift Valley. *Science of the Total Environment*, August, *367*(1), 182-190.

Wagatua RW (2019). Defeating Fluorosis *in* rural Kenya Using *the* Kilimanjaro Concept*: A* Feasibility Study *in* Naivasha. http://repository.pauwes-cop.net/handle/1/308

WASREB. (2016). Drinking Water Quality Guidelines – Welcome to Wasreb, https://wasreb.go.ke/drinking-water-quality-guidelines/ (date of access June 28, 2019)

Water Act, W. No. 43 of 2016. Laws of Kenya. https://wasreb.go.ke/downloads/Water%20Act%202016.pdf(date of access June 28, 2019)

Water, U. N. (2018). 2018 UN World Water Development Report, Nature-based Solutions for Water, http://repo.floodalliance.net/jspui/handle/44111/2726. (date of access November 10, 2020)

WaterWorld. (2014). Algeria's supersized 500,000 m3/day desalination plant open for business, https://www.waterworld.com/drinking-water/treatment/article/16214978/algerias-supersized-500000-m3day-desalination-plant-open-for-business. (date of access October 29,2020)

WHO. (2019). Health Topics: Health Impact Assessment. The World Health Organization. https://doi.org/10.11260/kenkokyoiku.19.77

WHO. (2009a). Global health risks. Mortality and burden of disease attributable to selected major risks. World Health Organization. https://apps.who.int/iris/handle/10665/44203

WHO. (2009b). Children's Health and the Environment. WHO Training Package for the Health Sector-World Health Organization. http://www. who. int/ceh; https://www.who.int/ceh/capacity/training_modules/en/; https://www.who.int/ceh/capacity/Water.pdf?ua=1. (date of access November 15, 2020)

WHO. (2005). Children's health and the environment: A global perspective: A resource manual for the health sector. World Health Organization. https://apps.who.int/iris/bitstream/handle/10665/43162/9241562927_eng.pdf;sequence=1(date of access November 15,2020)

WHO. (n.d.). Building capacity to prevent childhood diseases linked to the environment, https://www.who.int/activities/building-capacity-to-prevent-childhood-diseases-linked-to-the-environment. (date of access November 6, 2020)

World Bank (2018). Unlocking Supply of Affordable Housing in Kenya: The Naivasha Prototype http://documents1.worldbank.org/curated/en/573321585887752524/pdf/Unlocking-Supply-of-Affordable-Housing-in-Kenya-The-Naivasha-Prototype.pdf(date of access March 21, 2020)

Ecohydrological Phytoregulation of Riverine Ecosystems Using Riparian Vegetation

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Abstract

Riparian plants grow along natural watercourses and play critical ecohydrological roles, including regulation of river flow, service as a natural cleansing system and stabilization of riverine ecosystems for sustainable water provision. Population pressure and anthropogenic activities are known to worsen water security through excessive consumption of freshwater resources and compromise of sustainability criteria. This study focused on riparian vegetation distribution, human activities with consideration of gender distribution, and their impacts on the river ecosystem along Ngerengere River, Tanzania. The aim was to assess the applicability of natural ecosystemic approach as a means of enhancing water resources management, water security and sustainability. Biological data on vegetation were collected using the belt transect method along the river continuum at 100 m intervals, and respective species abundance was expressed in percentage. Riparian vegetation's diversity and richness are threatened by human activities which were assessed in this research via field direct observation, household questionnaire and checklist to native dwellers and then descriptively analysed by the Statistical Package for Social Sciences version 20 and Microsoft Excel 2019. The findings indicate the impacts of anthropogenic stressors on the river ecosystem. Minimally disturbed sites with plenty riparian vegetation have better hydrological conditions, improved water quality, better river flow and ecological stability. This reflects the need for natural ecosystem management approach to ensure water security, clean production, food security and natural ecosystem enhancement which all count toward achievement of sustainable development goals.

Keywords: Ecohydrology, Ngerengere River, Freshwater ecosystem, Sustainable Development, Tanzania

1. Introduction

The word riparian (translated from a Latin word *riparius*) means relating to, occurring along or located on the banks of a natural watercourse (Dufour and Rodriguez-Gonzalez, 2019). Sometimes referred to as riparian trees, riparian vegetation refers to vegetation species that occurs along watercourses that are usually rivers that form an important component of the fluvial and riverine ecosystem (National Research Council, 2002). They play many hydro-ecological roles in the river ecosystem such as preventing erosion and stream banks collapse, trapping sediments and pollutants; hence buffering river ecosystem stability (Naiman et al., 2005; Malan et al., 2018; Dufour and Rodriguez-Gonzalez, 2019). As noted by Dufour and Rodriguez-Gonzalez (2019), riparian vegetation species are commonly shrubs, physically regulate river-flow through offering protection to river banks thereby inducing river metamorphosis. Chemically, they support alteration of biogeochemical cycles within the river ecosystem and fluvial zone. Through such chemical regulation and buffering effects, they help to improve water quality, especially in human-impacted watersheds with non-point source pollution like agriculture (Malan et al., 2018; Chua et al., 2019). Water quality is maintained through their physical and biological actions of trapping, filtering and retaining pollutants and nutrients contained in effluents and other discharges from industries and agricultural runoffs (Zalewski, 2002; Malan et al., 2018; Chua et al., 2019). Their presence along the river continuum helps in maintaining stream flow by controlling incoming storm's velocity and the river water flowing from the upstream to downstream watercourse (Dufour and Rodriguez-Gonzalez, 2019; Chua et al., 2019), thereby, enhancing river health, creating habitat for aquatic biodiversity and organic matter input in the stream.

Concurrently, riparian zones are reported as being biologically species-rich with a wide biological diversity (de la Fuente et al., 2018; Dufour et al., 2018). Their shading effects on the stream environment through temperature regulation is recognized (Trimmel et al., 2018). Through provision of several ecosystem services exemplified by water purification, the surrounding community's socio-cultural wellbeing is improved. During low flow, they shade the channel, thus decreasing evaporation rate and water loss. During flooding, they buffer flood storm from the channel towards the floodplain (Dufour et al., 2018; Trimmel et al., 2018).

Despite their key eco-hydrological roles in the river ecosystem, riparian vegetation is still reported as one of the degraded ecosystems, and their roles are not well studied (Rangelands, 1997; Natkhin et al., 2013; Shagega et al., 2018; United Nations, 2018). They are frequently destroyed due to lack of full appreciation of their utility to eco-hydrology and livelihoods (Illhardt et al., 2000; de Sosa et al., 2018; Malan et al., 2018; Chua et al., 2019). Such degradation increases river bank erosion and sediment deposition in waterways, and reduces the ability of the fluvial ecosystem to filter incoming effluents from overland runoff, thereby, posing a threat to riverine ecosystems (Saha and Guida, 2014; Trimmel et al., 2018; Chua et al., 2019). In light of their eco-hydrological roles, riparian plants are considered as a scientifically applicable and adaptable material for river ecosystem management (Dufour et al., 2018; Malan et al., 2018; Chua et al., 2019). This has raised the need for an integrated management approach in which ecosystem components are used for river ecosystems management, hence the term-ecohydrology (Pacini and Harper, 2008; Lalika, 2020; Raphael and Lalika, 2020).

Ecohydrology is a growing nature-based solution for solving problems in water ecosystems and environmental management using biotic species. It is the subdiscipline of hydrology that focuses on ecological processes that occur within the water cycle (Zalewski, 2000; 2002), and a trans-disciplinary problem-solving science derived from mutual of the hydrological cycle and ecosystems (Zalewski, 2009; 2012; 2013). It is a platform for using biota to develop practical solutions for sustainable water resources and ecosystem management with active involvement of women to reduce gender gap (Zalewski, 2002; 2013; Raphael and Lalika, 2020) operating by three principles of framework, target and methodology (Zalewski, 2000). The framework principle describes the catchment and the river ecosystem as the superorganism influenced by; water circulation with the associated terrestrial and aquatic ecosystem coupling to modulate ecosystem processes, water and temperature which are the major driving factors of the freshwater ecosystem and finally by the dominant abiotic hydrologic processes which becomes self-manifested once stabilized. The target principle suggests that the ecosystem (superorganism) has in its natural state resistance and resilience against stress due to biological interaction of the biotic and abiotic components of the riparian zone and the river ecosystem (de Sosa et al., 2018; Zalewski, 2002). It thus provides the basis for enhancing the absorbing capacity of the river ecosystem against human impacts. Linking with ecological engineering, the methodology emphasizes the use of ecosystem properties in water resources management (de Sosa et al., 2018; Zalewski, 2000; 2013).

In spite of the utility of riparian vegetation to the river ecosystem, they are still being destroyed in some parts of the world, leading to degradation of the river ecosystems. Unfortunately, there is limited documentation of studies on riparian vegetation and the river ecosystem. Studies largely concentrate on water quality, land use and climate changes issues (Mero, 2011; IUCN, 2010; Natkhin et al., 2013; Shagega et al., 2018). To ascertain the role of these species on river ecosystem stability, especially under a changing climate and anthropogenic stresses, this study was performed along Ngerengere River -Tanzania. It focuses on analyses of riparian vegetation distribution, human activities including gender aspects, and their impacts on the river ecosystem.

2. Materials and methods

2.1. Study area

This study was performed along Ngerengere River in Mindu Dam Catchment, Morogoro Municipality, Tanzania. The river is located in Ngerengere sub-catchment of Ruvu Catchment within Wami-Ruvu basin in Tanzania (Figure 1), 6°30'00" - 7°10'00" (latitudes) South and 37°58'26" - 38°31'30" (longitudes) East. The river originates from the Uluguru Mountains and extends to other parts of Morogoro Region (IUCN, 2010; Saha and Guida, 2014; Eeden et al., 2017). It forms both the inflow and outflow of the Mindu Dam (the main Morogoro Municipality freshwater source) in its upper and lower stages, respectively (Mero, 2011). Finally, it joins the lower Ruvu River that runs into to the Indian Ocean. Its catchment is characterized by a bimodal rainfall with the first-short season spanning from November to January and the second (long one) spanning from March to May. The long dry season runs from June to October. The mean annual rainfall varies between 800 – 1000 mm, increasing to 2000 mm in the vicinity of the Uluguru Mountains where the river originates (Shagega et al., 2018; GLOWS – FIU, 2014).

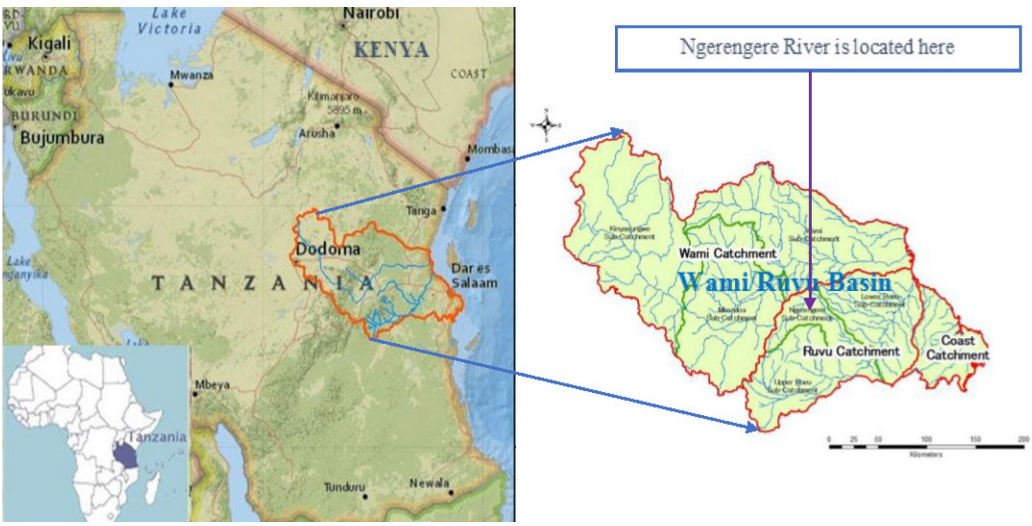

Figure 1. Location of Ngerengere River in Tanzania (Eeden et al., 2017, CC BY-NC-SA/3.0; GLOWS-FIU, 2014)

2.2. Biological (Vegetation) sampling

The Belt transects (5 m wide, 2 km long) method was used in this study for vegetation sampling within the riparian zone along Ngerengere River, within the riparian zone. 20 sampling stations were systematically (100 m interval) introduced with the aid of a Geographical Positioning

System (GPS) device. Vegetation (grass, shrubs and higher trees) sampling was done within a 2 m radius at each station. Plant species were identified on the field by their local names and then taken for technical examination and identification by Sokoine University of Agriculture's Botanists and Ecohydrologists. For the sake of accuracy, geographical coordinates were recorded at the respective sampling points.

2.3. Sampling procedure and data collection methods

A simple random probability sampling procedure was used during collection of household data by means of household questionnaire. This technique was adopted so as to eliminate bias in selection of study respondents such that each household had an equal chance of being involved in the study. The questionnaires were then administered to selected households to gather data related to anthropogenic interaction of the adjacent communities to the river, its ecosystem and how they impact each other.

Direct field observation was used to justify anthropogenic activities within the riparian zone along the river, distribution of gender roles in production, impacts of the activities conducted on the river and its ecosystem. It was performed to examine the extent of anthropogenic interaction to riparian vegetation. Checklist on key factors was also used to elicit baseline information on the evolution of the river in response to activities carried out along it in the riparian zone. This was through interviewing native elders known to have stayed in the study area for more than 50 years.

2.4. Data analysis methods

The data collected from questionnaires were descriptively analyzed using the Statistical Package for Social Science (SPSS-version 20) software after they were corrected and processed. Microsoft Excel software was used for additional data analysis and to ease graphical presentation of the results. Responses from interviews with checklist were subjected to content analysis to capture the themes presented by the respondents. Responses were also used in combination with what was evidenced in the field via observation, as the basis of discussion along with the facts gathered through household questionnaires. To obtain the proportions of the riparian vegetation species distributed in the study area, cross-tabulation of the count data for the respective species in the field was also done, and the percentage proportions were examined.

3. Results

3.1. Distribution of Riparian vegetetion along Ngerengere River

The composition and proportions of representative riparian vegetation species that are distributed along Ngerengere River ecosystem are presented in Table 1. As shown, it is clear that Ngerengere Riverine ecosystem is dominated mainly by seven riparian vegetation species which can be ecologically classified as grass, shrubs and trees (Table 1) with grass type being most dominant.

Table 1. Major riparian vegetation along Ngerengere River

Category	Common name	Botanical name	Percentage abundances	Category percentages
Grass	Phragmites	*Phragmites mauritianus*	25	
	Elephant grasses	*Pennisetum purpureum*	22	
	Reeds	*Phragmites australis*	22	
	Sedges	*Cyperus rotundus*	08	
	Bulrush	*Typha domingensis*	03	80
Shrubs	Sesbania	*Sesbania sesban*	14	14
Trees	Ficus	*Ficus sycomorus*	06	06
Total			**100**	**100**

The Ngerengere River ecosystem is to a great extent, covered by phragmites mainly due to their high regeneration potential as observed in the field, compared to other species. However, its high coverage is not an indication of not being disturbed by anthropogenic factors. Commonly, phragmites grow naturally in thickets with their surface covered by sharp hairs, making it rather difficult to penetrate in comparison to other species found along the river. Elephant grasses rank second in abundance and have rough erectile protective hairs as a defensive mechanism just like phragmites. In contrast, they do not grow as tall and tough as phragmites. Consequently, they are heavily harvested for pasture and mulching for grazed animals and cultivated fields.

Another plant species are reeds. Reeds are less preferred for livestock pasture and fodder. This accounts for their relatively high abundance. They are not subjected to much disturbance, except before the cultivation season when they are extensively removed with sedges (hence its low abundancy) as undesirable weeds. Bulrush (commonly known as Typha) dominates mostly in the fluvial zone which is in most cases transformed to paddy fields. Before they can grow and proliferate, they are usually cleared to create paddy fields, hence their low abundance. Moreover, they are used domestically for other utilities such as thatch for roofing. This also accounts for the observed low abundance.

Anthropogenic disturbance in the study area has made sites unfavorable for Sesbania and Ficus due to unstable soil and slopes due to uncontrolled cultivation practices that extend to the river banks throughout the riparian zone. This contributes to low abundance of Ficus relative to all other species. These results imply that a relatively large proportion of grass-type riparian vegetation is dominant over other categories of vegetation (shrubs and trees). It is also observed that trees are the least abundant vegetation in the riparian zone of Ngerengere River. This is due to severe impacts on trees by anthropogenic stressors, mainly charcoal burning and extraction of poles combined with their low regeneration rates.

3.2. Human activities with gender roles in the riparian zone

Figure 2 shows the major anthropogenic activities carried out in the riparian zone of Ngerengere River ecosystem. The major anthropogenic stressors of the river's riparian zone and the related ecosystem is unplanned cultivation especially those that involve the use of industrial fertilizers and mechanized tools such as water pumps for irrigation water abstraction. The river ecosystem is overexploited by the large segment of the population of the study area that mainly depends on land cultivation for their livelihoods. Grazing activity is another threat due to the attraction of abundant grass (Table 1). Such great proportion are taken as a favor among the locals for domestic grazed livestock, mainly cows, goats and sheep. This threatens grass riparian vegetation to possible disappearance unless strict interventions are adopted to manage them.

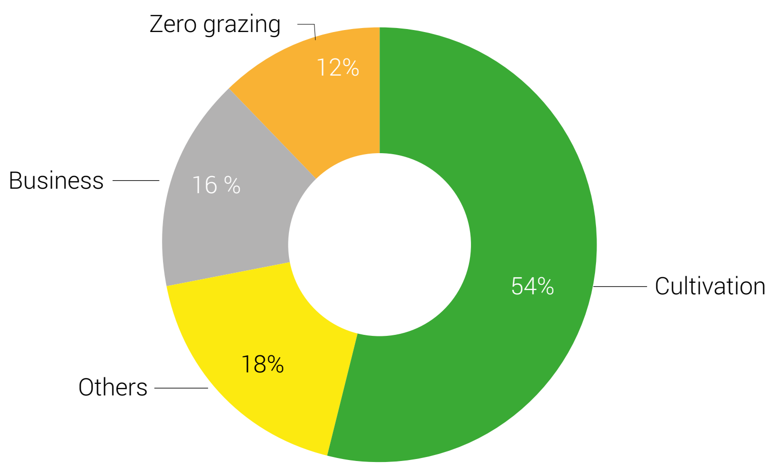

Figure 2. Anthropogenic activities along Ngerengere River

The distribution of production activities in the study area is gender-based (Figure 3). Men specialize and are directly engaged in heavy manual activities like sand extraction, charcoal burning, new farms preparation and fishing. On the other hand, women and young girls engage in cultivation of horticultural crops, gardening and harvesting.

Female-based work	Male-based work

Figure 3. Distribution of Gender-roles in human activities conduct © Antidius Raphael

3.3. Impacts of anthropogenic activities to the river ecosystem

The performance of human activities along Ngerengere River has given rise to several adverse impacts on the river ecosystem. Manifested in field observations and questionnaire responses, the major impacts were ranked on the basis of severity to the river the riparian vegetation communities as cross-tabulated in Table 2.

Table 2. Impacts of anthropogenic activities to the river and riparian vegetation

Effect to the river	Severity level (%)	Effect to riparian vegetation	Severity level (%)
Sedimentation	31	Plant disappearance	36
Reduction in volume	23	Deforestation	23
Bank erosion	20	Unplanned burning	22
Water pollution	18	Morphological changes	17
River channel Change	08	NA*	02
Total	**100**		**100**

* *Not aware of riparian vegetation*

Further details that indicate the impacts of anthropogenic activities were gathered to justify responses through interviewing native elders known to have resided in the study area for a long time (about 50 years and some for the entire life) guided by the street register.

As indicated in the above matrix (Table 2), the impacts on riparian vegetation are also reflected in river safety. The percentage severity levels of the impacts increase in the same magnitudes range as that of the degradation of the riparian vegetation. Sites that experienced high rate of riparian vegetation clearance and cultivation activities have worse hydrological conditions. Some of the adverse effects observed in the study area, include collapse of river banks, eutrophication, sedimentation and growth of algal blooms and water hyacinth (Figure 4 left) on the adjacent downstream. These observations imply the existence of relationship between land management and conservation of riparian vegetation with the safety and wellbeing of the associated river ecosystem. The fact that 2% of the respondents admitted to being unaware of riparian vegetation in the area conceivably hinders conservation. Some people treat them as destructive weeds because they lack knowledge on their utility to the river ecosystem. On the other hand, the sites with undisturbed to minimally disturbed riparian vegetation have clear water without deposited sediments (Figure 4 right).

Figure 4. Impacts of human activities to the river (left) and filtered water in riparian vegetated sites (right) © Antidius Raphael

4. Discussion

4.1. Riparian vegetation, River Ecosystem and Anthropogenic influences

Ngerengere is one of the tropical rivers with riparian vegetation and associated ecosystem that are under anthropogenic influences as found by this study and other documented studies (Shagega et al., 2018). Undefined irregular alignment of riparian vegetation (GLOWS-FIU, 2016; Raphael and Lalika, 2020), was also found to negatively impact attitudes on conservation in the vicinity of the river. For instance, vital riparian vegetation species has decreased progressively (de Sosa et al., 2018) due to clearance of vegetation for establishment of agricultural fields and grazing area. This study has found a considerable variation of vegetation species with the variation of geomorphology and hydrological conditions as Naiman and Decamps (1997) and de Sosa et al. (2018) proposed. The composition of Ngerengere riparian vegetation species was quite different from that of India, except for *Ficus* (Amithabachan K.H Limnological Association of Kerala, Iringalakkuda, unpublished project report, 2003). These findings are consistent with the findings of other studies (GLOWS-FIU, 2016) in Wami/Ruvu basin-Tanzania.

In light of several investigations (Naiman and Decamps, 1997; Rangelands, 1997; Amithabachan K.H Limnological Association of Kerala, Iringalakkuda, unpublished project report, 2003; de Sosa et al., 2018), it is now known that riparian vegetation plays key hydrological, biological and physical roles as regards stabilization of a river ecosystem: specifically, river banks regulate river water flow. Based on the results of previous studies, they are crucial in controlling bank erosion through soil particles molding, reduction of velocity of incoming and in-stream storm (Hultine et al., 2004). Additionally, river bank vegetation is vital for water filtration and retention of suspended particles and sediments (Corenblit et al., 2007). Phragmites and elephant grasses are known for sequestration of organic pollutants in the soil.

Similar to other riverine ecosystems across the world (National Research Council, 2002; Dufour et al., 2018; Dufour and Rodriguez-Gonzalez 2019), many riparian zones experience anthropogenic interactions due to high fertility potentials and sufficient moisture content favorable for agricultural production, the same is for that of Ngerengere River. Being close to permanent water source, water extraction from the river during periods of low flow to support irrigation activities threaten the stability and sustainability of the river (Corenblit et al., 2007; Eeden et al., 2017). Apart from physical degradation, inorganic chemical pollution is also of a great concern due to the application of synthetic fertilizers during early stages of planting. Organic pollution that has resulted from inappropriate application of organic fertilizers (green and farmyard manure) and tobacco residuals as pesticides, also alter water quality, thereby, disrupting the entire river ecosystem wellbeing (Naiman and Decamps, 1997; Rangelands, 1997; Corenblit et al., 2007).

Due to the presence of abundant forage in the riparian zone (Pinchak et al., 1991; Jemison and Raish, 2000), livestock grazing forms one of the cited sources of degradation in Ngerengere River flood plain. High abundance of elephant grass and phragmites favors zero grazing due to water availability and conducive pasture for goats, sheeps and cattle (Jemison and Raish, 2000). Consequently, livestock rearing is one of the most common land use types in the riverine ecosystem, with many effects on river corridor, fluvial ecosystem, and landform stability (Corenblit et al., 2007). Threats occur concurrently with overharvesting of riparian vegetation for pasture and forage, and other resources within the fluvial and riparian zones in complement with documented literary works (Jemison and Raish, 2000; DeBano and Schmidt, 2004; Corenblit et al., 2007). Unlawful and non-sustainable fishing, sand mining and brick making threaten freshwater resources by disrupting aquatic habitat and weakening bank stability, thus reducing essential biological diversity (Dufour et al., 2018; Corenblit et al., 2007). Charcoal burning in the riparian zone is also cited as a contributor to large-scale clearance of higher riparian vegetation (Dufour et al., 2015). This is supported by previous studies that concluded that human activities have a greater implication on river management and stability (Kondolf et al., 2007; Brown et al., 2018), mostly adversely impacting the river ecosystem and the riparian zone in general (Corenblit et al., 2007).

The influence of human activities in the riparian zone have been found to adversely impact both riparian vegetation cover and other freshwater resources well-being worldwide (National Research Council, 2002; Corenblit et al., 2007; Dufour et al., 2018; Dufour et al., 2015; Brown et al., 2018). Some of the impacts on the riverine ecosystem are sedimentation, reduction in river depth and volume, bank erosion, water pollution and change in river dynamics due to water diversion for irrigation. These impacts are becoming severe due to increasing population affluence along the water resources, together with irregular pattern of riparian vegetation (Dufour et al., 2018; de Sosa et al., 2018). Other significant drivers which were in other studies include bioclimatic regimes (Brown et al., 2018; Bendix and Stella, 2013), morphological pattern (Corenblit et al., 2015), and land use context through direct vegetation clearing and indirectly via unlawful water abstraction (Dufour et al., 2018). Bioclimatic factors drive the amount and the timing of water availability and post-floods disturbance relaxation times. Morphological pattern creates a physical template for vegetation colonization and growth and drives stress and disturbance regimes (Bendix and Stella, 2013; Corenblit et al., 2015). Several studies (Chua et al., 2019; Brown et al., 2018; Bendix and Stella, 2013) have found that bioclimatic, morphological and land use factors are all modified and intensified by human activities conducted in an area. Consequently, fluvial and riparian riverine ecosystems with complex trajectory are highly negatively impacted (Dufour et al., 2018; Corenblit et al., 2007) due to potentials therein.

Regardless of the degradation and anthropogenic influences, previous studies have acknowledged the significant role of riparian vegetation in water cleansing just like this study has done. In Australia for instance, pollutant trapping capacity was found to increase with the increase in the extent of riparian vegetation coverage (Chua et al., 2019). A study of riparian vegetation's influence on Fitzroy basin's water quality revealed that streams with poor riparian vegetation coverage had poor water quality scores and habitat (Chua et al., 2019; Dodds and Oakes, 2008). Poor water quality indicated by unpleasant odor and coloration in areas with no riparian vegetation across Ngerengere River was an indicative of a significant hydrological relationship between riparian vegetation and some water quality parameters. Rivers and streams with low riparian vegetation abundance are reported as the most vulnerable to pollution (Dodds and Oakes, 2008). Along Ngerengere River, collapsed river banks were prevalent where riparian vegetation was not present or just scant. Recognizing their hydrological role in Queensland, degraded riparian sites and low-ordered streams were considered priority sites for quick restoration with the rationale that vegetation would significantly aid in improving downstream water quality, regulate stream flow, maintain ecosystem assemblage and enhance ecological health (Chua et al., 2019; Pert et al., 2010). Thus, freshwater resource management systems should cover riparian vegetations to enhance natural ecohydrological management approach (Chua et al., 2019; Zalewski, 2013) in integration with enhancement of riparian vegetation (Chua et al., 2019).

4.2. Ecohydrology, Water Resources and Sustainable Development

Access to freshwater in sufficient quantity and quality is considered a basic human right and a pre-requisite toward achieving SDGs in the public health, food security and poverty reduction (Merrey, 2015; United Nations, 2018). Regardless of such recognition, fresh water demand exceeds the currently available amount in many regions and river basins in sub-Saharan Africa (Merrey, 2015). This is mainly due to anthropogenic influences which exert pressure on these resources as it was found by this study. Threatening and degrading potential freshwater resources and ecosystems as it was evidenced along Ngerengere River tend to compromise other sectors like food production, water supply and public health which are pertinent to sustainable development. For sustainable development to be attained, societies and the general public needs to sustainably exploit available natural resources including freshwater (Dickens et al., 2020). This implies minimization of threats to the availability of resources to avert crises (Albert et al., 2020). The current trends in population growth, changing lifestyles, production patterns and socio-economic activities along Ngerengere River as reported across the globe (Merrey, 2015; Dickens et al., 2020), are accelerating pressures on freshwater resources, indicating a risk of collapse of these ecosystems and sustainable development in that regard (Lim et al., 2018; Albert et al., 2020; Raphael and Lalika, 2020).

It is clear that water security through availability and sustainable management of water and sanitation is critical to sustainable development (United Nations, 2018). This calls for implementation of appropriate management systems for freshwater resources protection, especially in areas that are stressed by anthropogenic influences as exemplified by the Ngerengere River ecosystem and its riparian zone. In this regard, ecohydrology is among the recommended approach to enhance sustainability in water resources management by using nature components (Zalewski, 2002; Pacini and Harper, 2008; UNESCO, 2011; Lalika, 2020). Through enhancing natural ecosystems carrying capacity, water security is attained while at the same time buffering productivity of other resources in a sustainable manner without causing harm to other ecosystem components (Zalewski, 2000; UNESCO, 2011) while improving hydrological conditions like water flow using riparian vegetation as evidenced in the study area. This follow that, ensuring water security by appropriate management is ensuring food production too (Merrey, 2015), boosting freshwater ecosystem productivity, reducing poverty levels and meeting other SDGs (UNESCO, 2011; United Nations, 2018; Albert et al., 2020).

Integrated governance and management of water resources through application of ecosystem-based approaches contribute significantly to complying with SDGs by enhancing natural water resources management approaches for sustainable development (UNESCO, 2011; Dickens et al., 2020). The implementation of integrated water resources management, enhancement of natural ecosystems to ensure water security and sanitation at all levels is thus critical through ecohydrology to meet SDGs (UNESCO, 2011; Albert et al., 2020; Dickens et al., 2020) for sustainable environment, ecosystems, production, water resources, development and livelihood at large.

5. Conclusions

Major riparian vegetation species of Ngerengere River include Phragmites, Elephant grasses, Reeds, Sesbania, Sedges, Ficus and Typha. Unplanned cultivation, sand extraction and rearing of livestock are the major anthropogenic activities that affect Ngerengere River ecosystem by weakening river banks. Disturbing riparian vegetation affect the hydrology by reducing the river flow, depth and water quality. Contrary to vegetated sites, areas with intensive anthropogenic pressure and degraded riparian vegetation have poor hydrologic conditions including polluted water and low flow and due to collapsed banks and unstable riverine ecosystem.

Riparian plants maintain water quality and stream-flow and thus, need to be properly managed for continued river stability and adequate freshwater provision. Failure of existing traditional management approaches calls for a new paradigm and nature-based approach to enhance carrying capacity for sustainable management in a cost-effective and integrative manner. Ecohydrologic measures are that approach. Ecohydrology employs phyto-techniques and riparian vegetation interactions with water to ensure ecosystem stability for sustainable provision of safe and clean water, paving a way to SDGs achievement. Through novel approaches of enhancing absorbing and carrying capacity of the river ecosystem through creation of strong riparian buffer zone and artificial wetland for natural cleansing systems and stabilization of the river ecosystem, sustainable production and food security will be maintained and degraded ecosystems restored. Consequently, well-managed freshwater ecosystems will ensure availability of safe and adequate water and sanitation, public health, clean production, food security and poverty alleviation which counts for SDGs achievement.

Since many domestic activities like cultivation and water collection are carried out by women while interacting with the river and other freshwater ecosystem, ecohydrology emphasizes a need for women involvement in planning for sustainable and integrated water resources management. It is a platform for women involvement to reduce gender gap, reverse degradation, reducing climate change impacts through phyto-technologies in hydro-ecological interactions to both enhance river (and other freshwater) ecosystem stability and ensure availability and sustainable water management and sanitation for sustainable development.

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References

Albert, J., Destouni, G., Duke-Sylvester, S.M., Magurran, A., Oberdorff, T., Reis, R.E., Winemiller, K. and Ripple, W.J. (2020). Scientists' warning to humanity on the freshwater biodiversity crisis. Ambio. doi:10.1007/s13280-020-01318-8

Bendix, J. and Stella, J.C. (2013). Riparian Vegetation and the Fluvial Environment: A Biogeographic Perspective. In: Treatise on Geomorphology Vol. 12. Elsevier.

Brown, A.G., Lespez, L., Sear, D.A., Macaire, J.J., Houben, P., Klimek, K., Brazier, R.E., Oost, K. and Pears, B. (2018). Natural vs anthropogenic streams in Europe: History, ecology and implications for restoration, river-rewilding and riverine ecosystem services. Earth-Sci. Rev., (180), 185–205. https://www.sciencedirect.com/science/article/pii/S001282521730538X?via=ihub

Chua, E.M., Wilson, S.P., Vink, S. and Flint, N. (2019). The influence of riparian vegetation on water quality in a mixed land use river basin. River Res Appl., (35)3, 259-267.

Corenblit, D., Baas, A., Balke, T., Bouma, T., Fromard, F., Garófano-Gómez, V., González, E., Gurnell, A.M., Hortobágyi, B., Julien, F., Kim, D., Lambs, L., Stallins, J.A., Steiger, J., Tabacchi, E. and Walcker, R. (2015). Engineer pioneer plants respond to and affect geomorphic constraints similarly along water-terrestrial interfaces world-wide: Biogeomorphic feedbacks along water-terrestrial interfaces. *Global Ecol. Biogeogr.*, (24)12, 1363–1376.

Corenblit, D., Tabacchi, E., Steiger, J. and Gurnell, A.M. (2007). Reciprocal interactions and adjustments between fluvial landforms and vegetation dynamics in river corridors: A review of complementary approaches. Earth Science Review. doi: 10.1016/j.earscirev.2007.05.004

de la Fuente, B., Mateo-Sánchez, M.C., Rodríguez, G., Gastón, A., Pérez de Ayala, R., Colomina-Pérez, D., Melero, M. and Saura, S. (2018). Natural 2000 sites, public forests and riparian corridors: The connectivity backbone of forest green infrastructure. *Land Use Policy,* (75)1, 429–441.

de Sosa, L.L., Glanville, H.C., Marshall, M.R., Abood, S.A., Williams, A.P. and Jones, D.L. (2018). Delineating and mapping riparian areas for ecosystem service assessment. *Ecohydrology,* (11)2, 1-16.

DeBano, L.F. and Schmidt, L.J. (2004). Settings and history: Riparian areas of the Southwestern United States Hydrology, Ecology and Management. CRC Press.

Dickens, C., McCartney, M., Tickner, D., Harrison, I.J., Pacheco, P. and Ndhlovu, B. (2020). Evaluating the global state of ecosystems and natural resources: within and beyond the SDGs. Sustainability. doi: 10.3390/su12187381

Dodds, W.K., Oakes, R.M. (2008). Headwater influences on downstream water quality. *Environmental Manage.*, (41)3, 367-377.

Dufour, S., Rinaldi, M., Piégay, H., Michalon, A. (2015). How do river dynamics and human influences affect the landscape pattern of fluvial corridors? Lessons from the Magra River, Central–Northern Italy. Landscape Urban Plan. doi: 10.1016/j.landurbplan.2014.10.007

Dufour, S., Rodríguez-González, P.M. (2019). Riparian Zone / Riparian Vegetation Definition: Principles and Recommendations. Report, Cost Action CA16208, Converges European Riparian Ecosystems. Retrieved from https://converges.eu/resources/riparian-zone-riparian-vegetation-definition-principles-and-recommendations/. Cited 7 October 2020

Dufour, S., Rodríguez-González, P.M. and Laslier, M. (2018). Tracing the scientific trajectory of riparian vegetation studies: Main topics, approaches and needs in a globally changing world. Sci. Total Environ. doi: 10.1016/j.scitotenv.2018.10.383

Eeden, A.V., Mehta, L. and Koppen, B. (2017). Whose waters? large-scale agricultural development and water grabbing in the Wami-Ruvu River Basin, Tanzania. *Water Altern. (9)*3, 608-626.

GLOWS – FIU (2014). Wami River Basin, Tanzania, Environmental Flow Assessment Phase II. Florida International University.

Hultine, K.R., Scott, R.L., Cable, W.L. and Williams, D.G. (2004). Hydraulic redistribution by a dominant, warm desert phreatophyte - seasonal patterns and response to precipitation pulses. *Funct. Ecol., (18)*4, 530–538.

Illhardt, B.L., Verry, E.S. and Palik, B.J. (2000). Defining riparian areas: Riparian management in forests of the continental eastern United States. Lewis Publishers.

IUCN (2010). The Ruvu Basin: A Situation Analysis. xvi. IUCN - ESARO Publications Service Unit.

Jemison, R. and Raish, C. (2000). Riparian areas, Livestock management in the American Southwest: Ecology, society and economics. Elsevier Science.

Kondolf, G.M., Piégay, H. and Landon, N. (2007). Changes in the riparian zone of the lower Eygues River, France, since 1830. *Landscape Ecol., (22)*3, 367–384.

Lalika, M. (2020). Promoting Ecohydrology as a tool for water management in Tanzania. In: Book of abstracts - Maji Week 2020 Annual Scientific Conference, Global Water Partnership Southern Africa – Tanzania Water Partnership. Dar es Salaam. p 52.

Lim, M.M.L., Jørgensen, S. and Wyborn, C.A. (2018). Reframing the sustainable development goals to achieve sustainable development in the Anthropocene - a systems approach. *Ecology and Society, (23)*3,1-22.

Malan, J.A.C., Flint, N., Jackson, E.L., Irving, A.D., Swain, D.L. (2018). Off stream watering points for cattle: Protecting riparian ecosystems and improving water quality. *Agriculture, Ecosystem & Environment, (256)*1, 144-152.

Mero, R.E. (2011). Assessment of Water Quality and Spatial Distribution of the Major Pollutants in Ngerengere River Catchment, Tanzania. University of Zimbabwe.

Merrey, D. (2015). The Critical Role of Water in Achieving the Sustainable Development Goals: Synthesis of Knowledge and Recommendations for Effective Framing, Monitoring, and Capacity Development. United Nations Department of Economic and Social Affairs (UN DESA).

Naiman, R.J., Decamps, H. (1997). The ecology of the interfaces; riparian zones. Annu. Rev. Ecol. Syst., (28)10, 621–658.

Naiman, R.J., Decamps, H. and McClain, M.E. (2005). Riparia: Ecology, conservation, and management of streamside communities, Aquatic ecology series. Academic Press.

National Research Council (2002). Riparian Areas: Functions and Strategies for Management. National Academic Press.

Natkhin, M., Dietrich, O., Schäfer, M.P. and Lischeid, G. (2013). The effects of climate change and changing land use on the discharge regime of small catchment in Tanzania, Reg. Environ. Change. doi: 10.1007/s10113-013-0462-2.

Pacini, N. and Harper, D.M. (2008). Ecohydrological Analysis of Tropical River Basin Development Schemes in Africa. In: Harper, D., Zalewski, M., Pacini, N. (eds) Ecohydrology: Processes, models and case studies an approach to the sustainable management of water resources. Ecohydrology: Processes, Models and Case Studies. An approach to the sustainable management of water resources. Wallingford, CAB International. 223-246.

Pert, P.L., Butler, J.R.A., Brodie, J.E., Bruce, C., Honzak, M., Kroon, F.J. and Wong, G.A. (2010). Catchment-based approach to mapping hydrological ecosystem services using riparian habitat: A case study from the Wet Tropics, Australia. *Ecol. Complex.,* (7)3,378-388.

Pinchak, W.E., Smith, M.A., Hart, R.H. and Waggoner, J.W. (1991). Beef cattle grazing distribution patterns on foothill range. J. Range Manag., 1991, (44)3, 267-275.

Rangelands (1997) *Riparian zones: History and Human impacts* (pp.11)

Raphael, A. and Lalika, M. (2020). Ecohydrology regulating anthropogenic impacts on river basins and Riparian vegetation. In: Book of abstracts - Maji Week 2020 Annual Scientific Conference, Global Water Partnership Southern Africa – Tanzania Water Partnership. Dar es Salaam. p 41.

Saha, A. and Guida, V. (2014). Climate, forest cover and water resource vulnerability in the Wami, Ruvu and Coastal River Basins of Tanzania. Florida International University.

Shagega, F.P., Munishi, S.E. and Kongo, V.M. (2018). Prediction of future climate in Ngerengere River catchment, Tanzania. Phys Chem Earth. doi: 10.1016/j.pce.2018.12.002

Trimmel, H., Weihs, P., Leidinger, D., Formayer, H., Kalny, G. and Melcher, A. (2018). Can riparian vegetation shade mitigate the expected rise in stream temperatures due to climate change during heat waves in a human-impacted pre-alpine river? *Hydrol. Earth Syst.* Sci., (22)1, 437–461.

UNESCO (2011). Ecohydrology for Sustainability. International Hydrological Programme, Division of Water Sciences.

United Nations (2018) The Sustainable Development Goals Report. The United Nations.

Zalewski, M. (2000). Ecohydrology-the scientific background to use ecosystem properties as management tools toward sustainability of water resources. *Ecol. Eng.,* (16)1, 1–8.

Zalewski, M. (2002). Ecohydrology-the use of ecological and hydrological processes for sustainable management of water resources. *Hydrol. Sci. J., (47)*5,823-832.

Zalewski, M. (2009). Regulation of biotic feedbacks by hydrology. Top-down effects. Lewis Publishers

Zalewski, M. (2012). Ecohydrology: process-oriented thinking for sustainability of river basins. *Ecohydrol. Hydrol., (12)*2, 89-92.

Zalewski, M. (2013). Ecohydrology: Process oriented thinking towards sustainable river basins. *Ecohydrol. Hydrobiol., (13)*2, 97-103.

Unlocking the Potential of Ecohydrology in Climate Stressed Water Bodies: Experience from Mara River Basin, Tanzania

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Abstract

Mara River is a transboundary water body between Tanzania and Kenya that drains into Lake Victoria. This transboundary water body is crucial for various ecosystem services for the local communities along the catchment. Despite its ecological and economic significance, the river is under increasing pressure and losing many of its important functions with serious consequences in aquatic biodiversity, significant reduction of livelihood opportunities, water eutrophication, changed water regimes and increased water use conflicts. This study identify the drivers of climate change and environmental degradation, effects of mining activities on water quality, effects of agricultural activities on stream discharge and establish approaches for river basin management and environmental conservation. Socio-economic data were collected through household questionnaires, interviews and participant observation. Ecological data on water quality, flow and heavy metals concetration were obtained from gauging stations and Lake Victoria Basin Offices for analyses. The Statistical Packing for Social Sciences and Microsoft Excel were used in the analyses. The study revealed that environmental degradation along the Mara River Basin is caused by direct and indirect drivers. Direct drivers for environmental degradation are identified as agriculturel (41%), mining (34%), livestock keeping (13%) and deforestation (12%). It is found that impairment of water quality is due to excessive NO3- and PO43- concentrations that exceed the recommended in most sites by direct drivers which cause adverse impact on the ecosystem. Ecohydrology and management framework that encompasses integrated water resource management along the entire basin should be applied and also, developing new species susceptible to the impacts of climate change.

Keywords: Water regimes, Agriculture activities, Hydrological services, Mara River Basin, Tanzania

1. Introduction

With increasing population and related economic activities, the earth's natural resources and the environment are increasingly stressed. More virgin land is being turned into agricultural land, watershed hosting endemic flora and fauna being degraded and forests are being felled for timber, fuel wood and other uses at a pace faster than they are being replenished and degrading water resources. In recent years, it has been documented that (Lalika *et al.,* 2015a; b; Lalika *et al.,* 2017) the impact of increased human population on the natural ecosystems has been threatening the basic foundation upon which humans depend for steady supply of ES essential for human survival and ecological integrity.

The Ecohydrology is a relatively new and rapidly growing nature-based solution for solving water and environmental problems around the globe. It is a trans-disciplinary science, a nature-based solution and a problem-solving science derived from the larger earth systems science movement and examining mutual interactions of the hydrological cycle and ecosystems (Zalewski, 2002; Zalewski *et al.,*.2010). It is also an applied science focused on problem solving and providing sound guidance to catchment-scale integrated land and water resources management. The main scope of ecohydrology include (i) climate-soil-vegetation-groundwater interactions at the land surface with special implications for land use, food production and climate change; (ii) riparian runoff, flooding, and flow regime dynamics in river corridors with special implications for water supply, water quality, and inland fisheries; and (iii) fluvial and groundwater inputs to lakes/reservoirs, estuaries, and coastal zones with special implications for water quality and fisheries.This study was carried out along Mara River, a transboundary water body between Tanzania and Kenya which drains into Lake Victoria. Mara River Basin (MRB) is essential in ecological and economic aspects, the river is under increasing pressure due to significant loss of water quantity due climate change and human activities. In recent years it has lost its important functions with serious consequences in aquatic biodiversity, livelihood opportunities, changed water regimes and increased water use conflicts (Mango *et al.,* 2011).

Despite the fact that MRB is very important in supporting the livelihood of communities living around, the river has been altered through agriculture, mining and water abstraction. Small scale farmers and domestic users rely less on conveyance systems and more on the resource in the channel. Mining and agriculture are the largest user of freshwater resources along the MRB. However, mining activities are both cause and victim of water pollution through its discharge of pollutants (mercury, arsenic, phosphorous, sulphur and nitrate), also during rainfall it causes soil run off and sedimentation which contains heavy metal direct to the river and poor agricultural practices along the river banks. These actions often create a legacy of poor water quality, siltation, effect on aquatic biodiversity, effect on riparian biodiversity and poor stream discharge, disrupt channel systems and also cause eutrophication. Agricultural activities affect the quality of water if not managed well. Some of activities are; cultivating along the river banks, fertilizer application, pesticides application, irrigation etc. these activity affect physical, chemical and biological characteristics of water (Dafter *et al,*. 2019). The cutting down of trees (deforestation) along MRB watershed and other activities activate river banks erosion leading to high levels of turbidity in rivers and siltation of bottom habitat. Forests and Savannah glassland have been cleared and converted into agricurtural land (IUCN, 2000). Attribute the decline to increased human activity in the basin and climate change which they claim has resulted to erratic rainfall pattern (Dessu and Mellesse, 2012). Disruption and change of hydrologic regime often with loss of perennial streams causes public health problems due to loss of potable water.

The study is important since it focuses on future and current environmental conservation in the area and development of the different ways to reduce effects caused by human activities along the rivers. Besides, it would address the negative issues of human activities and immediate control measures for Sustainable Development Vision 2030.The study is important in the area; since there is a pressure of human activities and environmental degradation (pollution) which needed urgent address from both stakeholders and the government. As a result, information on water quality of the river is needed for the planning of its management and the control of eutrophication in the river and Lake Victoria in general (WWF, 2006; Nile Basin Initiative, 2007). The result will help not only information of similar interventions ,but also in the implementing of policies that will be used to address issues on water resources for sustainable use. As an ecological tool for conservation, ecohydrology practices increases resilience of river basins by managing multi-dimensional parameters such as water, biodiversity, ecosystem services for society and resilience to climatic changes in order to achieve sustainability in both ecosystems and human population (Zalewski, 2015). The study was carried out to: identify drivers for climate change along MRB; determine and assess the effects of mining activities on water quality; examine the effects of agricultural activities on stream discharge and establish Ecohydrology approaches for river basin management and environmental conservation.

2. Materials and Methods

2.1. Description of the study area

The study was conducted in three villages (Nyangoto, Nyabichune and Matongo) along MRB Tanzania. MRB is the Trans-boundary shared between Kenya and North Western Tanzania at between longitudes 33˚47'E and 35˚47'E and Latitudes 0˚28'S and 1˚52'S and (MRB) is home to more than 1.28 million people in Kenya and Tanzania and supports a number of critically important wildlife areas. (African Barrick Gold, 2013; MTL Consulting Company Limited, 2011;Zermoglio *et al.*, 2019).

2.1.1. Hydrology and drainage patterns

There are two distinct wet seasons, namely the 'long rains', from March to May and the 'short rains', from November to December. The average annual rainfall is approximately 1320 mm,the wettest month is April and the driest month is July. The study area is largely enclosed by the Nyarero Escarpment, which is observed to exceed 1,700 m a.m.s.l. in the eastern portions, and as such, the valley (referred to as the Kiribo Plains) drains from east to west towards Lake Victoria via a large wetland area (referred to as the Masirori Swamp also a known as a critical nursery for economically important fish species of Lake Victoria (LVBC and WWF-ESARPO, 2010; MTL Consulting Company Limited, 2018). While various other drainage lines within the study area, including those typically representative of smaller wetland systems (e.g. Nyabuchichibu, Nyamaku, etc.), direct water toward the Mara River and the aforementioned wetland area, the most prominent of these features is the Thigithe River, which also discharges into the Masirori Swamp, also all these tributaries discharges into MR towards lake Victoria.

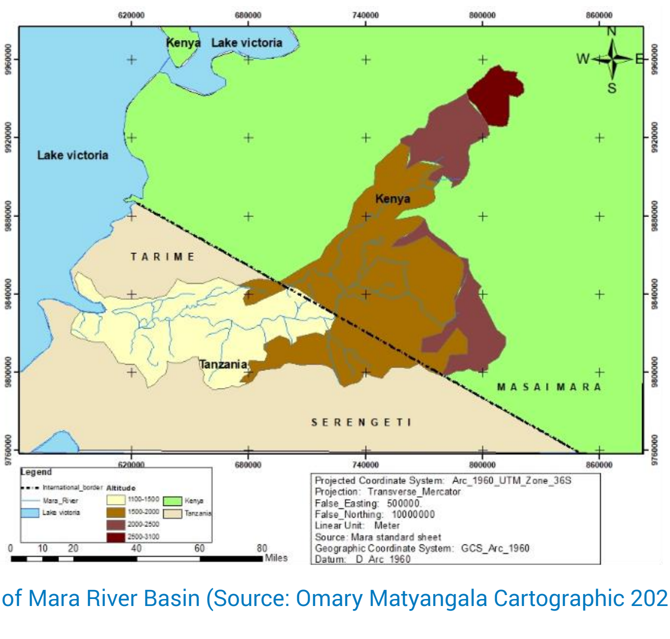

Figure 1. Location of Mara River Basin (Source: Omary Matyangala Cartographic 2021).

2 .1.2. Vegetation and ecological systems

The upper part of Mara basin consists of protected forest and woodland within the gazette area of Mau Forest Complex. Some of the areas which were originally forest have been cleared for cultivation. The middle part consists of grassland and bush land which is in the Serengeti National Park in Tanzania or Maasai Mara National Reserve in Kenya. Some of it is also under large-scale farming or ranching or small scale agriculture. The lower part in Tanzania consists also of agricultural land. Wetlands are found in the area close to Lake Victoria. The Mara basin has been subject to rapid changes in land cover over the last 50years. The forest provides honey, forest employment and forest farming, firewood, medicinal herbs.

2.1.3. Land use and socio-economic activities

The dominant and important land uses in the MRB are: forests conservation, especially in the catchment (expanding tea farms); A number of settlements and villages which surrounds MRB and conduct mining activities (or hamlets) within the immediate vicinity of the mining areas Includes Matongo, Nyabichune, Nyangoto and other village are like, Genkuru, Kerende, Kewanja, Nyakunguru and Nyamwaga are previously known as a prominent artisanal and small-scale mining (ASM) area and as such, agro-pastoral activities were regarded as a secondary livelihood (African Barrick Gold, 2013; MTL Consulting Company Limited, 2011). However, these activities have since been observed to dominate the surrounding land-use activities in terms of cultivated lands, livestock rearing and other general domestic uses. The basin has experienced substantial land use changes in the past 30 years that has seen a shift from forest and bush-land to agricultural farming (Mango *et al.,* 2011). Gold mining is an important source of revenue and a major employer in the Tanzania segment of Mara River Basin. ACACIA Gold mine (North Mara Gold Mine) located in the segment which is important that it is quoted on the New York Stock Exchange. Trade and commerce on the other hand is a feature of urban centers' like Tarime and Musoma. A majority of economic activities in the basin thrive because of the availability of water in basin. Any major negative changes in the quality and quantity of the basin's water may have an impact on the economy of the area.

2.1.4. Climate and ecological zones

Tanzania has a tropical climate with large regional climatic variations influenced by several factors, a coastline, a substantial section of the Great Rift Valley, some mountains and a central plateau (Nathan, C. *et al.,* 2019). There are usually three main air masses that significantly influence the rainfall regime of the Mara River Basin. The apparent movement of the Inter-Tropical Convergence Zone (ITCZ) determines the seasons on the basins, which receives annual rainfall. The temperature variations in the MRB are determined by altitudinal as well as rainfall variations, such that in elevated areas with high rainfall amount the temperatures drop to 20.6oC, while the lowlands in the central and southwestern parts of the basin the temperatures rise to 23.5oC. Temperatures are lowest in the wet months of March to May and the highest in the dry months of July and August . In general temperatures increase southwards and decrease northwards (North Mara Gold Mine Report, 2018).

2.2. Sampling procedure

Purposive and random sampling was used to select study villages and respondents in each village. While purposive sampling was used to select villages located along the MRB, random sampling was used to select respondents in each study area. Purposive sampling is important because it removes the bias when reselecting the respondents. In other words, it has the ability to remove bias and it gives an equal opportunity to each respondent to be sampled / selected for the study. In each sampled village, households were randomly selected in order to get respondents. These respondents were picked from a village register book where all households' members are listed. A total of 60 respondents were interviewed, i.e. 30 from each village. According to Bailey (1994), 30 individuals are recommended for a social research to meet a reasonable statistical analysis.

2.3. Data collection methods

While primary data were collected through household questionnaires, checklist for key informants, interviews and direct observation. Secondary data were collected through reading relevant literatures from previous studies in library, publications, books, journals and records. the water samples including as physical and chemical parameters of water quality were analysed through environmental laboratory from North Mara Gold Mine. The parameters for monitoring in water samples include physical parameters, cyanide compounds, metals, cations, anions, hydrocarbons, and microbiology. Also, some of the parameters for onsite and offsite data included pH, Conductivity, Dissolved Oxygen (DO), Total dissolved solid, Temperature, Salinity and Redox potential.

2.4. Data analysis

The data were collected, coded, classified, entered and tabulated where by analysis was done using Statistical Packing for Social Sciences (SPSS) version 20.0. Furth more Microsoft Excel was used to draw, charts, tables, and construct figure. Supplementary information, which was obtained from field visits, was used to cross check the information obtained from questionnaire and the secondary data which were obtained from various sources.

3. Results

3.1. Drivers for climate change and environmental degradation along Mara River Basin

Climate chnage and environmental degradation has continued to occur all over the world for years at rate increasing. Climate variability and change will multiply these pressures on water resources. This climate change vulnerability assessment for the MRB aims to shed light on the pressures that face the MRB and to offer insights on priority vulnerabilities of the MRB as a whole (Zermoglio *et al.,* 2019). Natural habitat and are being destroyed and

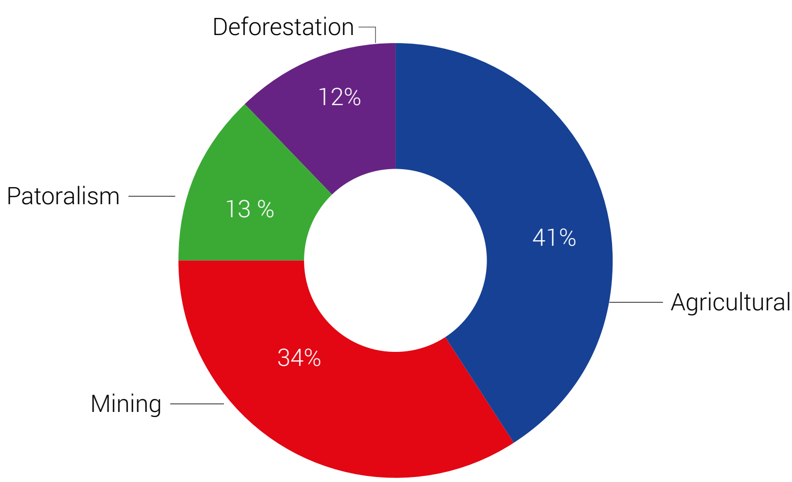

Figure 2. Drivers for climate change and environmental degradation along MRB

evidences of contamination in most part in the world become vivid (Matel, 2000). The study revealed a number of drivers for climate change and environmental degradation. They include agricultural (41%), mining (34%), livestock keeping (13%) and deforestation (12%).

3.2. Effects of mining activities on water quality

The findings in Table 1 show that 75.0% of respondents involves in mining activities which are small scale and large-scale mining. While 25% said that they not involved in mining activities. Mining activities involved the use of water in all operations including separations of minaral through chemical process, physical separation of materials such as in centrifugal separation. Majority of the community members who are involved in mining activities along MRB use water from Mara River for their daily activities.

Table 1: Mining activities along Mara River Basin

Mining activities	Frequency	Percentage
Yes	45	75.0
No	15	25.0
Total	60	100

3.2.1. Water pollution from mines is often cited as a major concern among stakeholders

Table 2. Concentrations (mg/l) of heavy metals in Mara River

Heavy metal	2015	2016	2017	2018	WHO
Cu	0.01	0.06	0.01	0.06	2
Fe	1.14	0.62	0.19	0.79	1
Cd	<0.02	<0.02	<0.02	<0.02	0.003
As	0.08	-0.01	0.06	0.01	0.01
Hg	<0.001	<0.001	<0.001	<0.01	0.006
Zn	0.08	0.01	0.01	0.06	0.02

Concentration ranges and means of heavy metals Cd, Fe, Zn, Hg, As and Cu measured in water samples from 8 sites of MRB are summarized in table 2. The results from the table show that the heavy metals varied over distinguishable range of concentrations. This range reflect the impact of varying settings, characteristic water and soil in land use practices spread over different sub-catchments in the Basin. Sources of these metals may therefore be attributed to the nature of the catchment areas, mining waste discharge, agrochemicals, geological weathering of parent rocks and atmospheric sources.

The findings in Figure (3) and (4) lead the conclusion that most of heavy metal are dangerously to the climate and environmental even if in low concentration.

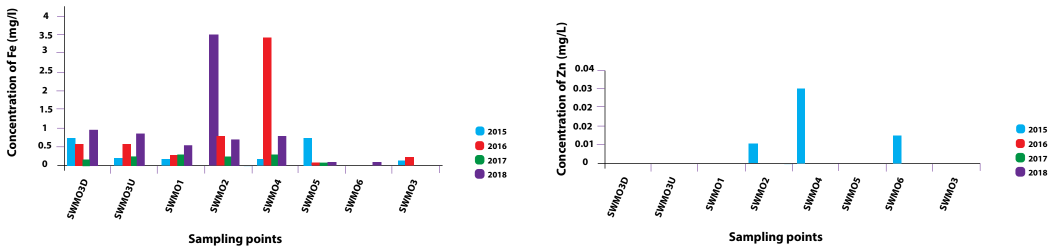

Figure 3 & 4. Iron and zinc concentration in Mara River

3.3. Effects of agricultural activities on stream discharge

Agricultural activities are among of the main activities conducted along MRB, look at Table 3 reveals that most of the people in the community engaged in agricultural activities along MRB.

Table 3: Agricultural activities

Agricultural activities	Frequency	Percentages
Yes	40	66.67
No	20	33.33
Total	**60**	**100**

Majority of communities within the MRB are mainly farmers engaged in mixed cropping and livestock husbandry, or both.

Table 4: Codes for Mara River monitoring point

SWMO1	Mara upstream of SWM2 GO VIA Mrito
SWMO2	Mara upstream of abstruction point go via the back of Rama dump
SWMO3	Mara at water abstraction point
SWMO3D	Mara river below Pipe line discharge
SWMO3U	Mara River immediately Upstream of SWMO3(Control site for Ingwe Discharge) water abstraction point
SWMO4	Mara River down of SWM3
SWMO5	Mara d/s Mine (back water channel)
SWMO6	Mara d/s Mine (back water channel)
SWMO7	Mara d/s Mine (Kirumi bridge)

3.3.1. Concentration of Phosphorous in Mara River

As figure 5 indicates, Phosphorous is a limiting plant nutrient and rarely found in high concentrations in fresh waters.

Table 5: Mean concentration ±Standard deviation (mg/l).

Sample code	2015	2016	2017	2018
SWM03D	11.8 ±4.0	3.9±2.9	6.2±6.2	
SWM03U	10.0±4.3	6.8±1.2	6.7±4.9	9.1±3.7
SWM03	17.4±17.4	10.8±1.85		
SWM02	14.5±.86	9.6±6.4	9.0±4.5	9.6±5.2
SWM05	0.1±.6.0	3.0±2.2	4.9±2.7	5.8±4.2
SWM01	60.3±40.4	12.2±.8.0	9.5±6.7	6.6±4.1
SWM04	51.0±.40.1	9.9±4.7	7.1±4.9	7.7±3.1
SWM06	4.9±4.9			

Mean concentration of Nitrate in river water of Mara River Basin

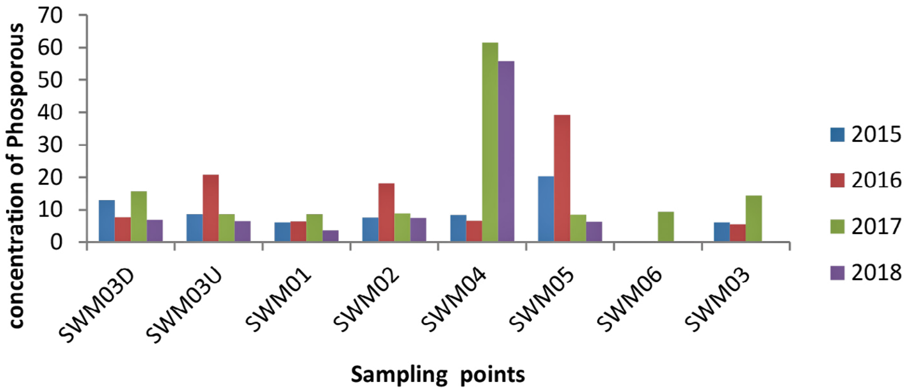

Figure 5. Phosphorous concentration in Mara River

3.4. Ecohydrology approaches for river basin management and environmental conservation.

In the table below the study found that only 33.3% of the community members engage themselves towards conserving the MRB by planting trees along MRB, and raise awareness on conservation activities, where most people in the community they were not engaged in. Also, the table below reveals that 66.7% of the respondents did not engage at all in conserving the MRB.

Table 6: Participations of community in Mara River Conservation.

Participation	Frequency	Percentages
No	45	67
Yes	15	33
Total	**60**	**100**

4. Discussion

4.1. Drivers for climate change and environmental degradation along Mara River Basin

Agricultural and Mining activities are the most drivers for climate change and environmental degradation along MR. Figure (2) reveals that most of the people in the community engaged in agricultural and mining activities along MRB. All these leads to the enrichment of nutrients (Eutrophication) in MRB and change of river flow and frequent floods. One of the serious problems is the contamination of water resources by toxic chemicals like mercury, cyanide, pesticides, fertilizers, livestock chemicals and the byproducts that originate from mining and agriculture site (Kihampa, and Wenaty, 2013).

The result shows that invasion of agricultural is the most activity that contributes to climate change and environmental degradation within the study area accounting for about 41%. Agricultural activities have been shown contributing immensely to climate change as it ranks third after energy consumption and chlorofluorocarbon production in enhancing green house emissions. In fact, emissions from agricultural sources are believed to account for some 15% of today's anthropogenic greenhouse gas emissions (Kihampa, and Wenaty, 2013). Land use changes, often made for agricultural purposes, contribute another 8% or so to the total (Ozor and Nnaji, 2011). The results from the figure (2) above imply that improper animal grazing along the MRB contributes significant climate change and degradation of environmental vegetation and land through regular feeding and trampling. Cutting down of trees for feeding livestock as well as normal feed by livestock reduce vegetative cover which act as a barrier for soil erosion since surface sediments become more exposed, therefore unstable and subject to weathering and erosion (Ziervogel *et al*., 2008). Livestock trampling cause soil compaction which prevents infiltration, which in turn prevents the groundwater table from recharging and therefore increases surface runoff. This increases the likely chance of a change of river flow and frequent floods. Improper cultivation is rampant along the MRB due to inadequate knowledge on how to perform sustainable agriculture within the area; this therefore leads to environmental degradation and climate change . A study by Kashaigili. (2011) shows that agriculture is the major land use by the indigenous community living close to this wetland where irrigated agriculture was found in the lower Ruvu and the western slopes of the Uluguru Mountains.

On the other hand, the result shows that mining in MRB was ranked as the second significant driver to environmental degradation and climate change within the study villages. The residents mention mining activities is one of the sources of income for both small scale and large scale miners along MRB. Mining activities involves different stages from starting point (exploration ,mining, and processing), through this stage activities like clearing vegetation, removing top soil, ,blasting are done and contribute to environmental degradation and climate change. While this was confirmed by local testimony of a few local by-passers, the extent of the contamination and its potential effect are unclear, especially since the cause of the spillage was believed to be vandalism of the liners at the Gokona Leachate Ponds. (Nathan,C. *et al.,* 2019).

Villages such as Nyangoto, Nyabichune and Matongo which lie close to MRB, results from the figure show that livestock grazing has contributed to the environmental degradation due to the lack of restrictions on land use. However, the deforestations is among of contributers to the environmental degradation and climate change along the MRB, the deforestation is lead by cutting tress to make charcoal, settlements and shifting cultivation . Negative impacts of deforestation and forest degradation include loss of ecological services (such as biodiversity and watershed), the loss of many goods such as timber, fuel wood, charcoal and None Wood

Forest Products (Lamb et al., 2005), and the loss of livelihood sources for more than 80% of rural Tanzanians (URT, 2005). Generally, the study found out climate change and environment are being threaten by over-exploitation of its functions, products and services from increased anthropogenic activities including agricultural, mining, livestock grazing by immigrants from various regions of Tanzania. Deforestation as well as growing population in different cities, towns and township from the country and neighbour country like (Kenya) lead to increased demand for food, income, and areas for settlement. Inappropriate grazing regimes and stocking rates associated with increasing livestock population, increasing irrigation activities as well as lack of proper environmental management policies and strategies continue to threat MRB areas in different parts of the world causing changes in the services and goods accrued from Environmental resources (URT, 2007).

4.2. Effect of mining activities on water quality

Heavy metals concentration ranges and means of heavy metals Cd, Fe, Zn, Hg, As and Cu measured in water samples from 8 sites of MRB are summarized in Table 2 as well Figure 2and Figure 3,respectively. The results from the tables show that the heavy metals varied over distinguishable range of concentrations. This range reflect the impact of varying settings, characteristic water and soil in land use practices spread over different sub-catchments in the Basin. The study by North Mara water management stratergy project (2016), cources of these metals may therefore be attributed to the nature of the catchment areas, mining waste discharge, agrochemicals, geological weathering of parent rocks and atmospheric sources . For instance Cd, Cu and Zn are reported to be a component of pesticides and fertilizers which attach to organic materials that can be released through surface runoff during the rainy season (Fulekar and Chhotu 2009; Okoro *et al*., 2012). Air from mining activities is reported to be a source of Pb, which is attached into dust particles that eventually settled in surface water (NMGM Report , 2017). Hg has been reported to be Part of the components of reagents used in mineral processing most in small scale around MRB .Mining also result in loss of vegetation and topsoil which causes climate change, flooding, and the water emerging from the debris contains toxic solutes which include metals. Generally, mining water is complex in nature and of widely varying metallic composition (Msagati and Mamba 2011).

According to the laboratory analysis of *North Mara Gold Mine,* the Table 2 above shows some of the secondary data of heavy metals concentrations found in Mara River at different sampling point, within four years. The contents of the heavy metals in water unlikely related to the corresponding contents in the sediments phase, In general there were higher concentrations in sediments than in water samples (Kihampa and Wenaty, 2013) .This has to be expected, because metals are slow to degrade, in water are adsorbed onto suspended particles and eventually settle to the sediments which are particular ‘sinks’ where chemicals tend to concentrate (Oruma, 2012).

The result from Table 2 shows that among seven heavy metals, its highest concentration of Cu in 2016 and 2018 years, Zn in 2015 and 2018 years, As in 2015 and 2017 years and Fe in 2015 year was observed in different stations in four years (it means exceeds the WHO standards limit) .This may attribute to the huge amount of raw sewage, ship breaking, agricultural and industrial wastes water discharge into the river (Abdel, 1997). Overall, As, Cu, and Fe all are highly toxic elements found in downstream sample sites .But some of heavy metal like mercury and Cadmium they not detected due to limitation of the machine cannot detect concentration amount less than 0.002 (<0.002)for cadmium and less than 0.001 (<0.001) for mercury , and this does not mean that there is no mercury or cadmium in Mara River, but in lower concentration which can have effects to some aquatic organism and also this amount once combine with another elements can cause negative impact to the environmental . For instance, the inorganic forms of tin (Sn), and mercury (Hg) are much less toxic or even do not show toxic properties while the alkylated forms are highly toxic (Kapustova, 2009; Sharma *et al.,* 2009).

4.3. Effects of agricultural activities on stream discharge

Majority of communities within the MRB are mainly farmers engaged in mixed cropping and livestock husbandry, or both. In fact, this study found in table 3 that farmers engaging in both intercropping and mixed cropping make 66.67% of the households within the MRB. Agriculture is also significant impacts freshwater, estuarine and coastal environments, leading to sedimentation, eutrophication and ecosystem damage. (Kihampa C. and Wenaty A., 2013). The economy of the upper reaches catchment section of the MRB is based on mixed small-scale, intensive farming due to abundant rainfall. In the middle reaches, however, the economy is mainly driven by nomadic pastoralism, crop plantations and tourism (Zeitler, 2000). Apart from Serengeti National Park, the economy within the lower catchment section of the MRB is dominated by agriculture, livestock production, mining, and to some extent fishing, business and petty trading (Majule, 2010). Data by Makalle et al., (2008) shows that about half (51.8%) of the community members within the basin are engaged in both livestock keeping as well as cultivation while 2.5% relied solely on livestock with a herd size per household of 50-1,000 cattle.

Figure 6. Uncontrolled livestock grazing and deterioration of the MRB © Magdaline Boniphace

These results confirm that subsistence farming is widespread in the lower catchment. Food crops grown in the lower catchment region include: cassava, maize, sorghum, finger millet, paddy, sweat potatoes and beans. Most of the cash crops grown in the MRB include: cotton, coffee, sunflower, tobacco and groundnuts. The production trend of these cash crops shows fluctuating yields, probably due to a corresponding fluctuation in weather conditions in the region (Majule, 2010). Improper cultivation is rampant along the MRB due to inadequate knowledge on how to perform sustainable agriculture within the area; this, therefore leads to water pollution in MRB. A study by Kashaigili (2011) shows that agriculture is the major land use by the indigenous community living close to the river where irrigated agriculture was found in the lower Ruvu and the western slopes of the Uluguru Mountains. As Malatu *et al.,* (2015) pointed out, a decline of upland productivity triggers more pressure to river cultivation which lead to more degradation to the River Basins.

4.4. Concetration of Phosphorous and nitrate in Mara River

Also, the study supported by secondary data from *North Mara Gold Mine (Laboratory analysis),* these physicochemical characteristics of the water: The results of the physicochemical parameters measured at 8 sites within MRB. Some of the North Mara Gold Mine Company expertise and respondents argue that that the amount of concentration, Ph and Nitrate within the MR increased due to agriculture activities by using fertilizer, attributed by the nature of nitrate-nitrogen being the most oxidized chemical form of nitrogen found in the natural systems and in living organism. The impacts are due to the increased use of agrochemicals inputs in order to meet agriculture production demand. Pollution from fertilizers occurs when they are applied more heavily than crops can absorb or when they are washed or blown off the soil surface before they can be incorporated. Excess nitrogen and phosphates can leach into groundwater or run off into waterways (Kihampa, and Wenaty, 2013).

Nitrate is a form of nitrogen that is an essential plant nutrient, but in excess amounts they can cause significant water quality problems. Despite of natural source of nitrate like igneous rock, plant decay and animal debris, in most cases the nitrate pollutions in water are the results of human activities. The normal range of nitrate concentration in natural waters is normally below 5 mg/l, any value above this level is an indication of manmade nitrate pollution (USEPA 2012; WHO 2007; EPA 2009; EU, 2014). Findings in table 5 indicates that limit of nitrate has been exceeded at SWM01 (Mara River upstream) and SWM04 (Mara river downstream) indicating potential contamination of the river waters, this increase of nutrients causes eutrophication. Both sites are surrounded by agricultural activities (tomatoes, green vegetables and livestock), thus possible sources of NO3-N contamination are agricultural runoffs containing fertilizers. Generally, the main contamination sources of surface waters by nitrate are potassium nitrate (KNO3) and ammonium nitrate (NH4NO3), both salts commonly used as fertilizers. Apart from nitrate, nitrogen in terrestrial and aquatic ecosystems can also be found in the form of NO2-N and NH3. The nutrient overload can cause eutrophication of lakes, reservoirs and ponds, leading to an explosion of algae which suppress other aquatic plants and animals

Phosphorous is actively taken up by plants and any excess amounts that are not used by a crop combine with the soil constituents and can be used by later crops. Potential sources of the phosphorus in this area are excessively used inorganic fertilizers, farmland manure and animal waste, particularly because livestock grazing by allowing them into the water source (Mara River) is a common practice (Oruma, 2009). High concentration of phosphorous is downstream (SWM04) in Mara River which causes accelerated plant growth and algae blooms which can then cause rapid oxygen depletion or eutrophication in the water. Increased fertilizers applications to cropland and runoff from soils with high nutrients are some of the major causes of eutrophication (McIsaac *et al.,* 2001). The end product is water with low dissolved oxygen which cannot support aquatic life including certain fish, invertebrates, and other aquatic animals (Oruma, 2009). Regarding health effects, phosphorous in water is not considered to be directly toxic to humans and animals. Any toxic effect caused by phosphorous in fresh water is indirect, such as toxic algal bloom.

4.5. Ecohydrology approaches for river basin management and environmental conservation

The study found in table 6, that only 33.3% of the community members are aware on different initiatives of conserving the MRB like planting trees and raising awareness on conservation activities, but most of the people in the community are not participating due to the low knowledge and skill in the tree planting. In other hand the study reveals that 66.7% of the respondents did not engage on conserving the MRB. While a lot of institutions and organizations have initiated projects in the past for the same reason, there is still much to be done. It is certain that these programmes cannot realize all their goals without active participation from all stakeholders, support from governments and a little push from the international community (Dhungana *et al,.* 2017).

Most of the respondents said that the responsibility of water resource management currently rests under the power of the District Executive Director. However; the water user will influence the technical personel responsible as the results we luck the intersectrol coordination and intergrated water resource management within the MRB. For example, agricultural experts are involved if water is to be used for irrigation while livestock experts are involved if water is collected in dams for livestock drinking and District water engineer are involved if water is used for domestic purpose. Ecohydrology uses the dual interaction between biota and hydrology to regret, remidiate and conserve ecosystem. More ever synergistic effects of various ecohydrological measures stabilise and improve the quality of water resources. (UNESCO,. 2006).

One of the major problems is lack of ecohydrology approaches to abstract significant amounts of water for various uses. For example, watering cans, small furrow canals and small powered water pumps are used to draw water from the river. Presently, local communities do not realize water quality could be a problem. However, there is a growing concern from the regional and districts authorities that water is being polluted from different sources mainly gold mining and fishing by using illegal chemicals. With regards to the gold mining, the effectiveness of the waste disposal dam monitoring, but still there challenges of linkages and overflow during the rain season. What is more worrying is the artisanal type of mining involving the use of mercury in gold extraction since the process is undertaken in streams draining into the main river system.

5. Conclusion

Africa is already under pressure from climate stresses which increase vulnerability to further climate change and reduce adaptive capacity. The adverse effects of climate change have a particularly devastating effect on agriculture, which is the mainstay of most African economies (Batima, 2006). The study revealed that most of the cause of environmental degradation and climate change along MRB are direct drivers, such as agriculture, mining and livestock keeping which are the major socio-economic activities in the basin. These activities cause adverse impact on the ecosystem. MRB is experiencing a number of natural resource management problems including deforestation, land degradation and pollution of the river water due to mining and illegal fishing using poison. Furthermore, it was revealed that MRB is grossly contaminated with heavy metals and nutrients contaminants. The concentrations of contaminants in most of the sites were above the recommended international and national limits for drinking and irrigation waters. The discharge of mining and agricultural effluents appears to be the potential source of the heavy metals and nutrients pollution in surface water and sometimes in sediments of MRB. As More land is converted to agricultural and mining activities. Heavy metals and nutrients monitoring is an imperative means in accessing, locating and mitigation main source of these chemical pollutants. The management approaches seem to be sectoral, thus lacking integration. A lack of specific climate change institutions to take on climate change work and the need for a better institutional framework in which to implement adaptation (Ngigi,2009). Also, it is recommended that Ecohydrology and management framework that encompasses integrated water resource management (IWRM) along the entire basin should be applied, Furthermore Ecohydrology, defined as an integrative sustainability science using the interactions between hydrology, biota and natural processes as management tools to reinforce ecosystem services on a broad range of landscapes (Zalewski, 2015*)* and also, developing new species susceptible to the impacts of climate change.

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References

Aboud, A. Obweyere, G. Mutinda, M. and Raini J. A. (2002). A rapid participatory socioeconomic assessment of the River Mara Basin, Mara River Catchment Basin initiative WWW-Eastern Africa, Regional Programmers Office, (EARPO).WWF, Nairobi, Kenya.

African Barrick Gold,. (2013). North Mara Gold Mine: Conceptual Mine Closure Plan (Issue April).

Bailey,K. (1994). Methods of social reserch (4th ed.). New York: The Free Press.

Batima, P. (2006). Climate change vulnerability and adaptation in the livestock sector of Mongolia. Assessments of impacts and adaptations to climate change. International START Secretariat, Washington DC, US.

Charles, K. and Alex, W. (2013). Impact of mining and farming activities on water and sediment quality of the Mara river basin, Tanzania; Research Journal of Chemical Sciences. Vol. 3(7), 15-24,

Dessu, S. B. &Mellesse, A. M. (2012). Modelling the rainfall–runoff process of the Mara River basin using the Soil and Water Assessment Tool.Hydrological Processes.

EPA. (2009). National primary drinking waterregulations. Environmental ProtectionAgency Washington, DC.

EU. (2014). (Drinking water) regulations.European Union Commission. Statutoryinstruments SI No 122

Fernanda, Z. Owen, S. and Mohammed, S. (2019). Vulnerability and Adaptation in the Mara River Basin; https://www.climatelinks.org/projects/atlas

Fulekar, MH. Chhotu, DJ. (2009). Phytoremediation of heavy metals: Recent techniques. Afr J Biotech. 8: 921- 928.

Hilda, D. Rose, K. Kingstone, S. George, C. John,M. and Saulos, N. (2019). Effects of agricultural activities on water quality in rural area rivers. Department of water resources, Malawi University of science and technology.

IUCN. (2000). Forest cover and forest reserve in Kenya. Policy and practice. Working paper no. 5. World Conservation Union (IUCN), Gland, Switzerland.

Kapustova, S. (2009). Heavy metals in the mountains streams. Oecological Montana 18: 27 - 30.

Kihampa, C. and Wenaty, A. (2013). Impact of mining and farming activities on water and sediments quality of the Mara river basin, Tanzania. *Res.J.chem.*Sci.**3** 15-24.

Lalika, M.C.S., Meire, P., Ngaga, Y.M., (2015a). Exploring watershed conservation and water governance along the Pangani River Basin, Tanzania. Land Use Policy 48, 351–361.

Lalika, M.C.S., Meire, P., Ngaga, Y.M., Chang'a, L., (2015b). Watershed dynamics and climate change and climate variability along Pangani River Basin, Tanzania. Ecohydrol. Hydrobiol. 15 (1), 26–38.

LVBC and WWF-ESARPO. (2010). Assessing Reserve Flows for the Mara River.

Mango, LM. Melesse, AM, McClain, ME, Gann, D, and Setegn, SG (2011). Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: Results of a modeling study to support better resource management. *Hydrology and Earth System Sciences*, 15(7), 2245-2258

Matyangala, O. Map of Mara River Basin. 2021.

McIsaac, G.F., M.B David, G.Z.Gertner and D.A. Goolsby. (2001). Nitrate flux in the Mississippi River. Nature 414:166-167.

Msagati, TAM. and Mamba, BB (2011). Development of supported liquid membrane techniques for the monitoring of trace levels of organic pollutants in wastewaters and water purification systems. J. Phys. Chem. Earth 36: 1167- 1177.

MTL Consulting Company Limited. (2018). North Mara Gold Mine: Integrated Environmental Management Plan Update - 2018.

MTL Consulting Company Limited. (2018). North Mara Gold Mine: Integrated Environmental Management Plan Update - 2018.

Nathan,C. Byron, B. and Robel, G. (2019). Baseline Aquatic Biodiversity Assessment at the North Mara Gold Mine, Tanzania

Ngigi, S.N. (2009). Climate change adaptation strategies: Water resources management options for smallholder farming systems in Sub-Saharan Africa. The MDG Centre for East and Southern Africa, the Earth Institute at Columbia University, New York. Pp.189.

Nile Basin Initiative. (2007). Transboundary Environmental Action Project, National Nile Basin Water Quality Monitoring Baseline Report for Tanzania, http://www.nileteap.org/docs/publications/WQ/W

North Mara Gold Mine Report. (2018).

North Mara Water Management Strategy Project Charter,Acacia ,24 June 2016.

Oruma S. Kipampi (2012). The effects of Mau Catchment Degradation on the flow of the Mara River, School of Water Resources, Science and technology, Kenya. Pp.56-57

Ozor, N. and Nnaji, C.E. (2011). The role of extension in agricultural adaptation to climate change in Enugu State, Nigeria. Journal of Agricultural Extension and Rural Development 3 (3): 42 – 50.

Sharma, RK. Agrawal, M. and Marshall, FM. (2009). Heavy metals in vegetables collected from production and market sites of a tropical urban area of India. J. Food Chem. Toxicol. 47: 583 - 591.

Tiffen, M., Mortimore, M., and Gichuki, F. (1994). More people, less erosion: environmental recovery in Kenya. John Wiley and Sons Ltd. Overseas Development Institute, London UNEP.(2006). African Environmental Outlook. UK: Earthscan Ltd

Tran, N, B. Shashwat, D. And Bhatta N 2017. A Case Study on Water Quality and Ecosystem Management in Mara River Basin – Kenya and Tanzania

United Republic of Tanzania. (URT) (2007),"National Adaptation Programme of Action (NAPA)".Vice President's Office, Division of Environment, United Republic of Tanzania.

USEPA. (2012). Edition of the drinking waterstandards and health advisories. USEnvironmental Protection AgencyWashington, DC.

WHO. (2007). Health Risks of Heavy Metalsfrom long-range transboundary airpollution. World Health Organization:Copenhagen. 5-113.

WHO. (2011). Guidelines for Drinking-WaterQuality, Fourth edition World Health Organization, Geneva. 180-365.

WWF-Tanzania Program Office (TPO) (2006). Mara River Basin Management Initiative, Musoma, Tanzania.

Zalewski, M. (2000). Ecohydrology-the scientific background to use ecosystem properties as management tools toward sustainability of water resources. *Ecological Engineering*, 16(1), 18.

Zalewski, M. (2002). Ecohydrology-the use of ecological and hydrological process for sustainable management of water resources. Hydrol sci J 47(5):825-834

Zalewski, M. Urbaniak, M. and Negussie, YZ (2010). Ecohydrological systemic solutions for reduction of siltation, eutrophication and dioxin-induced toxicity.The pilot study of the AsselaBioFarm Park Lake, Ethiopia.*Ecohydrology and Hydrobiology* 10 (2-4): 363 – 368.

Zalewski, M. 2015. Ecohydrology and hydrologic engineering: regulation of hydrology-biota interactions for sustainability. J. Hydrol. Eng. 20 (1), http://dx.doi.org/10.1061/(ASCE)HE.1943-5584.0000999.

Assessment of Citizen's Measurements Using Test Strips for Water Quality Monitoring in Medjerda Watershed (Northern Tunisia)

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Abstract

Citizen Science (CS) that is applicable to Water Quality Monitoring (WQM) is considered as an innovative approach to enhancement of the efficiency of hydrosystems' monitoring. The main objective of this study was to assess the quality of a CS-based WQM program based on water test strips for the Medjerda River, the main hydrosystem of Tunisia. The study focused on total alkalinity, nitrates and sodium chloride content. Three citizens participated in WQM with test strips, for wet and dry periods, using 96 samples collected and monitored in 12 sampling sites located in the Medjerda watershed. Regression analysis, based on Pearson Correlation Coefficient (PCC), determination coefficient (R^2), F test, and Cronbach's alpha (α_c) test were performed to statistically assess the difference between the citizens' datasets and the standard values. The results show that sodium chloride-sensitive test strips are the most reliable for measuring sodium chloride within wide range concentrations (0-7510 ppm). Nitrates-sensitive test strips are moderately reliable in the 0-25 ppm range. The total alkalinity-sensitive test strips are less reliable in the 3-20°F range concentration. Results also demonstrate a good agreement between the citizen-based outcomes and the analytical methods for the three citizens. However, the reliability depends on the citizen and the parameter to be tested. The test strips appear to be a suitable tool for WQM of the Medjerda watershed by citizens if the instructions of use are strictly followed. The latter can be achieved by a more consistent citizen training.

Keywords: Citizen Science, Water Quality Monitoring, Test Strips, Medjerda River, Tunisia.

1. Introduction

Water resources of Africa are subjected to many pressures that are related to urban growth and agricultural expansion which will be exacerbated by climate change (Bahri et al., 2016). These pressures jeopardise the attainment of the UN-Sustainable Development Goal 6 (SDG6) for clean water and sanitation. Efficient monitoring of water systems is pivotal for designing efficient water management strategies that alleviate the aforementioned pressures (Mutambara et al., 2016). Yet, water monitoring capacity in Africa is often very poor as a component of Water Quality Management (WQM).

Numerous analytical methods have been successfully developed for WQM. Besides measurements made gravimetrically and by titrimetry, advanced instrumental methods including electrochemical techniques, colorimetric and fluorescent probes, high performance liquid chromatography and atomic absorption spectrometry, have been used for water quality analysis (Sperling et al., 1992; Gupta et al., 2013; Ozdemir et al., 2016; Dopico et al., 2002; Siraj and Kitte, 2013; Bartram and Balance, 1996). These analytical techniques indicate the advantages of high sensitivity, accuracy, selectivity, versatility, and reliability. Nevertheless, there are limitations such as the need for expensive and complex pre-treatment process and requirement of highly qualified technical personnel (Cummings, 2010). As an alternative to traditional WQM, Citizen Science (CS) has been evolving over the last decade. It is a novel way of environmental monitoring and capacity building. CS uses smart and cost-effective technologies as tools for data collection (Buytaert et al., 2014; Walker et al., 2016; Fehri et al., 2020a; Fehri et al., 2020b). This concept was introduced in WQM in order to strengthen the local and international efforts aimed at achieving consistent monitoring of the quality of water bodies and for application to existing water quality databases (Njue et al., 2019; Jollymore et al., 2017; Farnham et al., 2017; Capdevila et al., 2020).

Water quality test strips (WQS) for on-site WQM can be used as an alternative CS tool for WQM. WQS for WQM programs have short response time; they are easy to use; they have a low bio-toxicity, and they are considered as low-cost tools (Forest et al., 2006). WQS have been used to analyze various species of free chlorine, hydrogen sulfide and formaldehyde (Arsawiset and Teepoo, 2020), tetracycline antibiotics (Li et al., 2019), Hg (II) ions (Lan et al., 2018), Zn (II) ions (Takahashi, 2014), microcystins (Humpage et al., 2012), hypochlorite (Ballesta Claver et al., 2004), water hardness (Capitán-Vallvey et al., 2003) and microorganisms (Martins et al., 1997). The reliability of WQS for WQM was assessed against laboratory-based standard methods (Naigaga et al., 2016; Mosley and Donald, 2005; Bischoff et al., 1996). However, test strips lack selectivity of detection due to the random diffusion of chromogenic reagents in the detection zone in the presence of common interfering agents (Evans et al., 2014). Given the stability and the highly portable nature of WQS, they could be easily used by everyday citizens in the framework of CS-based WQM programs (Gagnon et al., 2007). Capdevila et al. (2020) further identified attributes of the citizens, attributes of institutions, and the interactions between citizens and institutions as additional factors that determine the success of a CS-based WQM program.

The utility of CS is based on the potential social benefits of engaging, collaborating and actively involving citizens in data collection and knowledge generation. The quality of CS-based WQM is different when the system is compared to reference WQM. Hence, WQS programs need to be thoroughly validated. The main objective of this study was to validate the WQS as CS-based WQM program for the Medjerda watershed in Tunisia.

2. Materials and methods

The quality of a CS-based WQM program based on WQS for the Medjerda watershed in Northern Tunisia (Figure 1) was assessed. The study focused on total alkalinity, nitrates and sodium chloride content. Three citizens participated in the monitoring program in which WQS were used as the main data collection tool. The volunteers were selected on the basis of their motivation and ability to apply and read the WQS. A short training program was organized to ensure a good reliability of test strip readings. Overall, 96 samples were collected for water quality monitoring from 12 sampling sites on the Medjerda River, referred to as: Utique, Kantaret Binzart, Medjez El Bab, Slouguia, Siliana GP5, Ain Younes, Ain Jemmala, Tessa Sidi Medien, Tessa N5-Sers, Upstream Tessa-Zouarines, Rmal-Route Sakiat and Sarrath Pont Route. Site selection was based on the required spatial distribution of the volunteers and the availability of reference WQM stations.

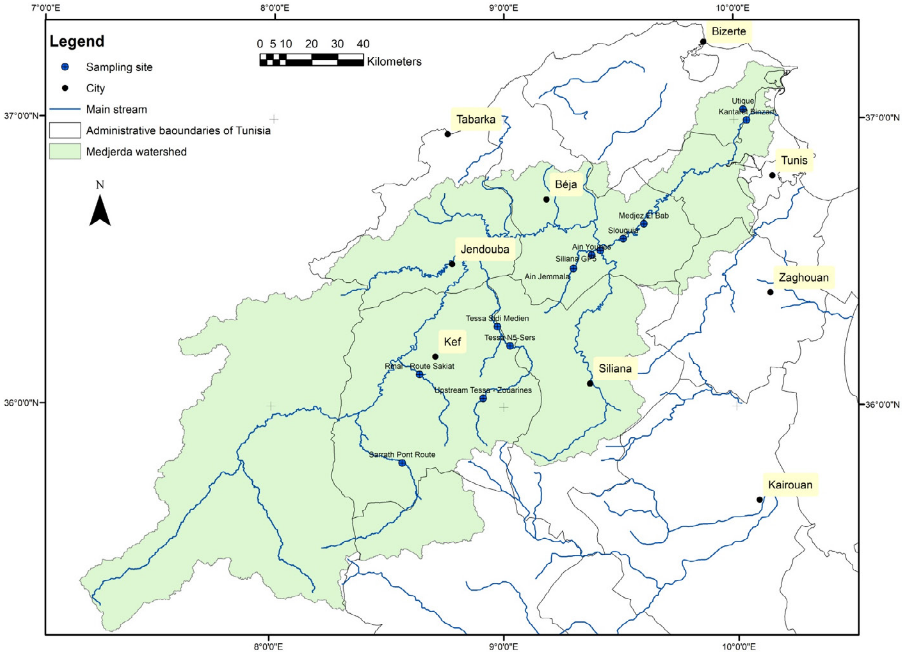

Figure 1. The study area indicating sampling sites in the main stream of Medjerda watershed

The main characteristics of the sampling sites are summarized in Table 1. Two sites are located in Medjerda downstream and two others in the Mid Valley of the basin. The remaining sites are located on its main tributaries (Siliana, Khalled, Tessa and Mellegue).

Table 1. Main characteristics of the sampling sites

Name	Geographic coordinates		Altitude (m asl)	Sub-watershed
	Latitude	Longitude		
Utique	37°2’8.16”	10°2’29.52”	28	Medjerda downstream
Kantaret Binzart	36°59’50.54”	10°3’22.16”	21	Medjerda downstream
Medjez El Bab	36°38’19.32”	9°36’26.13”	46	Medjerda Mid Valley
Slouguia	36°38’19.32”	9°31’26.14”	55	Medjerda Mid Valley
Siliana GP5	36°32’45.96”	9°25’4.45”	75	Siliana
Ain Younes	36°31’14.28”	9°31’0.76”	133	Khalled (spring)
Ain Jemmala	36°29’3.12”	9°18’4.86”	239	Khalled
Tessa Sidi Medien	36°16’54.12”	8°58’22.42”	299	Tessa
Tessa N5-Sers	36°12’52.92”	9°1’38.94”	567	Tessa
Upstream Tessa -Zouarines	36°1’53.04”	8°54’41.99”	657	Tessa
Rmal - Route Sakiat	36°38’19.73”	8°38’19.73”	357	Mellegue
Sarrath Pont Route	35°48’20.16”	8°33’55.65”	576	Mellegue

Surface water samples were taken and analyzed immediately in the laboratory. Water concentration levels for total alkalinity, nitrates, and sodium chloride were determined using standard reference techniques. The standard method for total alkalinity was titration with standard hydrochloric acid N/50 to the methyl orange endpoint. Sodium chloride concentration was analyzed using the titration method with silver nitrate N/10. Nitrates concentration was measured by molecular absorption spectrometry for λ=415 nm (Rodier et al., 2009). Additionally, parameters were also determined by two brands of WQS: test strips 6 in 1 of Aqua Velda™ and test for salt as sodium chloride of Aquachek™. WQM tests were performed for wet (January-March 2020) and dry (June-July 2020) periods. All the Aqua Velda test strips were immersed for 1-second in the sampled water, then shaken to remove the excess water. After waiting for 1 minute, the colors of the strips were compared with the color scale (Figure 2). Statistical analysis of the assessment of citizen's measurements was performed. Regression analysis, based on Pearson Correlation Coefficient (PCC), determination coefficient (R^2), F test, and Cronbach's alpha (α_c) test were applied to statistically assess the difference between the citizens' datasets and the standard values.

3. Results

3.1. Reliability of test strips in WQM of the Medjerda watershed

Results show a high correlation between data collected from WQS and those obtained from standard analytical methods (Table 2). The total alkalinity-sensitive test strips are less reliable in the 3-20°F concentration range. Nitrates-sensitive test strips are moderately reliable in the 10-25 ppm concentration range. The results show also that sodium chloride-sensitive test strips are the most reliable for measuring a wide range concentration (0-7510 ppm). The highest agreement between test strips and the standard method (PCC (0.962), R^2 (0.926), and α_c (0.982)) is obtained for sodium chloride.

3.2. Agreement between the citizen-based outcomes and the analytical standard

Agreement between the three citizen's readings and the analytical standard methods is observed by the comparison of the means and standard deviations of total alkalinity, nitrates and sodium chloride contents. The result show moderate to very good agreement between the results of citizen-based monitoring and the analytical standard methods. There is a good agreement between data on the three parameters obtained from the analytical standard methods and those collected by the three citizens. Water Test Strips (WTS) readings are underestimated for citizen (1) and citizen (2) and are overestimated for citizen (3) compared to analytical standard methods, particularly for sodium chloride. Nevertheless, the observed reliability is not dependent on the parameters of interest or even the identity of any of the three citizens (Figure 3, Figure 4 and Table 3).

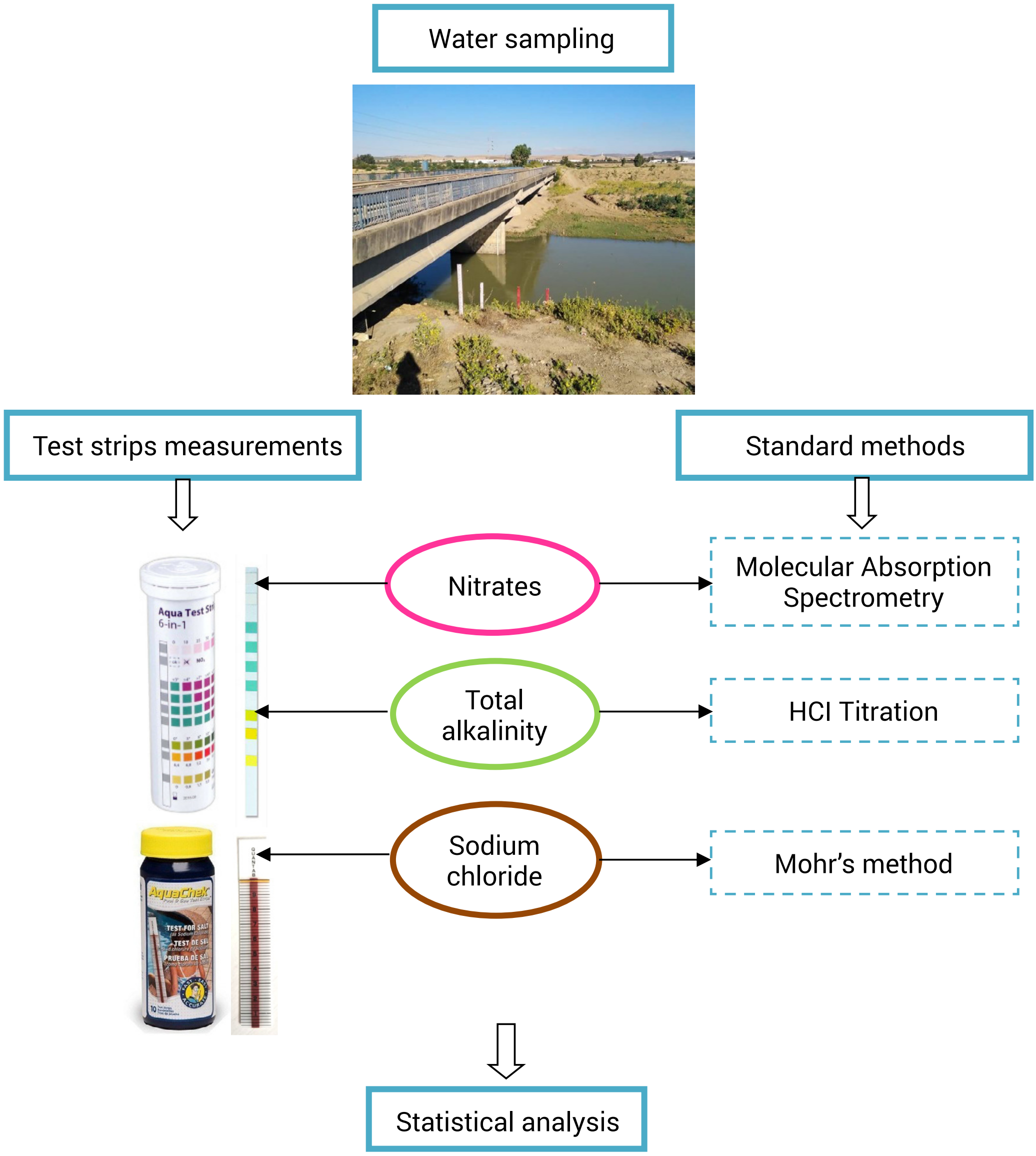

Figure 2. Methodology flowchart for test strips' reliability

Table 2. Results of statistical analyses testing reliability of water test strips

Parameter	α_c	F test	Prob	R²	PCC	Equation
Total alkalinity	0.918	2292.60	0.000	0.694	0.833	$Al_{WQS}=0.950 \times Al_{Standard}+1.000$
Nitrates	0.931	238.49	0.000	0.750	0.866	$N_{WQS}=0.940 \times N_{Standard}-1.162$
Sodium chloride	0.982	1187.41	0.000	0.926	0.962	$NaCl_{WQS}=0.970 \times NaCl_{Standard}+503.834$

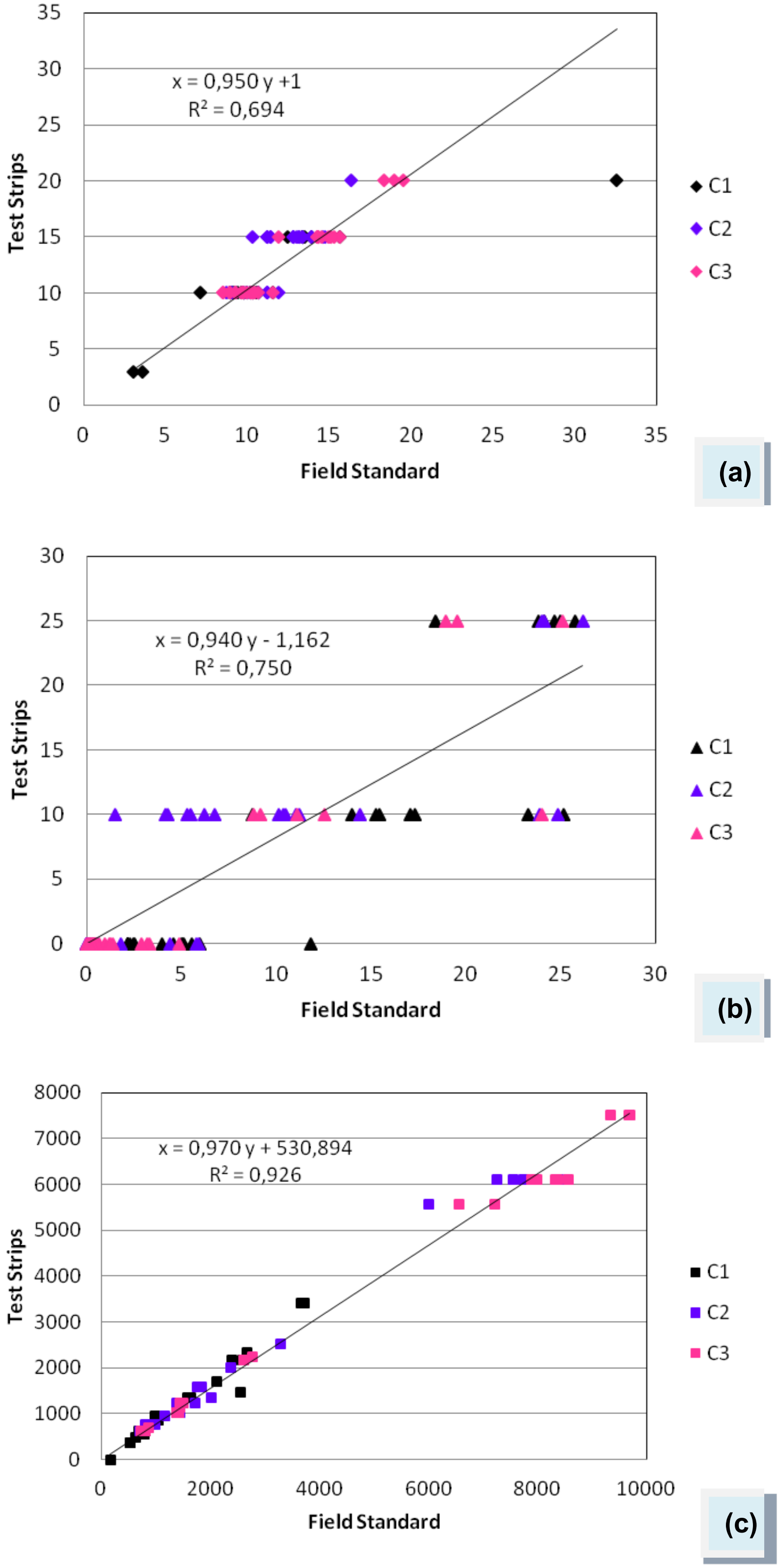

Figure 3. Plot for test strips versus field standard methods for the three citizen's readers (a) total alkalinity, (b) nitrates and (c) sodium chloride

Figure 4. Boxplots of total alkalinity (a), nitrates (b) and sodium chloride (c) for test strips versus field standard methods for the three citizen's readers

Table 3. Comparison of the average and standard deviation of total alkalinity, nitrates and sodium chloride among three citizens (numbers between parentheses indicate the number of collected observations for each citizen)

Parameter		Citizen 1 (33)		Citizen 2 (31)		Citizen 3 (32)	
		Test Strips	Standard	Test Strips	Standard	Test Strips	Standard
Total Alkalinity	Average	10.90	11.20	12.88	11.52	12.53	12.13
	Standard deviation	3.35	4.66	2.79	1.94	3.36	3.22
Nitrates	Average	7.34	10.40	7.57	8.17	4.49	5.28
	Standard deviation	9.60	9.27	7.62	8.49	7.80	7.44
Sodium chloride	Average	1088.67	1263.56	2754.86	3475.07	3767.29	2897.70
	Standard deviation	813.33	912.34	2360.91	3006.36	3511.78	2673.44

4. Discussion

The test strips and the standard laboratory methods were used to perform on-site analyses total alkalinity, nitrates and sodium chloride parameters for three volunteers in the framework of the WQM program of Medjerda watershed. Results indicate good agreement between data obtained from WQS and those from standard analytical methods. The total alkalinity-sensitive test strips are less reliable in the 3-20°F concentration range. The limited performance of the test strips for total alkalinity analyses may have resulted from the fact that the range of concentration of this parameter in Medjerda watershed has been often not high enough for assessing the reliability over their entire analytical range. Earlier comparison of the reliability of the WTS revealed that test strips generally gave a substantial agreement with the standard methods for total alkalinity (Naigaga et al., 2016). Nitrates test strips provide slight reliability in the 0-10 ppm NO_3^- concentration range where one method indicated zero nitrates while the standard revealed measurable concentrations. However, the agreements are best for intermediate to high nitrates concentrations (i.e., 10 to 25 ppm NO_3^-). Thus, the test strips may be most appropriate for preliminary analyses of large numbers of field water samples of low to intermediate nitrates content while; for relatively low nitrates concentration (< 10 ppm NO_3^-), the test strips may be inappropriate for their use in water quality monitoring. Previous results of studies by Bischoff et al. (1996) and Forest et al. (2004) revealed the importance criticality of interpretation of the test strip readings, especially in the range of 10 ppm NO_3^-, the upper health advisory limit for nitrates in ground water. The inferior reliability of test strips for nitrates compared to standard methods may be due to the presence of common interfering colloids agents (Forest et al., 2004). Other strips, such as API™ five-in-one aquarium and Tetra Easy™ six-in-one aquarium test strips, have been found not to agree with the standard methods for nitrates (Naigaga et al., 2016). The results show also that sodium chloride-sensitive test strips are the most reliable for measuring a wide range of concentrations (0-7510 ppm) with the highest correlation parameters (PCC (0.962), R^2 (0.926), and α_c (0.982)). Evaluation of the test strips used in WQM of Medjerda watershed show that this quick test is reasonably reliable for use in obtaining analytical information on the variability of sodium chloride concentration of the river.

The citizens' outcomes were compared to traditional analysis of total alkalinity, nitrates and sodium chloride by standard analytical methods. The agreement found between the citizen-based estimates and those of the analytical methods show good prospects for using the citizen's method for the determination of water quality parameters in the Medjerda watershed without the expense involved in a detailed laboratory analysis. Good agreement was also obtained between nitrates data collected by citizens (test strips' measurements) and those from measurements by high performance liquid chromatography and colorimetric analysis using a colorimetric ion analyzer (Bischoff et al., 1996). The implication of non-technical staff can use the test strips to determine reliable nitrates concentrations when screening wells prior to designing field data collection. This observed reliability seems to be affected neither by the citizen nor by the parameter to be tested. Safe use of the test strips can also be relied upon with even minimal training of volunteers to produce accurate readings of the test strips (Mosley and sharp, 2005).

5. Conclusions

This study presents the evaluation of a ready-to-use test strips based method for monitoring total alkalinity, nitrates and sodium chloride in water t of the Medjerda watershed in Northern Tunisia. The evaluation shows that these tools could be reliable for obtaining the concentrations of sodium chloride as well as nitrates and alkalinity. It is hereby concluded that while standard methods are more reliable, rapid and simple measurements using the test strips can be conveniently used by citizens for WQM if they correctly follow the manufacturer's instructions. With adequate training of users, the test strips should allow for a reliable, sensitive, and precise monitoring of water quality. The test strip procedure offers sufficiently good reliability, simplicity of use, environmentally friendliness (recyclable paper strips), and may be considered as an inexpensive alternative for obtaining analytical information within the framework of CS-based WQM program. The use of the test strips by non-technical staff could be relied upon to produce accurate results and would also save time and cost. In follow-up research, a larger group of citizens from different generations and educational levels will be engaged in the monitoring process before implementing a regional WQM program.

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References

Arsawiset, S., Teepoo, S. (2020). Ready-to-use, functionalized paper test strip used with a smartphone for the simultaneous on-site detection of free chlorine, hydrogen sulfide and formaldehyde in wastewater. *Analytica Chimica Acta,*(1118), 63-72. doi.org/10.1016/j.aca.2020.04.041

Bahri, A., Brikké, F., Vairavamoorthy, K. (2016). Managing Change to Implement Integrated Urban Water Management in African Cities World Water Week 2015, WWW 2015.*Aquatic Procedia,*(6), 3-14. doi: 10.1016/j.aqpro.2016.06.002

Ballesta Claver, J., Valencia Miron, M.C., Capitan Vallvey, L.F. (2004). Determination of hypochlorite in water using a chemiluminescent test strip. *Analytica Chimica Acta,*(522)2, 267-273. doi:10.1016/j.aca.2004.06.051

Bartram, J., Ballance, R. (1996). Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes Chapter 8 - Advanced instrumental analysis Published on behalf of United Nations Environment Programme and the World Health Organization © 1996 UNEP/WHO ISBN 0 419 22320 7 (Hbk) 0 419 21730 4 (Pbk)

Bischoff, M., Hiar, A.M., Turco, R.F. (1996). Evaluation of nitrate analysis using test strips: Comparison with two analytical laboratory methods. *Communications in Soil Science and Plant Analysis,*(27)15-17, 2765-2774. doi: 10.1080/00103629609369739

Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T.C., Bastiaensen, J., De Bièvre, B., Bhusal, J., Clark, J., Dewulf, A., Foggin, M., Hannah, D.M., Hergarten, C., Isaeva, A., Karpouzoglou, T., Pandeya, B., Paudel, D., Sharma, K., Steenhuis, T., Tilahun, S., Van Hecken,G., Zhumanova, M. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science*,(2)26. doi.org/10.3389/feart.2014.00026

Capdevila, A.S.L., Kokimova, A., Ray, S.S., Avellán, T., Kim, J., Kirschke, S. (2020). Success factors for citizen science projects in water quality monitoring. *Science of the Total Environment*,(728)137843. doi:10.1016/j.scitotenv.2020.137843

Capitán-Vallvey, L.F., Fernández-Ramos, M.D., Alvarez de Cienfuegos Gálvez, P., Santoyo-González, F. (2003). Characterisation of a transparent optical test strip for quantification of water hardness. *Analytica Chimica Acta,*(481)1, 139-148. doi:10.1016/s0003-2670(03)00073-4

Cummings, W.G., Verhappen, I. (2010).Chemical Analysis, *Instrumentation Reference Book,* 327-339. doi:10.1016/b978-0-7506-8308-1.00022-x

Dopico, M.S., González, M.V., Castro, J.M., González, E., Pérez, J., Rodríguez, M., Calleja, A. (2002). Determination of Triazines in Water Samples byHigh-Performance Liquid Chromatography with Diode-Array Detection. *Journal of Chromatographic Science,*(40), 523-528, October 2002.

Evans, E., Gabriel, E.F.M., Benavidez, T.E., Coltro, W.K.T., Garcia, C.D. (2014).Modification of microfluidic paper-based devices with silica nanoparticles. *The Analyst,*(139)21, 5560-5567. doi:10.1039/c4an01147c

Farnham, D.J., Gibson, R.A., Hsueh, D.Y., McGillis, W.R., Culligan, P.J., Zain, N., Buchanan, R. (2017). Citizen science-based water quality monitoring: Constructing a large database to characterize the impacts of combined sewer overflow in New York City. *Science of the Total Environment,*(580),168-177. doi:10.1016/j.scitotenv.2016.11.116

Fehri, R., Khlifi, S., Vanclooster, M. (2020a).Testing a citizen science water monitoring approach in Tunisia. Environmental Science and Policy, (104), 67-72. doi:10.1016/j.envsci.2019.11.009.

Fehri, R., Bogaert, P., Khlifi, S., Vanclooster, M. (2020b). Data fusion of citizen-generated smartphone discharge measurements in Tunisia. *Journal of Hydrology,* (590), 125518. doi:10.1016/j.jhydrol.2020.125518.

Isbell, F.I., Mercer, D.R., Iqbal, M.Z. (2006). Reliability of Water Quality Test Strips for Field Measurement of Nutrients Essential for Developing Mosquito Larvae. American Journal of Undergraduate Research, Vol 5, N° 2, 8p.

Gagnon, B., Marcoux, G., Leduc, R., Pouet, M.F, Thomas, O. (2007). Emerging tools and sustainability of water-quality monitoring. *Trends in Analytical Chemistry,*(26)4, 308-314. doi:10.1016/j.trac.2006.11.009

Gupta, V.K., Singh, A.K., Ganjali, M.R., Norouzi, P., Faridbod, F., Mergu, N. (2013). Comparative study of colorimetric sensors based on newly synthesized Schiff bases. *Sens. Actuators* B,(182), 642-651.

Humpage, A.R., Froscio, S.M., Lau, H.M., Murphy, D., Blackbeard, J. (2012). Evaluation of the Abraxis Strip Test for Microcystins for use with wastewater effluent and reservoir water. *Water Research,*(46)5, 1556-1565. doi:10.1016/j.watres.2011.12.015

Jollymore, A., Haines, M.J., Satterfield, T., Johnson, M.S. (2017). Citizen science for water quality monitoring: Data implications of citizen perspectives. *Journal of Environmental Management,* (200),456-467. doi:10.1016/j.jenvman.2017.05.083

Lan, L., Niu, Q., Li, T. (2018).A highly selective colorimetric and ratiometric fluorescent probe for instantaneous sensing of Hg2+ in water, soil and seafood and its application on test strips. *Analytica Chimica Acta,*(1023), 105-114. doi:10.1016/j.aca.2018.03.023

Li, C., Zeng, C., Chen, Z., Jiang, Y., Yao, H., Yang, Y., Wong, W.T. (2019). Luminescent lanthanide metal-organic framework test strip for immediate detection of tetracycline antibiotics in water. *Journal of Hazardous Materials,*(384), 121498. doi:10.1016/j.jhazmat.2019.121498

Martins, M.T., Castillo, G., Dutka, B.J. (1997). Evaluation of drinking water treatment plant efficiency in microorganism removal by the coliphage, total coliform and H2S paper strip tests. *Water Science and Technology,*(35)11-12, 403-407. doi:10.1016/s0273-1223(97)00293-x

Mosley, L.M., Donald, S.S. (2005). The hydrogen sulphide (H2S) paper-strip test: a simple test for monitoring drinking water quality in the Pacific Islands, SOPAC Technical Report 373, 21 p, ISSN: 1605-4377

Mutambara, S., Darkoh, M.B.K., Atlhopheng, J.R. (2016). A comparative review of water management sustainability challenges in smallholder irrigation schemes in Africa and in Asia. *Agricultural Water Management,*(171), 63-72. doi:10.1016/j.agwat.2016.03.010

Naigaga, S., Boyd, C.E., Gaillard, P., Abdelrahman, H.A., Molnar, J.J. (2016). Assessing the Reliability of Water-Test Kits for Use in Pond Aquaculture. *Journal Of The World Aquaculture Society,*(48)4, 555-562. doi: 10.1111/jwas.12377

Njue, N., Kroese, J.S., Gräf, J., Jacobs, S.R., Weeser, B., Breuer, L., Rufino, M.C. (2019). Citizen science in hydrological monitoring and ecosystem services management: State of the art and future prospects. *Science of the Total Environment,*(693), 133531. doi:10.1016/j.scitotenv.2019.07.337

Ozdemir, M. (2016). A rhodamine-based colorimetric and fluorescent probe for dual sensing of Cu2+ and Hg2+ ions. *J. Photochem. Photobiol,* A. (318), 7-13.

Rodier, J., Legube, B., Merlet, N., Brunet, R., Mialocq, J.C., Leroy, P., Houssin, M., Lavison, G., Bechemin, C., Vincent, M., Rebouillon, P., Moulin, L., Chomodé, P., Dujardin, P., Gosselin, S., Seux, R., Almardini, F. (2009). L'analyse de l'eau: Eaux naturelles, Eaux résiduaires, Eau de mer, 9ème Edition, Dunod, Paris, France, 1579p

Siraj, K., Kitte, S.A. (2013). Analysis of Copper, Zinc and Lead using Atomic Absorption Spectrophotometer in ground water of Jimma town of South western Ethiopia. International *Journal of Chemical and Analytical Science,*Volume 4, Issue 4, December 2013, Pages 201-204. doi:10.1016/j.ijcas.2013.07.006

Sperling, M., Xu, S., Welz, B. (1992). Determination of chromium (III) and chromium (VI) in water using flow injection on-line preconcentration with selective adsorption on activated alumina and flame atomic absorption spectrometric detection. *Anal. Chem.,*(64), 3101-3108.

Takahashi, Y. (2014). Dye Nanoparticle-Coated Test Strips for Detection of ppb-Level Ions in Water, Nanotechnology Applications for Clean Water, 2nd Edition, 63-72. doi:10.1016/B978-1-4557-3116-9.00004-4

Walker, D., Forsythe, N., Parkin, G., Gowing, J. (2016). Filling the observational void: scientific value and quantitative validation of hydrometeorological data from a community-based monitoring programme. *Journal of Hydrology,* (538), 713-725. doi:10.1016/j.jhydrol.2016.04.062.

F. WATER EDUCATION, A KEY TO WATER SECURITY

Youth and Childhood Education on Water Security: A Review of Research Literature

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Abstract

Water security is key to planetary resilience for human society to flourish in the face of global change. However, the state of water security across the globe continues to deteriorate at an alarming rate due to a complex web of social-ecological challenges. Water education seems to be an efficient solution to the problems related to water and the environment as it enables individuals to recognize many factors causing water problems in the society they live in and therefore start to create solutions. Especially, water education for children and the youth is significant as today's youth will, sooner or later, decide on the future use of water resources. In this study, literature on water education among children and the youth is examined. The results show that several factors determine individual's awareness, behaviors and attitude towards water, including age, school level, gender and willingness to pay for water fees. The studies evaluated also reveal that the implementation of water education is done in various forms, including lecturing as well as practical activities that seem to specially promote interest of water education among learners. Further, water education is effective in changing learners' awareness, conceptions, attitudes and behaviors towards water, as all eleven studies on the topic find positive results for water education outcomes. Particularly, the introduction of water education in the early years is noted as significant as it may affect how learners view and interact with water as adults.

Keywords: Water security, water education, youth and children.

1. Introduction

Water security is key to planetary resilience for human society to flourish in the face of global change (Keys et al., 2019). Humans depend on water for almost everything, and as noted by Vogel et al. (2015), the story of water and man is nearly as old as the story of human civilization. The state of water security across the globe, however, continue to deteriorate at an alarming rate due to a complex web of social-ecological challenges including, but not limited to, population growth, rising living standards, increasing demands and rising costs of food and energy, urbanization, and land use changes (Ardoin and Bowers, 2020). As such, the concept of water security has received increased attention in recent years in both policy and academic debates (Nepal et al., 2019).

There is increasing recognition of the role of humans in human-environment systems, whereby human impacts on the terrestrial hydro-sphere are now so widespread that it is difficult to find a watershed or aquifer that does not reflect interaction among human and natural hydrologic processes (Forbes et al., 2018; Vogel et al., 2015). As such, humans are inseparable from natural water systems (Forbes et al., 2018). Therefore, protecting and restoring water security will require transformative changes in human production and consumption behaviors, reflecting on individual choices as well as large-scale, cultural and mediated collective action (Ardoin and Bowers, 2020).

1.1. Water education as an approach to addressing water security

Being that water has impacts in many sectors from health and energy to culture and the economy, water literacy is an educational need (Sherchan et al., 2016). Water education seems to be an efficient solution to the problems related to water and the environment, and in many countries, many water education programmes have been developed and conducted for more than two decades (Zhan et al., 2019). By conducting water education, individuals can recognize many factors causing water problems in the society they live in and therefore will start to create solutions (Çoban et al., 2011). Also, water education enhances long-term changes in attitudes, knowledge and behaviors around water resources concerns, as well as creating citizens with readiness to take action on water issues (Amahmid et al., 2019). Water education is relevant throughout the life course, with lifelong engagement being particularly important as the scientific and social conditions around environmental and sustainability issues shift, requiring continued critical thinking, engagement, and decision-making not only as individuals, but also within communal settings (Ardoin and Bowers, 2020). Therefore, as a permanent solution for the problems related to water, it is necessary to educate people on the subjects related to water (Çoban et al., 2011; Davis et al., 2008; Ji, 2014).

1.2. Water education for the youth

Today's youth will, sooner or later, decide on the future use of water resources and the most efficient way to equip the next generation with knowledge and attitudes that promote the wise use of water and appropriate behavior is through educating the youth at school (Amahmid et al., 2019; Schaap and Van Steenbergen, 2002). Environmental education researchers and practitioners have found that it is during early educational grades that the young can acquire lifelong learning and awareness, and make more informed value judgements based on a valid knowledge of water-related concepts (Amahmid et al., 2019; Ardoin and Bowers, 2020; Çoban et al., 2011; Dieser and Bogner, 2016; Ji, 2014). Childhood experiences in nature have been associated with the nascence of adult water and environmental concern and participation in environmental behaviors (Amahmid et al., 2019; Ardoin and Bowers, 2020). Furthermore, students educated on the benefits of water conservation may carry those messages far beyond the school walls, therefore bringing lasting improvement even to their families and wider community (Amahmid et al., 2019; Ji, 2014). Justifiably, increasing attention is being given these days to the education of children and youth on water related topics (Amahmid et al., 2019).

Various studies have focused on finding out the status of water education in school curricula (Amahmid et al., 2019; Ardoin and Bowers, 2020; Cockerill, 2010; Martínez-Borreguero et al., 2020), the process of developing and reinvigorating environmental education (Lotz-Sisitka et al., 2020; Scott and Reid, 1998), assessing young people's conceptions of sustainable water use (Benninghaus et al., 2018) as well the impact of water education among young learners (Çoban et al., 2011; Dieser and Bogner, 2016; Thompson and Serna, 2016). Although many studies have focused on water and environment education, there are barely any reviews of research in water education. Existing reviews focus on environmental education which entails a broader range of topics, including early childhood environment education (Ardoin and Bowers, 2020), education for sustainable development (Hedefalk et al., 2015), and teaching methods in environmental education (Monroe et al., 2019).

Motivated by the existing gaps in literature, a systematic review of water education literature with the intention of researching empirical outcomes related to water education programs and practices was undertaken. In particular, effort was made to identify major outcomes and practices of interest in water education studies. The research questions guiding this review were: (a) What practices have been reported in published water education research? and (b) What outcomes and associated findings have been reported in published water education research?

2. Methods

Systematic review methods are increasingly being used to comprehensively assess the current state of knowledge by applying rigorous, objective and transparent steps and criteria to reach conclusions from a body of scientific literature (Honingh et al., 2020; Petticrew and Roberts, 2008). In contrast to a traditional literature review, a systematic literature review aims to avoid any bias, intentional or unintentional, in the selection of the publications by identifying all likely relevant literature in transparent and explicit steps (Honingh et al., 2020; Petticrew and Roberts, 2008). In environmental education studies, such systematic reviews are growing in popularity because of their effectiveness in presenting a comprehensive synthesis of evidence (Bilotta et al., 2014).

The first step in this study was to design review protocols to ensure a transparent and rigorous selection of studies on water education for the young. We adopted a broad conceptualization of water education as encompassing those school programs in primary, secondary, and university levels and learning experiences designed with the goal of creating water literate, engaged youth. Literature was selected using two main inclusion criteria: (a) reviews, editorials, peer-reviewed articles, published and online first, to ensure the quality of the included articles (Honingh et al., 2020); (b) articles explicitly designed to investigate water education among young people. We used terms to narrow the scope to studies focused on water education and youth and childhood water-related studies. As recommended by (Ardoin and Bowers, 2020), we selected the search terms through review of titles, abstracts, and keywords of articles already identified as relevant as well as results of exploratory searches. We performed the searches in two databases: The Web of Science (WOS), one of the largest scientific databases for social research; and Educational Resource Information Centre (ERIC), the domain-specific database that collects only educational research (Honingh et al., 2020).

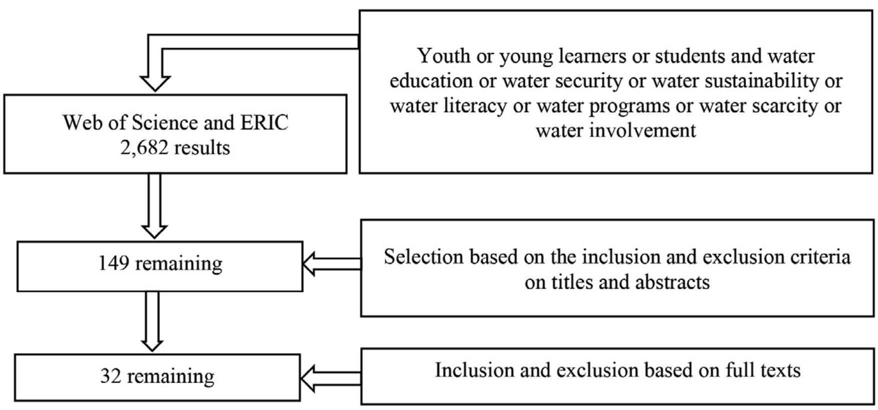

Figure 1. Schematic representation of the systematic literature selection

Table 1. Themes addressed in the study

Data on water education	Frequency
Water awareness/conception/attitude among students	13
Water education in primary, secondary and university curriculum	18
The effects of water education on students	11
Total	32

Some articles address more than one theme. We identified 3 themes in the 32 articles under study.

3. The Results

3.1. Water awareness, conception, and attitude among students

In the majority of the articles on water education among students, common themes include water awareness, conception, and attitude (Amahmid et al., 2019; Benninghaus et al., 2018; Covitt et al., 2009; Kacoroski et al., 2016; Zhan et al., 2019). Humans are affiliated with nature, which makes them constantly aware of their environmental surroundings. Indeed, various studies show that virtually all students have some important understandings and awareness of water (Amahmid et al., 2019; Aydogdu and Çakir, 2016; Benninghaus et al., 2018; Covitt et al., 2009). This understanding and awareness seem to differ among learners, with some having scientific and personal conceptions as well as high and low levels of knowledge about water issues. Age and level of study are also a significant factor and older learners seems to have a better understanding of water. A study that assessed students from upper elementary school through high school in the United States revealed that although all students had some important understanding of water, the depth of their understanding varied with school level (Covitt et al., 2009). High school students had a better understanding of the chemical and physical nature of water, conservation and treatment of water, while younger elementary learners only had a basic understanding of water. This phenomenon is echoed by a study on Chinese elementary school children's preliminary understanding of water and its conservation, which reveals that the young learners' understanding of water is simple and incomplete (Zhan et al., 2019). The young learners conveyed an understanding of water which included water sources and creatures, but were less aware of the importance of water for human beings (Zhan et al., 2019). In a study of primary and lower secondary school students in Morocco, Amahmid et al. (2019) revealed that the students' knowledge on water topics was low, and only 45% of them were aware about the alarming decreasing trend in water availability. A recent study by Martínez-Borreguero et al. (2020) among secondary school students in Spain analysed the cognitive demand required of students for learning about water and revealed that lower levels of knowledge and comprehension predominate. The lack of systematic understanding of water makes it difficult for young learners to trace and conserve water (Covitt et al., 2009; Zhan et al., 2019).

Various studies show that students at different levels of school have preconceptions about water issues, which according to Reinfried et al. (2012) can have a deleterious effect on people's understanding of the scientific facts and their interrelations that are of relevance to sustainable water management. In Finland, a study on pupils' conceptions of water-related issues before a Science, Technology and Society instruction program shows that pupils' conceptions of water were only descriptive and were situated in regard to their everyday lives, and pupils considered their water-use subjectively (Havu-Nuutinen et al., 2018). Further, pupils rarely were able to explain the relationship between concepts and phenomena (Havu-Nuutinen et al., 2018). In a study among lower secondary school students in Switzerland, (Reinfried et al., 2012) found that although half of the students had some basic hydrological knowledge, several preconceived notions that can impede the understanding of hydrological concepts were found. A common preconception concerned the idea that solid rocks cannot be permeable and that large underground cavities constitute a necessary precondition for the formation of springs (Reinfried et al., 2012). A recent study among high school students in Germany revealed that although the students' conceptions are similar to scientific concepts, they also have their own conceptions (Benninghaus et al., 2018). The conceptions indicated that participants regard the entire African continent as affected by water scarcity, which for most of the students, was not strictly a construct of climate geography, but rather they also network social and economic nuances into their response. In Israel, Ben-zvi-Assarf and Orion (2005) revealed that junior high school students lacked the dynamic, cyclic, and systematic perceptions of the system, and that they possessed an incomplete picture of the water cycle including many preconceptions and misconceptions about it.

The studies reveal both positive and poor students' attitude towards water. Lucio et al., (2018) conducted a survey on Italian university students aimed at examining the relationships between attitudes towards water conservation, incorporation of supplementary costs into water prices, and willingness to pay for water services. The study shows family values as well as willingness to pay for water services as key determinants of pro-environmental behaviours. In Morocco, Amahmid et al. (2019) reveal that while students' attitudes towards water were positive, their water use habits did not match their attitudes as up to 70% of the investigated students showed water wasting practices. Another study, through assessment of the ratio of students' personal water consumption, reveals that only few students have a realistic conception of the ratio; this can be explained by the fact that they only have a limited awareness of the significance and consequences of this ratio (Benninghaus et al., 2018). These poor attitudes towards water could also be attributed to a gap that exists between students' knowledge, awareness and behaviour. The knowledge lack may affect negatively the establishment of water awareness and positive attitudes as well as behaviours in relation to water issues (Amahmid et al., 2019).

Interestingly, a study among secondary school students in Turkey revealed gender differences in the students' awareness towards water, whereby female students had significantly higher levels of awareness of water than male ones (Aydogdu and Çakir, 2016). This has been noted previously by other studies (Gopinath, 2014; Lucio et al., 2018; Middlestadt et al., 2001; Zhan et al., 2019), which reveal that gender plays an important role in the use of environmental resources, with girls showing greater awareness than boys in environmental awareness. This phenomenon is attributed to the fact that female students approach house holding more sensitively and mindfully than their males in the society in which they live (Aydogdu and Çakir, 2016).

3.2. Water education in primary, secondary and university curriculum

Water education is included in school curricula in a myriad of ways, and conducted in various forms of teaching, including physical and online classes, field visits, experiments, as well as short-term and long-term school programmes. It is also included in subjects like Science, Biology, Geography, and Chemistry as well as in multi and interdisciplinary approaches.

Articles reveal that water education is included in various subjects and topics. In the United States, a review of water resources education among 129 Geography Departments reveal that the majority of water-related courses focused on climatology or climate change, suggesting that students are regularly provided opportunities to learn about water topics primarily through the lens of climatology and water resources (Pease et al., 2019). Özalemdar (2019) investigate the units and topics that include the concept of water within 9th, 11th, and 12th grades' biology textbooks. The study reveals that these units and topics address the structure and characteristics of water; its role on nutrition, respiration, circulation, metabolic events; its significance on living structure, natural sciences; and its relationship with osmotic pressure and some structures of living beings. The findings also reveal that water has a special place in biology education and biology education is an important tool in conveying the significance of water for the living beings. This is echoed by Fuentes and Entezari (2020) who present laboratories in introductory Biology as ways for students to study water. Irvine et al., (2015) give a reflection on water resources education in Singapore. They state that water education in Singapore has been forward-thinking in integrating and scaffolding multidisciplinary elements at all levels, from primary through civil society. Martínez-Borreguero et al. (2020) analyse the presence of the concept of water in the curriculum that regulates secondary education in Spain. The study shows that the concept of water appears moderately in the curriculum focusing on some aspects of sustainable development. Amahmid et al. (2019) explore the status of water education in Moroccan curricula designed for primary and lower secondary school levels. The results show that water-related topics are integrated in the curricula with multi and interdisciplinary approaches and the most involved are Sciences and Geography (Amahmid et al., 2019).

The majority of the articles reveal period class lecturing as the backbone of the teaching activity. A study on the characteristics of 14 postgraduate programmes in various fields of environmental water resources engineering and management in Greek universities reveals that lecturing is the main form of learning (Latinopoulos and Angelidis, 2014). Sherchan et al. (2016) develop an interdisciplinary course that integrates water issues in the State of California in order to better educate and inform students and faculty at the California State University-Fresno. The course is designed to meet 3 hours a week, with two hours being dedicated to lectures in which theories, practice and issues related to water literacy are taught (Sherchan et al., 2016). Further, Thompson et al., (2011) developed an age-appropriate, hands-on water conservation lesson programme that involved period class lessons as the first learning step, whereby teachers began with questions about learners' perceptions and conceptions about water and water issues (Thompson et al., 2011). This strategy is echoed by Reinfried et al., (2015) who developed a learning environment to change students' intuitive conceptions about water springs. In their study, they also recognised determining students' previous knowledge and conceptions as an important first learning step, followed by introduction and description of the new concept (Reinfried et al., 2015). In that manner, the teacher could determine whether there were any myths, which might have needed to be dispelled or misdirected knowledge that needed to be brought into focus (Thompson et al., 2011), to facilitate conceptual changes among learners.

Experiments also seem to be a favoured form of learning. Experimental teaching is fundamental to science education, as it enhances learners' conceptual understanding, creativity, practical ability and positive attitudes (Kolil et al., 2020; Logar et al., 2017; Qiongjing and Jinxiang, 2011). In Greek universities, Latinopoulos and Angelidis (2014) revealed that among other forms of learning, is active learning carried out through field and laboratory experiments. Fuentes and Entezari (2020) present a model incorporating a semester-long authentic research-based set of laboratories in introductory Biology through which students conduct experiments to determine the water quality in areas close to their communities. The laboratories were useful in building students critical thinking, inquiry and problem solving. In designing their Science, Technology and Society instruction for pupils, Havu-Nuutinen et al. (2018) include short water-related problem-based experiments to enhance learning about the process of water states and to observe different aspects concerning water. In Morocco, Amahmid et al. (2019) noted that among other ways of delivering primary school curricula, is active learning which includes practical experiments. In China, Zhan et al. (2019) attempted to help elementary school children develop action competence by involving them in a water conservation education programme. Action competence was adopted as the major teaching approach in the programme, whereby the children were regarded as active agents, and participated in a variety of inquiry activities such as experiments to understand real-life problems (Zhan et al., 2019).

Fieldwork is widely regarded as an essential part of education in environmental sciences as it represents one of the most effective and enjoyable forms of learning for students (Çaliskan, 2011). It is noted to promote a positive attitude towards the topic that students are learning about, as learners who carry out practical experiences aimed at promoting water-saving habits show a higher level of knowledge and willingness to conserve water (Martínez-Borreguero et al., 2020; Middlestadt et al., 2001). Sherchan et al. (2016) revealed that the course they developed allots time for field trips to observe real world projects. Novak and Krajcik (2019) develop a project-based learning curriculum and implement it across sixth to twelfth grade learners, who examine the water quality of a nearby stream. The course facilitated students to explore the water quality system by visiting the stream and engaging in scientific practices such as asking questions, collecting and analysing data and explanations integrated with several disciplinary core ideas (Novak and Krajcik, 2019). Hanley et al. (2019) develop a year-long curriculum integrating field experiences with online modules focusing on the water cycle, water quality, and human impacts. The study found that online education can combine well with field-based, data-rich research experiences.

Another form of teaching is through the use of mobile devices. Kacoroski et al. (2016) investigate the use of mobile devices in a field study with young learners on water education. The study concluded that even though students were initially interested in mobile devices, their interest and excitement did not prove to be greater than their interest in water and nature (Kacoroski et al., 2016). A previous study by James and Bixler (2008) also shows young learners to be more engaged when in nature, as experiences in the natural world target sensory practices, thus creating richer understanding. Hence, water education among young learners could be more effective carried out in nature, which seems to prevail over digital technology.

A few studies also mention organizing seminars and inviting professionals to give talks about water (Latinopoulos and Angelidis, 2014; Sherchan et al., 2016). Sherchan et al. (2016), while developing their course designed to meet 3 hours a week, dedicate the third hour for weekly seminars in which invited professionals, academicians, and practitioners present different projects. In Greek universities, courses on water education allot time for seminars (Latinopoulos and Angelidis, 2014).

Interdisciplinarity in water education is also highlighted by several studies (Amahmid et al., 2019; Irvine et al., 2015; Latinopoulos and Angelidis, 2014; Sherchan et al., 2016). Forbes et al. (2018) developed and taught an interdisciplinary course on water which was offered by an interdisciplinary team of hydrology, economics and science education faculty. Students engaged in principled analysis of and reasoning about socio-hydrologic systems, including their scientific, ethical, social, economic, cultural and civic dimensions, to make informed decisions about water resource use (Forbes et al., 2018). In Morocco, an analysis on the curricula found that water theme is included in a broad series of topics that lend themselves to interdisciplinary approaches instruction (Amahmid et al., 2019). Sherchan et al. (2016) developed an interdisciplinary curriculum on water education, which they envisioned could integrate different perspectives of water in different social contexts and help students understand the theory, practice, issues, and challenges beyond their own majors. In Singapore, the curriculum approaches water education from an interdisciplinary perspective, a type of creative thinking that bodes well for the future of Singapore (Irvine et al., 2015).

3.3. The effects of water education on students

Water education is noted to play a key role in transforming students' knowledge, awareness and conceptions of water issues. Havu-Nuutinen et al. (2018) conducted a study on the instruction of Science, Technology, and Society (STS) to enhance primary school pupils' conceptual change process with water-related concepts and phenomena in scientific, societal and technological contexts. They find out that prior to instruction, pupils' idea of water was fragmented and described water from several perspectives but could not reason about or justify the phenomena. After the instruction, some aspects of water were still fragmented and not fully understood, but most of the pupils were able to change their conceptions. Çoban et al. (2011) present the results of a project conducted through a water school workshop study among students from 6th, 7th, and 8th grade levels who were given water education. They conclude that the water school workshop is generally effective on the students' conception about water, attitudes toward water usage, awareness of environment and general opinions related to water. Birch and Schwaab (1983) evaluated the effectiveness of a water conservation instructional unit in increasing students' knowledge of water conservation practices and influencing their attitudes about efficient water use. The study found that the knowledge about water use of students could be changed after being taught a unit of water conservation (Birch and Schwaab, 1983). Hanley et al. (2019), after developing and implementing their curriculum on water education, found that environmental education focused on water issues can improve science literacy. In China, Zhan et al. (2019) reveal that before joining a water education programme, learners appeared to have superficial understanding of water, low awareness of saving water, and limited knowledge of water conservation methods. After completing the programme, the learners' water conservation action competence in the knowledge, willingness and self-efficacy aspect was significantly improved in a holistic way (Zhan et al., 2019). In Jordan, Middlestadt et al. (2001) made comparisons between students whose teachers implemented an interactive curriculum and promoted household water-conservation behaviours and students whose teachers did not participate in the curriculum. The study revealed that students who were exposed to the curriculum demonstrated a higher level of knowledge about water conservation more than students who were not exposed to the curriculum (Middlestadt et al., 2001). Reinfried et al. (2015) design and analyse the efficacy of a learning environment aimed at changing Swiss students' intuitive conceptions about water springs. Prior to participation in the study, learners had conceptions based on intuitive knowledge. However, the study revealed that an educationally reconstructed learning environment led to significant knowledge gains and a relatively stable and detailed memory of what was learned (Reinfried et al., 2015).

In addition to knowledge gains, students' behaviours and attitudes towards water seem to improve after participating in water education. Davis et al. (2008) evaluates a water awareness program for young learners and find out some benefits that rose from participation in the program, including young learners' advocacy for water conservation as well as reductions in water usage. Thompson and Serna (2016) investigate whether the commitments of students of a water education program may have resulted in actual water savings in Dallas Texas. The results demonstrate that the students who committed to a water conservation behaviour change may have incorporated that change, and may have influenced their family members to do the same. This is echoed in studies in the United States, China, and Jordan which revealed that the attitudes among students about water issues changed and students performed recommended behaviours more often than before participating in water education (Birch and Schwaab, 1983; Middlestadt et al., 2001; Zhan et al., 2019).

The introduction of environmental education in the early years, including preschool is noted as significant as it may affect how learners view and interact with nature as adults (Broom, 2017). Samaltani and Christidou (2013) conducted a study on the effectiveness of a program designed for preschool children in promoting their awareness of water shortage and the importance of water conservation. The study revealed that preschool children are capable of dealing with the value of water for life, the issue of its shortage, and the importance of its conservation at a primary level (Samaltani and Christidou, 2013). Hence, water conservation is a topic that can introduce young children to the concepts of man-environment interaction and interdependence, and to assist them in developing the ability to participate in finding solutions to environment problems (Samaltani and Christidou, 2013).

Furthermore, students' knowledge seems to have a spill over effect and impact even their families and communities. As noted by Amahmid et al. (2019), school provides unique opportunities for awareness raising as they bring large groups of people together for learning purpose and usually have systems for production and dissemination of educational material. This phenomenon is echoed by Hanley et al. (2019), who highlight the important role students play in disseminating knowledge to their communities and families through creative products, including posters podcasts and brochures (Hanley et al., 2019). A study in the United States confirmed that students who committed to a water conservation behaviour change may have incorporated that change, and may have influenced their family members to do the same (Thompson and Serna, 2016). This may therefore create lasting improvement to their families and the wider community.

4. Conclusion and Policy Implications

In light of the increased attention on water security, the present study aimed to identify the role of water education among the youth and children in promoting water security. This was achieved using a systematic review in which frameworks for water education were synthesised. Based on the literature, we distinguished three themes: 'water awareness, conception, and attitudes among students', 'water education in primary, secondary, and university curriculum', and 'the effects of water education on students'. The three themes provide a comprehensive overview of the domain of water education among the youth. This review of literature found that access to water education is generally associated with improved awareness, conceptions, attitude and behaviours towards water as reported by teachers, students and school leaders. All eleven studies on the topic find positive results for water education outcomes. Each of the studies on the topic find that access to water education is associated with improvements in water issues.

These positive results suggest that increasing access to water education could improve the state of water security in the world. The studies reveal that water education plays a significant role in changing youth and children's knowledge, awareness, attitude and behaviour towards water. After participating in water education, young learners show improvement in water use and advocacy for water (Birch and Schwaab, 1983; Davis et al., 2008; Middlestadt et al., 2001; Zhan et al., 2019). The benefits of water education seem to go beyond the students themselves as they further influence their families' water use habits (Thompson and Serna, 2016). Also, young people have the capability to develop creative solutions to deal with water problems, including participation in community outreach activities (Hanley et al., 2019). The youth and children make up almost half of the world's population, and changing their understanding and attitude towards water could go a long way.

Furthermore, when young learners deal with environmental problems from their early years, they shape environmentally responsible behaviours (Samaltani and Christidou, 2013). Therefore, introducing suitably designed water education programs from a young age could have a positive lifelong effect, whereby learners develop a deep understanding and positive attitude and behaviour towards water.

In addition to class lecturing, fieldwork, experiments, and practical activities have particularly been noted as effective forms of learning in water education. They are effective in that they allow learners to clarify concepts by observing real world examples. In addition to being effective, practical activities are also the most enjoyable forms of learning for students (Çaliskan, 2011), and may aid in promoting a positive attitude towards the topic that students are learning about (Martínez-Borreguero et al., 2020; Middlestadt et al., 2001). Hence, including practical activities, experiments and fieldwork in the curriculum could promote students understanding, awareness, attitude and behaviour towards water and promote their willingness to participate in solving water problems.

The concept of interdisciplinarity in water education has been noted by several authors. We live in a world where biophysical and social processes are tightly coupled and changes in hydrologic systems impact socioeconomic, ecological, and climate systems at a number of scales, leading to a coevolution of these interlinked systems (Vogel et al., 2015). Vogel et al. (2015) notes that it is becoming increasingly difficult to study energy, food, health, or the environment without some expertise in water. Thus, it is critical to capture these transdisciplinary subjects, and rather than treating them as parallel entities, Forbes et al. (2018) suggest integrating them in meaningful ways through purposefully designed interdisciplinary education. Interdisciplinary education integrates different perspectives of water in different social contexts and help students understand the theory, practice, issues, and challenges beyond their own majors (Sherchan et al., 2016). Therefore, teaching water from an interdisciplinary approach could prove to be more beneficial to students, and would help them understand the importance of water conservation from economic, social, and cultural perspectives in a holistic way.

The literature surrounding differences between the attitudes towards water usage based on gender is limited. Aydogdu and Çakir (2016) found that females have a higher level of awareness and a more careful attitude towards water use than their male counterparts. Zhan et al. (2019) noted that girls outperformed boys in changing their pro-environmental behaviours. Aydogdu and Çakir (2016) attributes this to the fact that female students approach house holding more sensitively than males in the society in which they live. Lucio et al. (2018) revealed that females have stronger environmental and water conservation concerns than men, but do not give an explanation as to why.

Additional research on the influence of gender differences in water education would be welcome. In particular, more research on the specific reasons why females seem to have a higher awareness and more mindful attitude towards water than males is needed. It is also important to research suitable ways in which males' behaviours could be changed to overcome this gender gap. Future research could also focus on the state of water education in African countries. Only one of the thirty-two studies under review investigated water education Africa. This calls for more research to provide information on the extent and impacts of water education among African children and youth.

References

Amahmid, O., El Guamri, Y., Yazidi, M., Razoki, B., Kaid Rassou, K., Rakibi, Y., . . . El Ouardi, T. (2019). Water education in school curricula: Impact on children knowledge, attitudes and behaviours towards water use. *International Research in Geographical Environmental Education,* 28(3), 178-193.

Ardoin, N. M., & Bowers, A. W. (2020). Early childhood environmental education: A systematic review of the research literature. *Educational Research Review*, 100353.

Aydogdu, B., & Çakir, A. (2016). An Investigation of Middle School Students' Attitudes and Awareness of Water Use. *International Journal of Environmental Science Education, 11(16)*, 9520-9536.

Ben-zvi-Assarf, O., & Orion, N. (2005). A study of junior high students' perceptions of the water cycle. *Journal of Geoscience Education,* 53(4), 366-373.

Benninghaus, J. C., Kremer, K., & Sprenger, S. (2018). Assessing high-school students' conceptions of global water consumption and sustainability. *International Research in Geographical Environmental Education 27*(3), 250-266.

Bilotta, G. S., Milner, A. M., & Boyd, I. (2014). On the use of systematic reviews to inform environmental policies. *Environmental Science,* 42, 67-77.

Birch, S. K., & Schwaab, K. E. (1983). The effects of water conservation instruction on seventh-grade students. *The Journal of Environmental Education,* 14(4), 26-31.

Broom, C. (2017). Exploring the relations between childhood experiences in nature and young adults' environmental attitudes and behaviours. *Australian Journal of Environmental Education,* 33(1), 34.

Çaliskan, O. (2011). Virtual field trips in education of earth and environmental sciences. *Procedia-Social Behavioral Sciences*, 15, 3239-3243.

Çoban, G. Ü., Akpınar, E., Küçükcankurtaran, E., Yıldız, E., & Ergin, Ö. (2011). Elementary school students' water awareness. *International Research in Geographical Environmental Education,* 20(1), 65-83.

Cockerill, K. (2010). Communicating how water works: results from a community water education program. *The Journal of Environmental Education,* 41(3), 151-164.

Covitt, B. A., Gunckel, K. L., & Anderson, C. W. (2009). Students' developing understanding of water in environmental systems. *The Journal of Environmental Education,* 40(3), 37-51.

Davis, J. M., Miller, M. G., Boyd, W. A., & Gibson, M. L. (2008). The impact and potential of water education in early childhood care and education settings: A report of the Rous Water Early Childhood Water Aware Centre Program.

Dieser, O., & Bogner, F. X. (2016). Young people's cognitive achievement as fostered by hands-on-centred environmental education. *Environmental Education Research 22*(7), 943-957.

Forbes, C. T., Brozović, N., Franz, T. E., Lally, D. E., & Petitt, D. N. (2018). Water in Society: An interdisciplinary course to support undergraduate students' water literacy. J*ournal of College Science Teaching, 48*(1), 36-42.

Fuentes, A.-L., & Entezari, M. (2020). Water in your neighbourhood: a model for implementing a semester-long course-based undergraduate research project in introductory biology. Education Inquiry, 1-65.

Gopinath, G. (2014). A study on the environmental awareness among secondary school students in a district of Kerala state. *International Journal of Education Psychological Research, 3*(2), 54-57.

Hanley, C., Freeman, R. L., Fryar, A. E., Sherman, A. R., & Edwards, E. (2019). Water in India and Kentucky: Developing an Online Curriculum with Field Experiences for High School Classes in Diverse Settings. *Journal of Contemporary Water Research Education,* 168(1), 78-92.

Havu-Nuutinen, S., Kärkkäinen, S., & Keinonen, T. (2018). Changes in primary school pupils' conceptions of water in the context of Science, Technology, and Society (STS) instruction. International Research in Geographical Environmental Education Research, 27(2), 118-134.

Hedefalk, M., Almqvist, J., & Östman, L. (2015). Education for sustainable development in early childhood education: A review of the research literature. *Environmental Education Research, 21*(7), 975-990.

Honingh, M., Ruiter, M., & Thiel, S. v. (2020). Are school boards and educational quality related? Results of an international literature review. *Educational Review, 72*(2), 157-172.

Irvine, K. N., Seow, T., Leong, K. W., & Cheong, D. S. I. (2015). How high's the water, Mama? A reflection on water resource education in Singapore.

James, J. J., & Bixler, R. D. (2008). Children's role in meaning making through their participation in an environmental education program. *The Journal of Environmental Education, 39*(4), 44-59.

Ji, D. (2014). High School Curriculum of Water Conservation.

Kacoroski, J., Liddicoat, K. R., & Kerlin, S. (2016). Children's use of iPads in outdoor environmental education programs. *Applied Environmental Education Communication, 15*(4), 301-311.

Keys, P. W., Porkka, M., Wang-Erlandsson, L., Fetzer, I., Gleeson, T., & Gordon, L. J. (2019). Invisible water security: moisture recycling and water resilience. *Water Security, 8*, 100046.

Kolil, V. K., Muthupalani, S., & Achuthan, K. (2020). Virtual experimental platforms in chemistry laboratory education and its impact on experimental self-efficacy. *International Journal of Educational Technology in Higher Education, 17*(1), 1-22.

Latinopoulos, P., & Angelidis, P. (2014). Postgraduate programmes on environmental water resources engineering and management in Greek universities. *European Journal of Engineering Education, 39*(1), 31-44.

Logar, A., Peklaj, C., & Savec, V. F. (2017). Effectiveness of student learning during experimental work in primary school. *Acta Chimica Slovenica, 64*(3), 661-671.

Lotz-Sisitka, H., Rosenberg, E., & Ramsarup, P. (2020). Environment and sustainability education research as policy engagement:(re-) invigorating 'politics as potentia'in South Africa. *Environmental Education Research*, 1-29.

Lucio, M., Giulia, R., & Lorenzo, C. (2018). Investigating attitudes towards water savings, price increases, and willingness to pay among italian university students. *Water Resources Management, 32*(12), 4123-4138.

Martínez-Borreguero, G., Maestre-Jiménez, J., Mateos-Núñez, M., & Naranjo-Correa, F. L. (2020). Water from the Perspective of Education for Sustainable Development: An Exploratory Study in the Spanish Secondary Education Curriculum. *Water,* 12(7), 1877.

Middlestadt, S., Grieser, M., Hernandez, O., Tubaishat, K., Sanchack, J., Southwell, B., & Schwartz, R. (2001). Turning minds on and faucets off: Water conservation education in Jordanian schools. *The Journal of Environmental Education,* 32(2), 37-45.

Monroe, M. C., Plate, R. R., Oxarart, A., Bowers, A., & Chaves, W. A. (2019). Identifying effective climate change education strategies: a systematic review of the research. *Environmental Education Research,* 25(6), 791-812.

Nepal, S., Neupane, N., Belbase, D., Pandey, V. P., & Mukherji, A. (2019). Achieving water security in Nepal through unravelling the water-energy-agriculture nexus. *International Journal of Water Resources Development,* 1-27.

Novak, A. M., & Krajcik, J. S. (2019). A case study of project based learning of middle school students exploring water quality. *The Wiley Handbook of Problem Based Learning,* 551-572.

Özalemdar, L. (2019). The Importance of the Concept of Water in Biology *Education. Journal of Turkish Science Education,* 16(2), 264-277.

Pease, M., Chaney, P. L., & Hoover, J. (2019). A review of water resources education in geography departments in the United States. *Journal of Contemporary Water Research Education,* 168(1), 93-105.

Petticrew, M., & Roberts, H. (2008). *Systematic reviews in the social sciences: A practical guide*: John Wiley & Sons.

Qiongjing, D., & Jinxiang, L. (2011). Strengthening Quality Monitoring System of the Experiment Teaching, Enhancing the Quality of the Experiment Teaching. In *Education and Educational Technology* (pp. 261-267): Springer.

Reinfried, S., Aeschbacher, U., Kienzler, P. M., & Tempelmann, S. (2015). The model of educational reconstruction–a powerful strategy to teach for conceptual development in physical geography: the case of water springs. *International Research in Geographical Environmental Education,* 24(3), 237-257.

Reinfried, S., Tempelmann, S., & Aeschbacher, U. (2012). Addressing secondary school students' everyday ideas about freshwater springs in order to develop an instructional tool to promote conceptual reconstruction. *Hydrology Earth System Sciences,* 16(5), 1365.

Samaltani, D., & Christidou, V. (2013). Water conservation in the nursery school. Global NEST J, 15(3), 421-429.

Schaap, W., & Van Steenbergen, F. (2002). *Ideas for water awareness campaigns:* Global Water Partnership.

Scott, W., & Reid, A. (1998). The revisioning of environmental education: A critical analysis of recent policy shifts in England and Wales. *Educational Review,* 50(3), 213-223.

Sherchan, S., Pasha, F., Weinman, B., Nelson, F. L., Sharma, F. C., Therkelsen, J., & Drexler, D. (2016). Seven faculties in search of a mission: A proposed interdisciplinary course on water literacy. *Applied Environmental Education Communication,* 15(2), 171-183.

Thompson, R. R., Coe, A., Klaver, I., & Dickson, K. (2011). Design and implementation of a research-informed water conservation education program. *Applied Environmental Education Communication*, 10(2), 91-104.

Thompson, R. R., & Serna, V. F. (2016). Empirical evidence in support of a research-informed water conservation education program. *Applied Environmental Education Communication,* 15(1), 30-44.

Vogel, R. M., Lall, U., Cai, X., Rajagopalan, B., Weiskel, P. K., Hooper, R. P., & Matalas, N. C. (2015). Hydrology: The interdisciplinary science of water. *Water Resources Research, 51*(6), 4409-4430.

Zhan, Y., He, R., & So, W. W. M. (2019). Developing elementary school children's water conversation action competence: a case study in China. *International Journal of Early Years Education, 27*(3), 287-305.

Leveraging Citizen Science for Sustainable Development Education and Water Security in Northern Ghana

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Abstract

West Africa is facing food insecurity mainly due to its high dependence on rain-fed agriculture, an unpredictable rainy season accentuated by climate change, and a lack of accurate rainfall information. With water insecurity expected to increase in the coming years, local youth involvement is necessary to address this problem. Citizen science is emerging as a complement to traditional methods, involving the population and tackling real-world problems. Its application to Sustainable Development Education (SDE) can provide youth with practical opportunities to learn and apply science-based methods to tackle challenges faced by their communities. However, attempts to apply citizen science in educational settings have found multiple challenges. To overcome these challenges, previous studies defined Key Success Factors (KSFs) to be considered in the design and development of citizen science projects. The ability of these KSFs to enable SDE while contributing to science has not been extensively proven yet. This research assesses the applicability of these KSFs in a citizen science project in northern Ghana, framed within the Schools and Satellites (SaS) project. SaS aims to produce accurate rainfall information for better informed agriculture in the region by, among others, implementing citizen science as part of an educational module on climate change and the water cycle in schools. The results show that applying these KSFs in citizen science projects in an educational setting leads to interested, engaged, and educated schools and scientifically valuable outputs. These findings will be valuable for future development of citizen science projects in formal education settings in (West) Africa.

Keywords: Citizen science, Sustainable development education, Water security, Climate change, West-Africa

1. Introduction

As a complement to traditional theoretical formal education, Citizen Science (CS) can provide youth with practical and real-life opportunities to apply science-based methods to solve problems faced by their communities. When CS is applied in a classroom setting, it is a form of science education – that challenges students to make more informed choices, think critically, and believe they can make a difference (Mueller et al., 2012). Since the establishment of the Sustainable Development Goals (SDG), it is universally acknowledged that formal education, and specifically education for sustainable development, is needed for rapid and profound societal transformation toward sustainability (Keller et al., 2019). More specifically, there is a need to increase (young) people's competencies and critical engagement, thus empowering individuals to deal with the complexity and dimension of the sustainability subject (Mochizuki and Bryan, 2015). CS methods can be employed as innovative approaches to learning by bringing about specific cognitive, socio-emotional, and behavioural learning outcomes that enable individuals to deal with the challenges of each SDG (UNESCO, 2017). It can provide improved scientific literacy, environmental awareness, leadership, skills, and the potential to inspire the new generation as aware and active citizens (Wals et al., 2014; Pitt and Schultz, 2018; Ballard et al., 2017).

Science has the potential to not only amaze, but also transform the way one thinks of the world and one's place within it. This is because the analytical processes of science have significant similarities to, and are deeply resonant with, the natural processes of play. Play enables humans (and other mammals) to discover and create relationships and patterns. When one adds rules to play, a game is created. Science can, therefore, also be described as the process of playing with rules that enable one to reveal previously unseen patterns of relationships that extend our collective understanding of ourselves and the world around us. In this way, CS in formal education becomes an enlightened and intuitive process of asking questions and devising games to address those questions.

However, because the outcome of game-playing is unpredictable, supporting this 'messiness', which is the engine of science, is critical to good science education. Many wonder whether CS is therefore even possible as part of formal education, since it requires schools to embrace a certain degree of messiness. How could youth, who are often nearly powerless in schools and rarely decision-makers outside of school, be in control of a rigorous scientific process (Barton, 2012)? Weinstein (2012) expresses in his response to Mueller, Tippins, and Bryan's original article, that CS is unlikely to happen in schools for schools are fundamentally undemocratic places. However, according to Barton (2012) CS as part of schooling is a daunting project, but not impossible: The basic tools needed to bring CS to fruition in schools are already available— if we are creative and persistent.

Understanding how we can incorporate CS as part of schooling and formal education requires a close look at what factors are needed to make it suitable for the educational infrastructure and purposes, while still achieving scientific outputs. Scientific outputs must remain a central goal for a project to be considered citizen science, instead of science education, conservation volunteering or awareness-raising exercises (Soanes et al., 2019). What motivates teachers to be open and make efforts to incorporate citizen science into their teaching? And how should a CS project be designed to enable a teacher to include it in the daily education schedule? What makes a CS project successful when applied in a formal education setting?

Several studies have analysed citizen science projects in a school setting. They all highlight the difficulties in generating robust data from school-based citizen science projects (Ballard et al., 2017; Esch et al., 2020; Soanes et al., 2019). A literature study by Soanes et al. (2019) shows the little number of published examples of school-based citizen science projects in wild-life research, 18 to be precise, which indicates that there are probably many unpublished examples of such projects that failed to generate the data quality expected. Furthermore, to the best of the authors' knowledge, there are no cases of citizen science methodologies applied in West-African formal education, nor in the entire African continent. However, culture strongly influences people's motivations to join a citizen science project (Rotman et al., 2014), and the authors expect it also influences other factors of a citizen science project.

This paper aims to investigate whether CS methodologies can function as an action-orientated learning method for formal education, while contributing to the formation of a citizen observatory in West-Africa. This is done by examining a citizen science project since the project formulation, throughout the start and implementation, and during the first phase of the CS campaign. This research is framed within the Schools and Satellites (SaS) project, which is a cooperation between the Ghana Meteorological Agency, Trans-African Hydro-Meteorological Organisation, Delft University of Technology, SmartPhones4Water and PULSAQUA. The project aims to create accurate rainfall information in the five regions in northern Ghana by, among others, building a Citizen Observatory (CO) to collect rainfall data. It is targeted at Junior High Schools (JHS) in the region and includes action-oriented education on climate change.

The paper first elaborates on previous studies that provide information concerning success-factors for citizen science projects, especially when applied to formal sustainable development education (SDE). This is followed by introducing the SaS case-study, problem, and research goals of establishing the CS observatory. The chosen methodology is then explained, after which the research results are presented. The paper ends with a discussion on the key-factors for a successful citizen science application in a formal education setting.

2. Key-success factors for CS application in formal SDE

A previous study (Rutten et al., 2017) highlights the key-success factors (KSFs) of general citizen science projects, later ratified by Golumbic et al. (2019). Figure 1 shows a comparison between the KSFs of general CS projects (blue box) and those of SDE projects (white box). The KSFs which were also identified in SDE settings are surrounded by a white box.

The KSFs that are of particular importance for application in SDE settings have been extracted from (Soanes et al., 2019; Esch et al., 2020), and are described here in more detail:

1. To understand teacher and student motivation (citizen motivations) and barriers, schools should commit from the start to embed the research project within the curriculum. This will ensure that activities such as data collection are allocated adequate time and effort.
2. Establish formal partnerships that can ensure that both schools and scientists have access to the infrastructure and administrative support required to develop meaningful and sustainable projects. Furthermore, the project should connect to broader CS initiatives that interact meaningfully with students.
3. CS work should be relevant to the local community to ensure community support.
4. Robust data can be collected if appropriate measures are used, e.g. age-appropriate training, regular validation, simplified protocols, etc. The methods should be tailored to the research objectives and to the age of the students. This will allow students to engage with the topic in a safe and interesting manner, while contributing to reliable data.
5. Assist teachers to lead the students through the scientific aspects of the project. CS work should be meaningful, not just procedural, to teachers and students.
6. Keeping students and teachers interested is critical to success. This can be done by allowing students and teachers to contribute ideas and research questions and provide students with the opportunity to analyze and present the data themselves.
7. Engagement and educational outcomes should be explicitly measured.
8. Giving feedback on the gathered data to the participants can be another way to keep them engaged while also allowing them to participate in the end-to-end project.

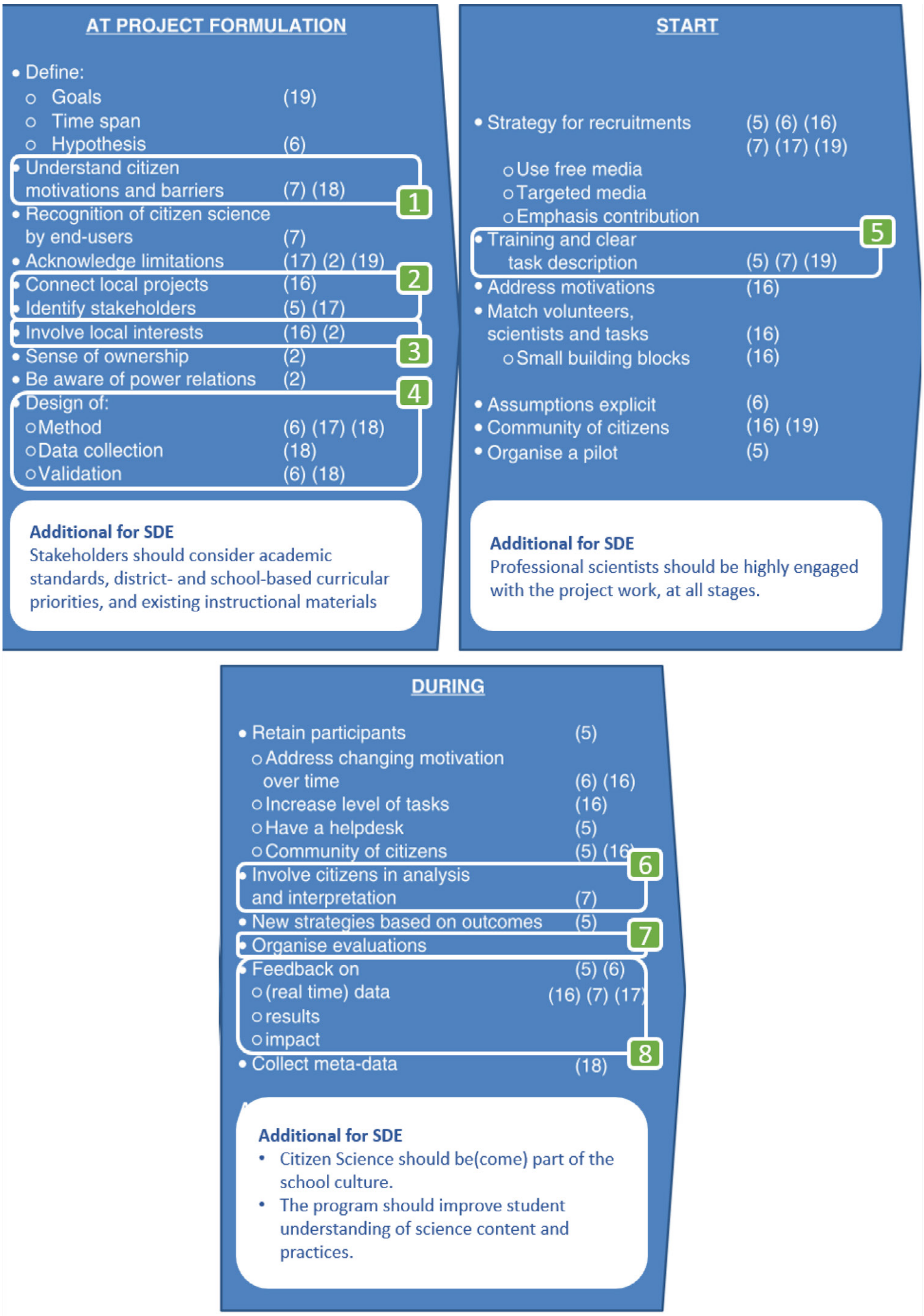

Figure 1. Key-success factors found by Rutten et al. (2017) for citizen science projects, highlighting those also found as particularly important by studies for application in Sustainable Development Education (SDE) (Soanes et al., 2019; Esch et al., 2020; Rutten et al. 2017)

3. Case Study and Methods

3.1. Case study description

West Africa's economy is mainly sustained by agriculture, and particularly Ghana's economy depends on rain-fed agriculture (Antwi-Agyei, 2012). Many crops are grown in the West African Savanna, of which sorghum, millet, groundnut, cowpea, and cotton are the major rain-fed crops occupying approximately 60 to 80 percent of the cultivated land (Kassam, 1976). Economic growth and food security in this region are therefore highly dependent on the knowledge of rainfall patterns. According to the IPCC, the Global South will seriously suffer from climate change (IPCC, 2007 and 2019). As traditional rainfall patterns shift, accurate rainfall information becomes crucial for farmers to optimize food production.

The situation in northern Ghana is a typical example of the described problems. Not only are over 70% of the inhabitants of these communities depending on rain-fed agriculture for their livelihood, but their children will also most likely inherit their parent's lands and become farmers themselves. Income and well-being are causally linked to agriculture. Farming is seasonal in this semi-arid region of Ghana and will become more and more lucrative due to climatic variability. According to the Climate Change Knowledge Portal of the World Bank, annual rainfall in Ghana is projected to decline by 20.5% in 2080. There is also a trend in the projections toward a decrease in January – June rainfall, the dry season, and an increase in July – August rainfall, the wet season (World Bank Group). The onset of this wet season has been changing in the past years, making it hard for farmers to know when to plant crops (farmers in northern Ghana, personal communication, 2020; Kniveton et al., 2009). The Ghanaian government has acknowledged that climate change will influence the next generation and has therefore made it one of the obligatory themes in the educational curriculum. However, action-oriented teaching and learning methods where students learn by doing are lacking (Boakye, 2015).

The rain gauge network in Ghana counts predominantly with rain gauges from the Ghana Meteorological Agency (GMet) and the Trans-African Hydro-Meteorological Organisation (TAHMO)-Ghana. Other rainfall observations include those carried out by independent studies and other organisations such as the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL). The data available to this study comprised that from 8 TAHMO stations and 16 GMet stations, across the five northern regions of Ghana.

The goal of SaS was to produce a model based on Deep Learning that can estimate precipitation using only Earth observation images. To train and validate the model, a significant quantity of rainfall data is needed from the ground. For this purpose, SaS expanded the rainfall observation network by including low-cost acoustic rainfall sensors – disdrometers – and citizen science observation. The northern regions, namely, the Upper West, Upper East, North East, Northern, and Savannah regions, are divided into 55 metropolitans, municipalities, and districts. These five regions take up almost half of the country, as can be seen in Figure 2.

3.2. Applied Methods

To test whether the KSFs found in previous research, if applied, can function as action-oriented learning method for formal SDE while at the same time contributing to science, the authors applied as many of the KSFs as possible. This is done at project formulation, during the start of the project implementation, and during the first phase of the project, until the first evaluation. The paper first explains how these KSFs were applied throughout the project. To investigate the results of implementing these KSFs, the authors held an online survey among the citizen scientists to evaluate and possibly improve the project methodology. The survey was held using Survey Monkey, and the survey questions can be found in the Supplementary Material.

Together with the resulting data series of the first phase of the project (two months of precipitation data) the project is evaluated concerning (1) the achievement of delivering good and representative data for scientific input, and (2) application of the project for SDE purposes.

To evaluate whether number 1 is achieved, the research needs are compared to the project deliverables concerning the area coverage per location in the network; the number and time of record of the measurements; the reliability and consistency of the data; and the networks proportionality to the existing precipitation network.

To evaluate whether number 2 is achieved, the authors evaluate the motivation levels expressed by the survey respondents and compare them with the number of measurements taken by those respondents; the motivations for joining the project and whether it compared to the motivations used to design the project; the perception concerning influencing factors for motivation, namely received feedback, duration of work, and difficulty of participation; the amount and type of involvement of students in the project; the use of the supplied teaching materials; and the perception of usability of this project to achieve learning goals for their students.

4. Application of identified key-success factors

4.1. Project formulation phase

KSF: ‘Defining goal, time span and hypothesis’

The changing rainfall patterns in northern Ghana due to climate change are hard to analyse due to the scarce rain gauge distribution and data transmission challenges. Satellites could offer a solution to this problem, but existing rainfall satellite products fail to account for local characteristics of the rainfall process and achieve poor correlation with ground data. To overcome this, the authors propose a Deep Learning-based rainfall retrieval algorithm. Training and validating such an algorithm requires a high amount of ground truth data. Since rain gauges are scarce in West Africa, a (temporary) high-density observation network is necessary to strengthen the dataset provided by the currently existing ground measurement networks of GMet and TAHMO.

KSF: ‘Consider academic standards, curricular priorities, and existing materials’

The Ghanaian government’s recent addition of a Climate Change module into the school curriculum, has revealed a need of teachers and schools for action-oriented teaching and learning methods where students learn by doing. If the project can deliver substance for this need to teachers and schools, there is a direct motivation to join the project.

Figure 2. Ghana map with the separate regions, including the new regions established in 2019. The case study area is placed within the rectangle. Adapted from https://en.wikipedia.org/wiki/Regions_of_Ghana

KSF: 'Involve local interests'

Many teachers are also small-holder farmers, and their students are children of farmers. The success of the project's outcome would also directly benefit them. Therefore, participants see this project as an opportunity to monitor rainfall in their respective communities. They acknowledge the impact it will have on their decision making as far as their farm work is concerned.

KSFs: 'Design of method, data collection and validation' and 'Organize a pilot'

To enable teachers and students to easily take and report rainfall measurements, the authors chose a citizen science method designed by SmartPhones4Water (S4W) and tested and validated in Nepal (Davids et al., 2018). This method uses soda bottles to construct DIY (do-it-yourself) rain gauges to collect precipitation. The bottle is levelled using concrete, up to the level where the uniform diameter of the bottle begins. The additional weight of the concrete also helps to keep the gauge upright and unaffected by wind and other disturbances. Bottle lids are cut off at the point towards the top of the bottle where the inward taper begins. This lid is then inverted and placed on top of the gauge to minimize evaporation losses. A simple measuring ruler of sufficient length with millimetre graduations is glued vertically onto the side of the bottle. The ruler is placed with the zero mark at precisely the same level as the surface of the concrete. This way, a simple, sturdy, and low-cost rain gauge can be made by citizen scientists themselves. To perform the precipitation measurements, the citizen scientists use an Android smartphone application called Open Data Kit Collection (ODK Collect; Anokwa et al., 2009). This application makes recording of the measurement simple, and helps to record date, time, and GPS coordinates. The measurement is then easily saved locally to smartphone memory and sent to the S4W ODK Aggregate server running on Google App Engine. It furthermore enables a validation and training method, by requiring the citizen scientist to take a photograph of the water level with the smartphone camera level to the water surface. S4W then compares the photograph and the recorded measurement for data quality control. If the measurement is incorrect, a correction is made, and the citizen scientists receive feedback on how to improve their measurements.

To test the method in the Ghanaian context, a select group of six farmers around Nyankpala in the Northern Region of Ghana – "observers" in the following - were recruited as citizen scientists for the pilot phase of the project. The rain observers received an Android smartphone with the ODK application installed on it and ready for use, and a S4W rain gauge. The S4W gauge applied in Ghana is made of an empty 1.5 L Fanta bottle available locally. The two main evaluation criteria for a suitable bottle were an almost continuous diameter and no patterns/ riddles on the plastic between base and top. Although the Fanta bottle had the limitation that the bottom diameter (9.2cm) is 0.2cm bigger than the top diameter (9cm), it was chosen for being the closest to meet the evaluation criteria out of all options locally available. Because of this difference in diameter, the recorded measurement should be recalculated afterwards by multiplying by 1.0449. However, the error this provides is considered neglectable considering the other errors these low-cost rain gauges have concerning condensation, concrete soaking, and evaporation (Davids et al., 2018).

Together with the six first observers, the design, data collection and validation methods were tested and improved. Some of these improvements are:

- The smartphone used was not able to estimate the GPS location correctly. Another smartphone was chosen thereafter where the GPS functions well (Itel A56) and which is available in Ghana.
- Thanks to this pilot phase the authors realized that there should be a local contact available to troubleshoot and assist the citizen scientists.

The observers would furthermore receive feedback of the resulting mapped precipitation in graphs, enabling them to compare their measurements with their fellow observers.

KSF: 'Understand citizen motivations and barriers'

When this was optimized fully, three of the authors - a local expert of the Ghanaian educational system, the engineer and researcher building the algorithm and using the data collected by the observatory, and an expert on CS in water security - conducted a field campaign of three weeks at case-study location. The team travelled through northern Ghana and performed semi-structured interviews with 16 educational district offices, 13 schools and 8 JHS students to explain the plan and understand the needs, possibilities, and interest for such an educational program and to join the Citizen Observatory. Furthermore, the team visited the six original observers and interviewed them concerning experiences, needs and feedback methods.

After three weeks a total of 66 JHS registered for the SaS project and another 40 schools were interested. Reasons mentioned for interest in the project boiled down to the same two arguments:

- Understanding rainfall patterns is significant for our livelihoods.
- Practical education on rainfall patterns is a great addition to our education on climate change.

One teacher explained that "as a teacher and a small-scale farmer this project can give me the learning opportunity to develop myself both in the field of farming and teaching. It also gives my students the opportunity to learn new ideas, since they will be actively involved in the entire project." Another teacher clearly stated that "we suffer a lot from climate change" (anonymous teachers in northern Ghana, personal communication, 2020). With the input received during the fieldwork, the authors designed an educational module, of which the structure can be found in Figure 1 and the full manual can be found in project URL: https://tahmo.org/schoolandsatellites/ and a program of requirements to be found in Table 1.

KSF: 'Acknowledge limitations'

The design limitations demonstrate the biggest challenges to ensure that this CO also delivers scientifically useful outputs.

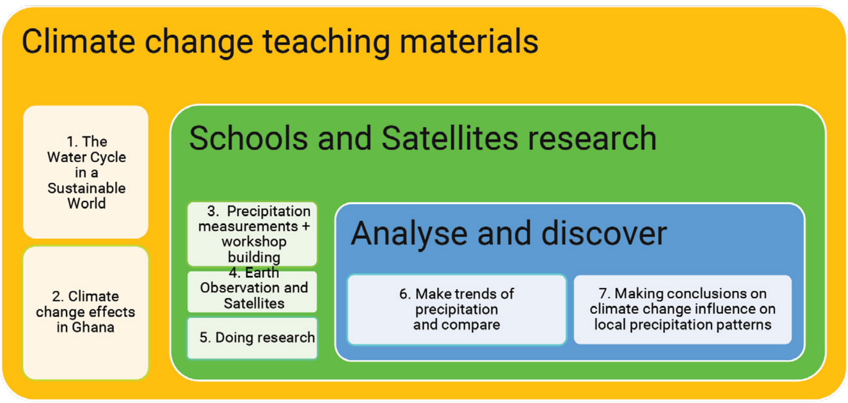

Figure 3. Climate Change teaching module design.

KSF: 'Be aware of power relations'

At the start of the fieldwork, the authors were made aware of the educational structure in Ghana: For schools to join the project, the district/metro/municipality educational office must approve and agree upon the project goals and intentions. These office directors are also responsible to decide which schools join the project. Furthermore, the ODK collect online form includes a one-time request to record personal data and whether the observer consents to be mentioned by name in future references.

KSF: 'Recognition of citizen science by end-user'

For continuity and further use of the data collected by the CO in Ghana, a meeting took place with the Director-General of the Ghana Meteorological Agency. During the meeting, the Director-General recognized the value of the collected data by such a CO as an addition to their own stations. The continuation of the measurements with schools and farmers after this project was also discussed and is being considered.

4.2. Start of the project implementation

KSF: 'Strategy for recruitments'

In the end, the fieldwork provided not only input for the project formulation, but also recruitments of the schools via their educational offices. The benefit of this was that the educational offices could allocate schools in a well-distributed manner, by choosing one school in every secute. A secute is a smaller administrative division within the district/metro/municipality. The authors also made use of Facebook to increase outreach and recruit interested teachers. However, this was not as successful as initially envisioned.

Finally, four education offices provided a list of schools to join the project. These were West Mamprusi (North East Region), Wa East, Sissala East, and Sissala West (Upper West Region). The number of schools visited included 10 in West Mamprusi, 10 in Wa East, 17 in Sissala East and 6 in Sissala West. One was also installed at Gbewaa College of Education in the Upper East region. This sums up to a total of 44 schools/sites where rain gauges were installed, mapped in Figure 4.

Table 1. Program of requirements for the SaS project.

Program of requirements for the SaS project	
Conditions	• The educational lessons fit in the Ghanaian education curriculum demands. Educational offices need to agree and be aware of this project and observatory. • The smartphone used to take the measurements is not kept by a student. This needs to be overseen and owned by the teacher, because smartphone use is not allowed in class.
Functional demands	• Daily measurements around 9 AM will be possible. All schools are open by then, and most have their daily break. For weekends and holidays, they will create a schedule for the students. • Not all schools have computers available. This means that the educational module may not rely on online tasks and materials. • Training should be given to the teachers. • Materials (smartphone, rain gauge, etc.) need to be provided to enable a school to join. • To enable to upload the collected precipitation data, monthly internet data should be provided.
Wishes	• A measurement syllabus explaining how to take the measurements should be included and distributed. The measurement syllabus can be found here. • A pen pile setup with another country might be a good method to encourage and engage the students. • Challenges organized between the schools to keep them engaged are approved upon. • Receiving the results of the measurements would be best in pictures, graphs, or presentations. Feedback of the results should come as a monthly precipitation graph showing the measurements taken. Furthermore, a map to see other measurement locations would be appreciated very much. • To enable more rain gauges to be built in the future, possibly also by the students, instructions should be included. In this video and the manual 'Building your own rain gauge' instructions are given.

Program of requirements for the SaS project	
Design limitations	• Daily measurements around the same time for all schools is to be strived for but might not always be possible. When it rains in Ghana, it pours. Interviewees explained that going outside at the agreed time of measurement while it poured was not possible. The measurement would be taken once the downpour decreases. • A highly distributed network of measurements: schools need to be well distributed throughout northern Ghana. • Cover the full rainy season is for scientific output a necessity. This can sometimes already start in March with small rains. That is a long period to take measurements (March – October)

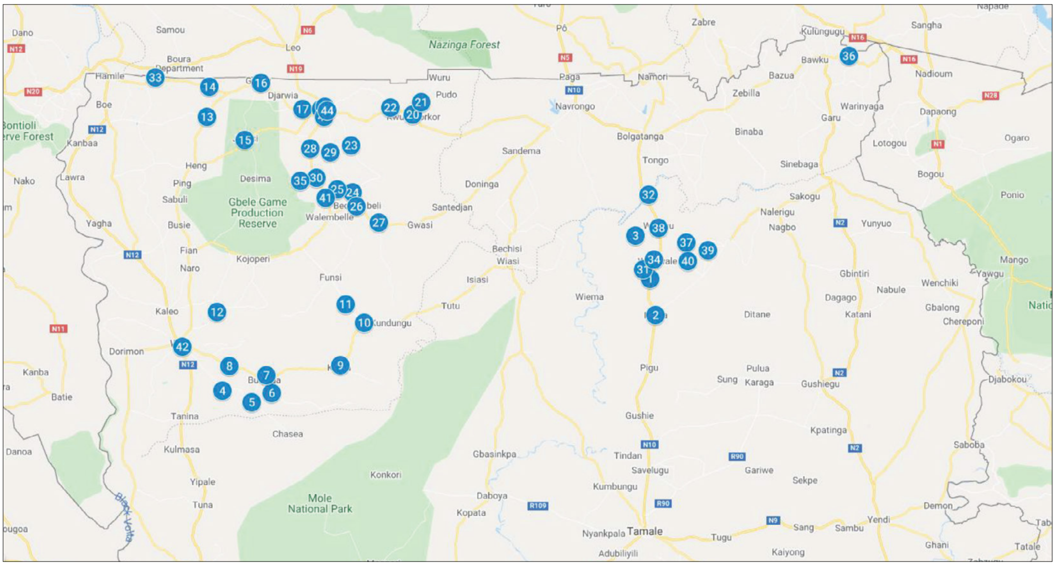

Figure 4. Map of the 44 CO locations. Visualized in Google Earth.

KSFs: 'Training and clear task description' and 'Match volunteers, scientists, and tasks'

The SaS project was to provide all the needed logistics to enable the teachers to carry out the task. The teachers received one-on-one training from one of the authors on how to take measurements as well as use the education materials co-developed for their lessons. This enabled the teachers to train their students in taking measurements, so the teacher can focus on implementing the educational module. Breaking down the tasks this way into smaller building blocks can allow a better match between observers and tasks as well and allows teachers and students to have control over their level of contribution.

The material made available to the selected schools and assigned teachers included (Figure 5):

- A plastic rain gauge made from a Fanta bottle and a metal stand for the bottle as part of quality control; all rain gauges were installed together with one of the authors on the same height and in an open location
- A mobile phone (Itel A56) including the ODK app and educational materials provided directly
- A branded gear with the name of the project
- An outside sticker to indicate the school is a SaS school

KSF: 'Sense of ownership'

The education offices and their selected schools welcomed us and the project. Most of them expressed great optimism about the project. They have made commitments that they will take care of all the project material. The project also received the endorsement of the assigned (head) teachers. They promised to also keep hard copies of the daily records.

KSFs: 'Address motivations' and 'Assumptions explicit'

The selected schools for the project are all located in farming communities. From the interactions with the teachers, rainfall data will be useful to the community. Farmers still often depend on traditional knowledge for the onset of the rains and the peak period. On many occasions, this approach fails, and they lose their investment (crops). The project has the prospect of influencing decisions of farmers in the communities where these rain gauges have been installed. Hence, allowing farmers to make better-informed decisions and avoid losses. The involved teachers have been encouraged to share the outcome of this research work with their communities.

Educational offices and teachers were made aware that the use of the collected precipitation data in this project was after one complete rainy season. This is not only expected and useful for the scientific output, but also by the observers themselves to have a full overview of the full rainy season.

KSF: 'Community of citizens'

The teachers were invited to join a WhatsApp Group called 'SaS active rain observers' to interact among themselves and the project team and receive feedback on their measurements. The original observers were also included in this group. Lastly, this WhatsApp group was also used by the authors to introduce themselves to the participants.

Figure 5. JHS in Tarsaw/Kulfor receiving materials © Ali Nansia

KSF: 'Professional scientists should be highly engaged with the project work, at all stages'

The lead scientists that will ultimately make use of the citizen science data were included throughout the whole process, assisting with the decision making.

4.3. During project execution – first phase

KSFs: 'Give feedback' and 'Collect meta-data'

In September and October 2020, the CO collected 751 measurements, of which 132 needed to be corrected. Feedback included:

- Image should be taken from eye level (the water level in the picture should be clear)
- Scale errors should be reduced/subtracted/deducted from the observed reading
- A scale error of 2mm due to the lower meniscus should be observed

Furthermore, the observers received monthly graphs showing the average precipitation measurements taken by all participants [Figure 6], and the total number of measurements taken. To enable fast and direct feedback, a simple Python script was written to analyse and visualize the data. Besides the rainfall measurement, the recorded data includes the date, time, GPS location of the measurement and any additional comments by the observers, such as the state of the weather or an estimation of the wind force at the time of the measurement.

Furthermore, the observers can view their measurements and compare them with other observers results on the S4W data platform. Detailed explanations on how to map their measurements were given in the WhatsApp group. In Figure 6 the end of the wet season can also be observed. The observers also noticed this and asked for instructions for continuation. See Figure 1 in the Supplementary Material for an impression of the conversation held via the WhatsApp group.

KSF: 'Organize evaluations'

The dry season (harmattan) has put a hold on the rainfall measurements and created a perfect occasion to ask the newly joined observers to reflect on their participation and give input on what to improve in the educational material provided.

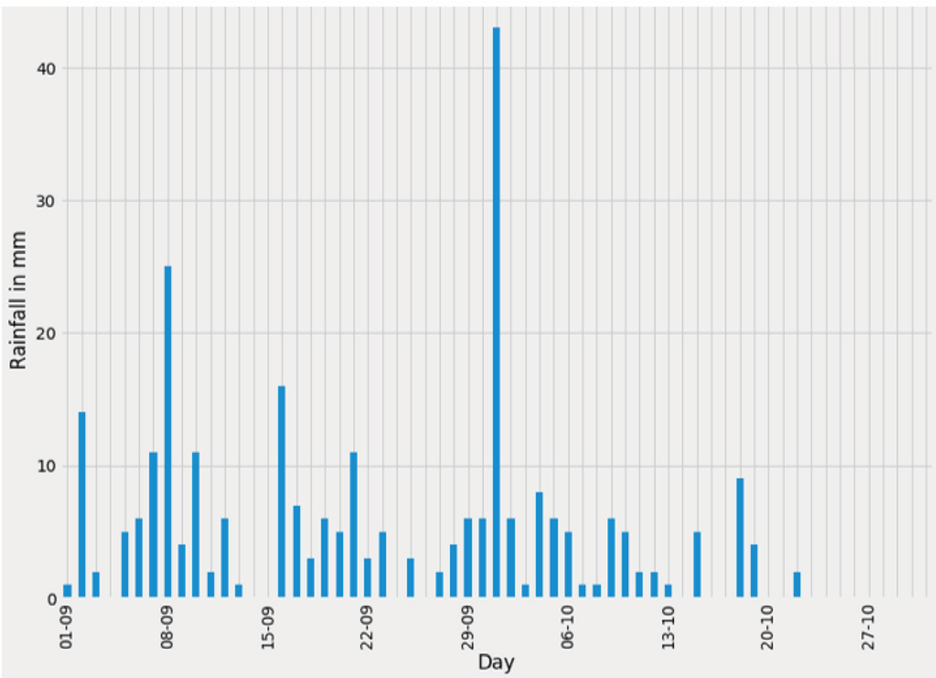

Figure 6. Mean precipitation measured by CO in September and October 2020. Dates on they x-axis with mean precipitation in mm per day measured by the observers in the CO on the y-axis.

5. Results

15 out of 44 observers responded to the evaluation survey. Of these 15 respondents, 12 are teaching at a JHS, one teaches a Primary School, one is from a participating Education Office, and one teaches at the Gbewaa College of Education in Pusiga, where new teachers are trained.

5.1. Data for scientific input

Assuming that the schools are well-distributed, the coverage per school is presented in Table 2. Here we assume all observers take measurements. However, out of the 44 newly joined observers, only 35 took measurements. A total of 16 (46%) of these observers received feedback on how to improve the precipitation measurements. In total, 17% of all measurements needed correction.

Figure 7 shows the percentage of observers recording a certain number of measurements. The measurements were divided into blocks of 10. More than 50% of all observers did not record more than 10 measurements over a period of 60 days. The performance of at least half of the observers was therefore quite low.

Table 2. Coverage per school.

Region	Schools	Area [km^2]	Coverage [km^2/school]
West Mamprusi	10	2602	260
Sissela East	17	5100	300
Sissela West	6	1854	309
Wa East	10	4335	434
Pusiga	1	254	254

However, the number of measurements is influenced by the understanding of when to take measurements. Although the training and manual provided to the observers state that measurements should be taken and recorded every day, including when it does not rain, not all observers follow this instruction. Figure 8 shows the result of the survey: The graph on the left shows that 70% of the respondents took measurements every day when it rained. Only 26% of the respondents also took and recorded measurements when it did not rain. This can partly explain the reduced number of recorded measurements.

The time when measurements are taken further influences the usefulness of a certain measurement. The more measurements that are taken in a similar time frame, the better the measurements can be compared and function as a network. While Figure 8 demonstrates in the right pie chart the time that observers claim to take their measurements, the pie chart in Figure 7 shows the actual timing of the observations taken. As explained in the Design limitations of the Program of Requirements (Table 1), part of the observers choose the time to take the measurement according to the rainfall patterns or to their own availability. The observers have been instructed to take measurements around 9 AM. Still, only 30% of the measurements are between 8 AM and 10 AM.

In Figure 9 the means of the accumulated precipitations of the TAHMO and CO networks have been plotted against each other in a Double Mass Curve. The TAHMO network accounts for an accumulated precipitation of 133 mm over October, while the CO measured a total of 41 mm. This is visualized in the Mass Curve to be found in Figure SM2 in the Supplementary Material.

5.2. Applying the project for SDE

5.2.1. Motivation of the teachers to be part of SaS

The respondents to the survey were asked to rank their motivation (on a scale from 1 to 5, 5 being highest) for joining this project and taking measurements. All respondents ranked their own motivation positive. The respondents were either quite motivated (ranked 3), very motivated (ranked 4), and extremely motivated (ranked 5). However, when we compare their indicated motivation with the recorded measurements, the respondents indicating to be extremely motivated, recorded measurements ranging from 7 to 45, and the highest number of recorded measurements were taken by a respondent indicating to be only quite motivated.

The highest-ranking reasons/motivations for joining the project are:

- By measuring rainfall now, we can help collect sufficient data to improve rainfall information in the future, to know when the rainy season really starts – 14 out of 15 respondents.
- To give my students practical education on rainfall patterns and climate change – 10 out of 15 respondents.

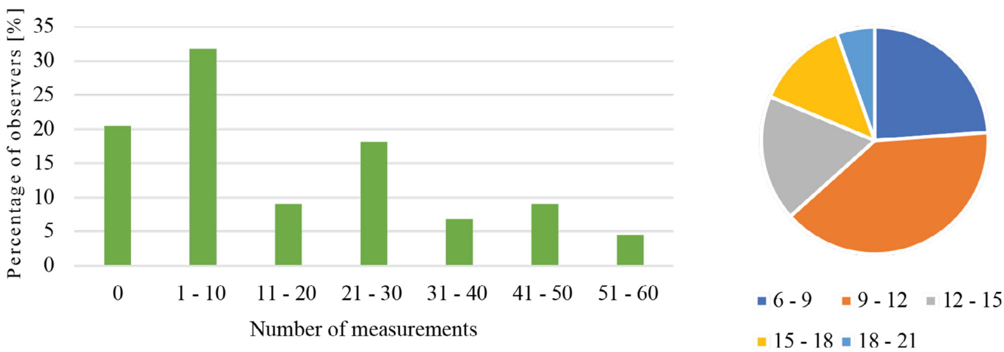

Figure 7. Percentage of observers taking a certain number of measurements during September and October 2020 (left), and the percentage of measurements taken in different time frames (right).

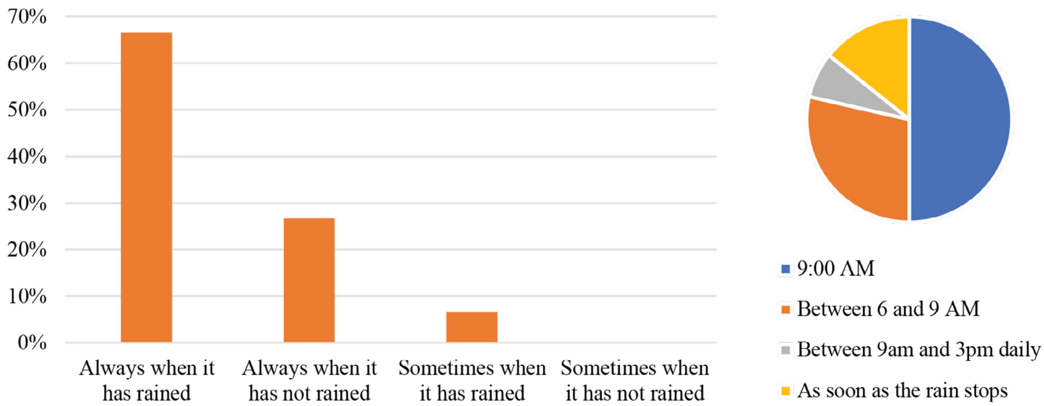

Figure 8. Response to survey concerning regularity: when (left) and at what time (right) observers claimed to take their measurements.

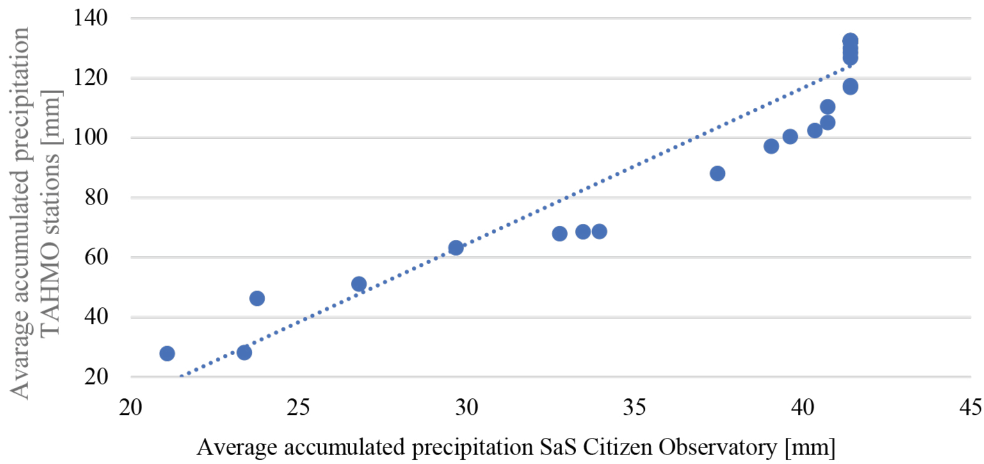

Figure 9. Double mass curve depicting the accumulated precipitation measured by TAHMO (y-axis) plotted against the accumulated precipitation measured by the SaS CO (x-axis)

Table 3. Ranked motivation compared to the number of measurements taken by respondents

Indicated motivation	Number of measurements taken			Number of respondents indicating a level of motivation
	Min.	Max.	Average	
Quite motivated	0	58	22	6
Very motivated	8	51	23	6
Extremely motivated	7	45	20	3

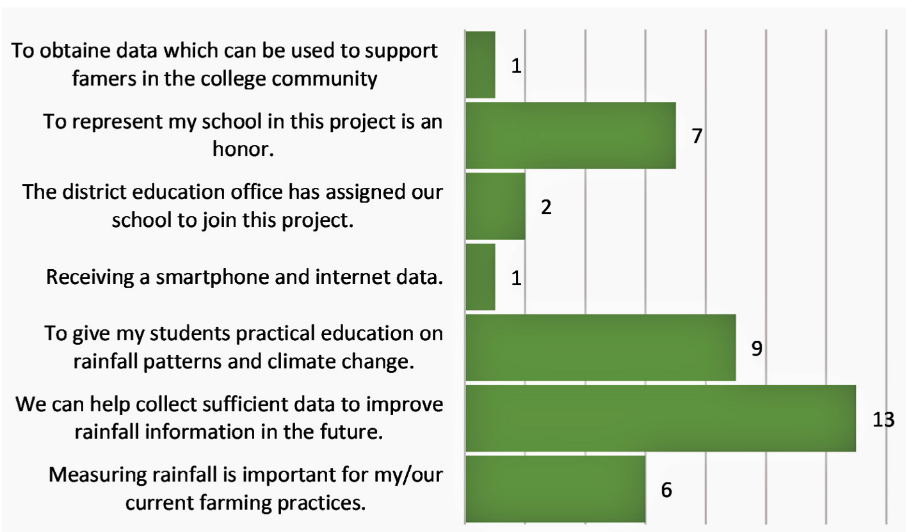

Figure 10. Given motivations for joining the project. The respondents were able to choose more options

The two observers that also chose for the options [Receiving a smartphone and internet data] and/or [The district education office has assigned our school to join this project], only took 7 or 8 measurements respectfully. These options were not chosen as standalone motivations.

Motivation can be influenced by the (1) difficulty of doing the work, (2) time spent on doing the work, and appreciation of feedback received. In Figure 11, Figure 12, and Figure 13 respectively the respondents indicate these factors. Overall, responses are ranked as quite easy and very easy, not too time-consuming (on average not more than 5 to 10 minutes of work), and the feedback received as useful to very useful.

When the respondents to the survey were asked whether they had enjoyed taking measurements, 12 of the respondents answered yes. One respondent said that it was not enjoyment but curiosity that he/she experienced, and this was due to the time and commitment the work needed. Only one respondent clearly indicated that there had not been enjoyment, explaining that he/she "was located in northern Ghana, where it is possible to get rainfall during the dry months". Since the average dry season means no rainfall at all, the project has been paused, and probably this observer feels alone.

The given reasons for enjoyment came down to educative (5 respondents); fun/exciting/interesting (4 respondents); the procedure is simple (1 respondent); adding to research (1 respondent); it creates independence in taking rainfall measurements (1 respondent); knowing how rainfall measurements are taken (2 respondents). Respondents furthermore learned things about how a rain gauge works (2 respondents); how to take accurate readings from a rain gauge (5 respondents), recognizing rain patterns: amount of precipitation and number of storm events within a certain period (4 respondents); to make an instrument for measuring rainfall (1 respondent).

5.2.2. Application of the SaS project for SDE

From the 15 respondents, 10 respondents answered question related to SDE. To the question whether they had already included their students in taking the measurements, 7 respondents answered positively. The way teachers apply the inclusion of their students is done in many ways. Some teachers choose for students to observe whilst the teacher takes the measurement or are meant as Teacher Learner Activity. Most teachers, however, include their students by teaching or training one or more students to take and record the measurement. One respondent also made clear that "year 3 was taught to draw the precipitation graph for one whole month". Another respondent did not mention any inclusion in the practical work, but to "explain to them the impact and usefulness of the facility [meaning the rain gauge] and how to protect it".

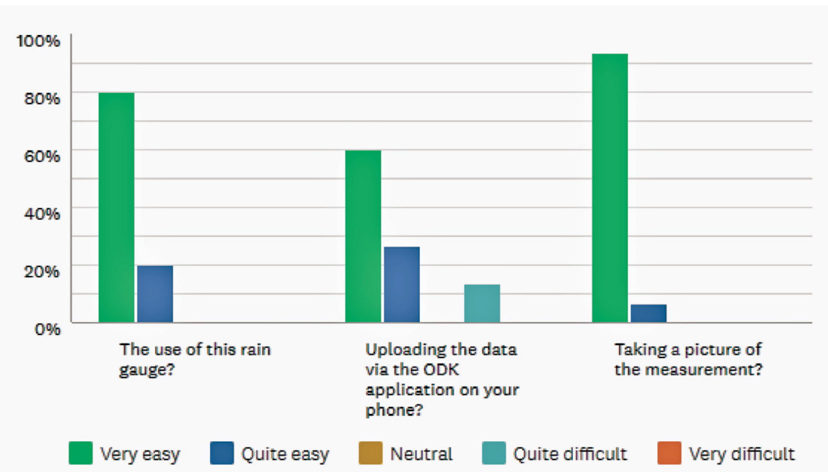

Figure 11. Level of difficulty indicated by the respondents for the actual observing tasks involved.

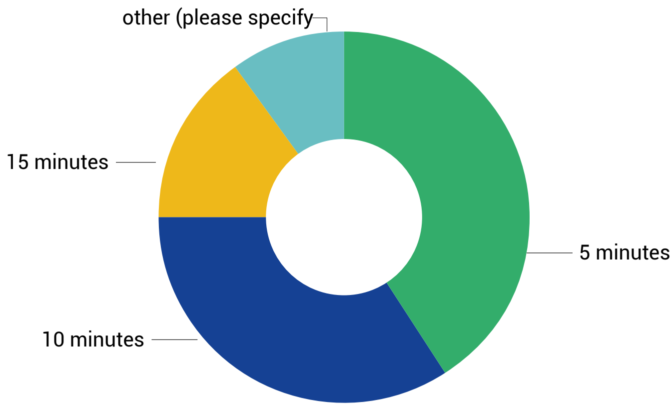

Figure 12. Time spent on observing tasks by observers. Other was specified as: More than 15 minutes because of the network speed.

To keep the students engaged and to encourage the student to take measurements, the 10 respondents indicated different measures that will be taken:

1. The students will be encouraged to explain what they have learned about rainfall and climate change to their parents.
2. The students will be explained the importance and usefulness of taking measurements and studying rain fall patterns. (2 respondents)
3. The students will be allowed to take rainfall measurements themselves. (2 respondents)
4. By giving the students the opportunity to express themselves.
5. By teaching and encouraging students to make their own rain gauge.
6. By starting a weather monitoring club, where the students will design charts using their own home instrument to measure rainfall.

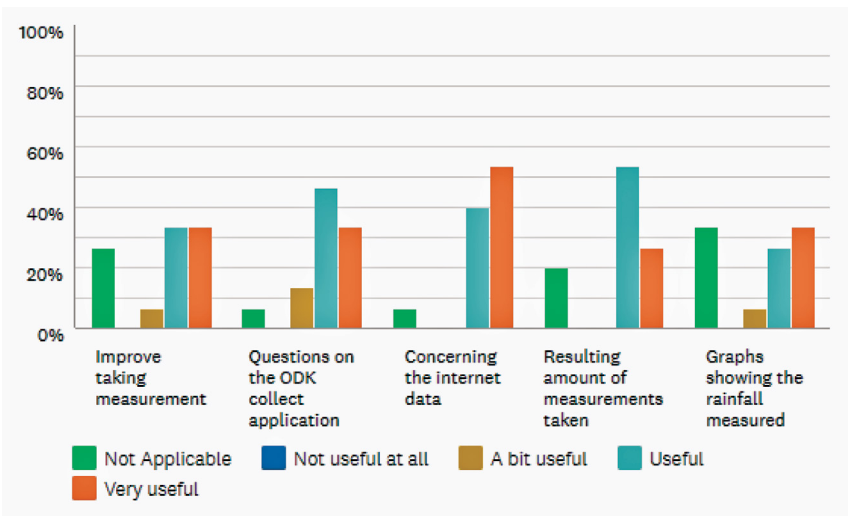

Figure 13. Perceived appreciation of different types of feedback received.

Figure 14 shows that almost all respondents have been able or are planning to use the teaching material provided by the SaS project. Two of the respondents did not look at the materials provided yet.

Of the 10 respondents, 4 are (until now) happy with what the materials provide, 3 have yet to study it well or indicate that they did not receive the material, and 4 indicated some missing materials:

- A raincoat and/or umbrella should be provided to take the measurement when it rains
- Work sheet for practical lessons should be added
- There should be more graphs and illustrations in the material provided
- Explanatory material on how to interpret the provided graphs given as feedback
- Reading materials on rainfall so that they can learn more about rainfall

The respondents also indicated what learning goals they set for their students, and what they expected their students to have learned after this project. These results are compared in Figure 15. Of the 10 respondents, 7 respondents expected the learning points after teaching with SaS to be equal to their set learning goals. However, 3 of the respondents saw that their goals would not completely be met by what SaS provided. One respondent indicated that [Understanding how climate change can influence rainfall patterns] was one of the set learning goals but did not expect this to be learned by the students during the project. The same respondent indicated [Making their own rain gauge] as an expected learning point, although it was not a specific learning goal. Another respondent had set [Understanding rainfall patterns] as single learning goal, and expected this as a resulting learning point, but also added all other learning points as expected results from the project. The last respondent indicated to aim for all given learning goals but did not expect that [Taking rainfall measurement] nor [Understanding satellite measurements] would be achieved.

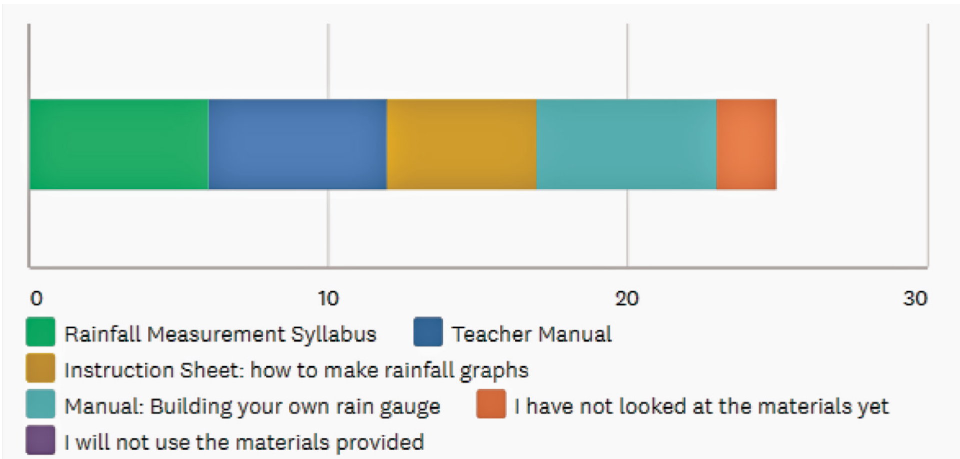

Figure 14. Applying teaching materials made available by the SaS project to their teaching.

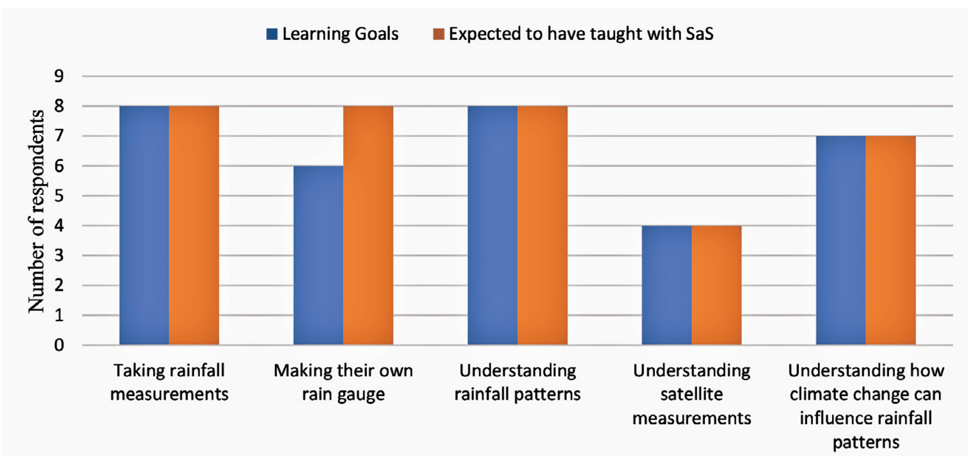

Figure 15. Learning goals compared to expected learning points after students taking rainfall measurements are being taught about it in class.

6. Discussion and recommendations

The intermediate results give a good indication of whether this project is, and in the future will be, able to deliver good and representative data for scientific input and applicable for SDE purposes. Currently, the 5 northern regions, in total accounting for about 97702 km2, count with 8 TAHMO and 16 GMet stations. That is an average coverage of 4070 km2 per station. With a coverage of approximately 311 km2 per measurement site, the network is densified by about 13 times. Of course, for now this only applies to 4 divisions (metropolitans, municipalities, districts) of the 5 regions, but its possibilities are promising.

However, for the sites to be an addition to the network, continuous measurements should take place. The early results of the CS campaign - with a considerably low number of daily measurements – raise an issue of concern for the future reliability of the CS data. For example, there might be storm events missed. Although the survey shows that this can be partly explained by missing recordings in dry days, the number of participants in the survey mentioning such practices does not compare to the number of missing recordings. Furthermore, the timing of the recording has been inconsistent. For correct training and validation of the rainfall retrieval model, it is of high importance that all measurements are taken at the same time – or, failing that, as uniformly as possible. Therefore, special emphasis must be made on correcting this aspect in the future of the project, for a successful continuation.

Data validity is high due to the proven validation method of S4W. All measurements have been corrected when needed. Furthermore, it is expected that the rate of needed corrections will decrease in the future, due to the feedback mechanism where observers can learn to improve their measurements. Data reliability - whether all the precipitation is measured - is less secure due to the clearly visible lack of recording of at least half of the observers. The survey indicates that this is not only because no recording equals no rain. The Double Mass Curve follows quite a straight line, showing that the measurements taken by the observers are proportional to the measurements taken with the TAHMO stations. They however also show that the TAHMO stations overall have measured more than three times as much precipitation as the CO. This either indicates that many storm events have been missed in a continuous manner by the CO, or that the variability of rain is indeed clearly visible. To be conclusive on this, the CO network should be expanded. To ensure that all measurements taken by the CO can be included for training and validation of the rainfall retrieval model, the time of measurement and continuity of taking measurements should be regulated better.

Indicated motivations for joining the project are positive, but do not always reflect the actual recorded measurements taken by those respondents. Motivations for joining the project confirm the reasons to which the project was designed: improving rainfall information, which is the main reason for this research, and giving practical education on rainfall patterns and climate change. It is also interesting the high number of respondents that indicated the motivation "To represent my school in this project is an honour", representing more than half of the respondents. This ratifies a recurrent topic in conversations with local communities – the strong sense of honour and purpose of individuals within a community inherent to the culture of northern Ghana. The respondents in general respond in a positive manner concerning factors that strongly influence the motivation of citizen scientists; time consumption, level of difficulty, feedback received. Needed time for the tasks and level of difficulty were ranked low. Time consuming projects are in general not encouraging the participation of citizen scientists (Land-Zandstra et al., 2016). However, other research points out that when participants perceive tasks as meaningful, they feel a sense of mission to devote substantial time and energy to the task, which also works vice versa, by designing a project that enables the citizen scientist to devote considerable time and energy for completing a task, to perceive it as meaningful (Tinati et al., 2017; Zou et al., 2020). Feedback received was indicated to be useful. Several studies highlight feedback as one of the consistently returning prerequisites for prolonged engagement by the citizen scientist (Chu et al., 2012; Devictor et al., 2010; Sullivan et al., 2009; Land-Zandstra et al., 2016).

With the teachers being motivated, students are indirectly included and motivated as well. Involvement of students has already occurred with 7 out of 10 observers. This involvement is being implemented in several ways, depending on the teachers' own perception of what is necessary and possible. The educational material provided by the project was on average received well and no significant missing aspects were identified. This was also confirmed by the good alignment between learning goals stated by the respondents and the learning points they expect to reach when applying the educational module of SaS. The fact that one of the teachers is planning to start a weather monitoring club is extremely positive and could show the start of a community of observers that goes beyond project level.

The project is already contributing to SDG4 - Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all – and in specific target 4.4 and 4.7. The project is for example assisting to increase relevant skills for farming and incorporates knowledge and skills needed to promote sustainable development through education for sustainable development. Understanding rainfall patterns should in the end add to achievement of SDG6.4 – to address water scarcity and substantially reduce the number of people suffering from water scarcity –, SDG8.4 – by decoupling economic growth from environmental degradation -, and SDG13.3 – improving education and human capacity on climate change adaptation and impact reduction (United Nations 2020). The project therefore allows education to play a clear and critical role in capacity-building for sustainability, which is defined by UNESCO (2018) as the process of empowering learners and society to develop the competences needed for sustainability to emerge. Teachers and students are acting as change agents, with an alignment of their community needs, which are opportunities geared to achieving the SDGs (Kioupi & Voulvoulis, 2019).

After the pilot phase of the SaS project - started in August 2019 – the intention was to carry out the complete CS campaign during the whole 2020 rainy season, approximately from June until October. However, the project faced the challenge of the COVID-19 pandemic. Limitations included closing international borders – that prevented the international SaS team to give collective trainings in Ghana starting in April 2019 – and the closure of schools – that made it impossible to implement the educational module and engage students in the CS campaign. With the help of local partners from TAHMO Ghana, the installation of the Schools and Satellites (SaS) rain gauges began on the 10th of August 2020. The adapted plan was to engage the education directorate to assist SaS with potential schools for the installations. To ensure that the measurements were done daily, the head teacher or the teacher at the selected school had to be resident in the community where the school was located. This condition is especially relevant in the context of northern Ghana, where communities are spread in rural areas and not always easily accessible by road. Simple resulting limitations to the engagement of the observers and the applicability to SDE due to these restrictions directly include:

- The observers received only a limited training and were not able to meet most of the authors face to face, nor meet each other, decreasing the sense of community.
- Classes at schools were discontinued due to the lock-down during the project execution, influencing the number of students that could be involved.
- Due to the mainly online involvement, all educational material is available online, which is an extremely limiting factor in such remote areas. Only 3 out of 10 respondents in the survey indicated having access to computers with an internet connection. To increase the outreach and implementation for SDE, printed education material should be handed to teachers.

Except for KSFs that are to be implemented in a later stage of this project, all have been applied successfully. The input provided in the survey will be applied to improve the CS engagement plan previously made before the next rainy season and complete CS campaign. Future work considered for implementation during the duration of the project include:

- Extend the CS network to other divisions in all regions. For example, before the corona outbreak there were more education offices eager to join the project than those that are currently participating. It is expected that their interest will be renewed after or in a later stage of the pandemic.
- Further investigate, on an individual basis, the reason for the reduced number of measurements the observers took. In this way results will be improved in the future.
- The suggestions for improvements and additions to the educational module and material will be discussed and when possible, implemented.
- Find ways to motivate participants to change the timing of the measurements and to avoid missing recordings in dry days.
- Encourage the teachers to share ways of engaging their students in this topic and for example assist the creation of a weather monitoring club between the students at the different schools.
- To keep engagement, a local Ghanaian young professional and/or a Ghanaian university student will be involved in the coordination team. Furthermore, this transfer knowledge will contribute to sustainability of the project.
- Once the lock-down has passed, improve concerning mentioned limitations due to the lock-down, like for example enabling workshops and printed material that can be handed over for the teachers and students to be used.

This way, the project will work towards implementing all possible KSFs. To ensure sustainability after full project implementation, the SaS Citizen Observatory will be continuously supported by GMet, TAHMO and S4W concerning use of data, community engagement and data recording and validation. Additionally, other networks such as active youth networks working in environmental issues in northern Ghana, could potentially be involved in the project.

7. Conclusion

It can be concluded that it is not only possible but desirable to implement CS in a formal educational setting, when both an educational gap can be filled as well as the relevance of the topic of research is clear and particularly of high importance for the participating schoolchildren and teachers. Furthermore, by including the needs and school setting demands early in the design stage of the CS research project the practicalities can be tailored to the school setting. By implementing the Key-Success Factors earlier defined by previous research, a CS project applied in an SDE setting can provide both scientific input and a method for Sustainable Development Education in school settings. Such CS projects however will always need continuous attention and work and iteration for improvement is inevitable. When researchers and schools are willing to work together towards a common sustainable goal, cooperation via CS will enable both their own needs and the globally agreed upon Sustainable Development Goals.

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References

Antwi-Agyei, P., Fraser, E.D.G., Dougill, A.J., Stringer, L.C., Simelton, E. (2012). Mapping the vulnerability of crop production to drought in Ghana using rainfall, yield and socioeconomic data. Applied Geography, Volume 32, Issue 2, 2012, Pages 324-334, ISSN 0143-6228. https://doi.org/10.1016/j.apgeog.2011.06.010.

Calabrese Barton, A.M. (2012). "Citizen(s') science: a response to 'The Future Of Citizen Science'." Democracy & Education, vol. 20, no. 2, 2012. Accessed 30 July 2020.

Ballard, H.L., Dixon, C.G., Harris, E.M. (2017). Youth- focused citizen science: examining the role of environmental science learning and agency for conservation. Biol. Conserv. 208, 65–75.

Boakye, C. (2015). Climate Change Education: The Role of Pre-Tertiary Science Curricula in Ghana. First Published December 16, 2015 Research Article. https://doi.org/10.1177/2158244015614611

Chu. M., Leonard, P., Stevenson F. (2012). Growing the base for citizen science: Recruiting and engaging par- ticipants. In: Dickinson JL and Bonney R (eds) Citizen Science: Public Participation in Environmental Research. Ithaca, NY: Cornell University Press, pp. 69–81.

Davids, J.C., Devkota, N., Pandey, A., Prajapati, R., Ertis, B.A., Rutten, M.M., Lyon, S.W., Bogaard, T.A., van de Giesen, N. (2018). Soda bottle science - citizen science monsoon precipitation monitoring in Nepal. Frontiers in Earth Science.

Devictor, V., Whittaker, R.J., Beltrame, C. (2010). Beyond scarcity: Citizen science programmes as useful tools for conservation biogeography. Diversity and Distributions 16(3): 354–362.

Golumbic, Y.N., Baram-Tsabari, A., Koichu, B. (2019). Engagement and Communication Features of Scientifically Successful Citizen Science Projects, Environmental Communication, DOI: 10.1080/17524032.2019.1687101

IPCC, Geneva. (2007). IPCC Fourth Assessment Report. Url: archive.ipcc.ch

IPCC, Geneva. (2019). IPCC Special Report on Climate Change and Land. Url: https://www.ipcc.ch/srccl/

Kassam, A.H. (1976). Crops of the West African Semi-Arid Tropics. INTERNATIONAL CROPS RESEARCH INSTITUTE FOR THE SEMI-ARID TROPICS 1-11-256, Begumpet, Hyderabad 500 016, A. P., India. Url: http://oar.icrisat.org/641/1/RA_00016.pdf. Cited on 30-11-2020.

Keller, L., Stötter, J., Oberrauch, A., Kuthe, A., Körfgen, A., Hüfner, K. (2019). Changing Climate Change Education: Exploring moderate constructivist and transdisciplinary approaches through the research-education co-operation k.i.d.Z.21. GAIA - Ecological Perspectives for Science and Society, Volume 28, Number 1, 2019, pp. 35-43(9). Publisher: oekom verlag. DOI: https://doi.org/10.14512/gaia.28.1.10

Kniveton, D.R., Layberry, R., Williams, J.R., Peck, M. (2009). Trends in the start of the wet season over Africa. International Journal of Climatology, 29, 1216–1225. https://doi.org/10.1002/joc

Kioupi, V., Voulvoulis, N. (2019). Education for Sustainable Development: A Systemic Framework for Connecting the SDGs to Educational Outcomes. Sustainability 2019, 11, 6104; doi:10.3390/su11216104

Land-Zandstra, A.M., Devilee, J.L.A., Snik, F., Buurmeijer, F., van den Broek, J.M. (2016). Citizen science on a smartphone: Participants' motivations and learning. Public Understanding of Science 2016, Vol. 25(1) 45 –60. DOI: 10.1177/0963662515602406

Mochizuki, Y., Bryan, A. (2015). Climate Change Education in the Context of Education for Sustainable Development: Rationale and Principles. First Published June 4, 2015. Research Article. https://doi.org/10.1177/0973408215569109

Mueller, M.P., Tippins, D., Bryan, L.A. (2012). The future of citizen science. Democracy & Education, 20(1). Article 2. Available online at http://democracyeducationjournal.org/home/vol20/iss1/2/.

Pitt A.N., Schultz, C.A. (2018). Youth-based citizen science monitoring: Case studies from three national forests. J. Forest. 116, 109–16.

Rotman, D., Hammock, J., Preece, J., Hansen, D., Bowser, A. (2014). Does Motivation in Citizen Science Change with Time and Culture?

Rutten, M., Minkman, E., van der Sanden, M. How to get and keep citizens involved in mobile crowd sensing for water management? A review of key success factors and motivational aspects WIREs Water 2017, 4:e1218. doi: 10.1002/wat2.1218

Soanes, K., Cranney, K. Dade, M.C., Edwards, A.M., Palavalli-Nettimi, R., Doherty, T.S. (2019). How to work with children and animals: A guide for school-based citizen science in wildlife research. Ecological Society of Australia. doi:10.1111/aec.12836

Sullivan, B.L., Wood, C.L., Iliff, M.J., Bonney, R.E., Fink, D., Kelling, S. (2009). eBird: A citizen-based bird obser- vation network in the biological sciences. Biological Conservation 142(10): 2282–2292.

Tinati, R., Luczak-Roesch, M., Simperl, E., & Hall, W. (2017). An investigation of player motivations in Eyewire, a gamified citizen science project. Computers in Human Behavior, 73, 527–540.

UNESCO, Paris. (2017). Education for Sustainable Development Goals. The Global Education 2030 Agenda

UNESCO, Paris. (2018). Issues and Trends in Education for Sustainable Development. Published in 2018 by the United Nations Educational, Scientific and Cultural Organization, 7, place de Fontenoy, 75352 Paris 07 SP, France. ISBN 978-92-3-100244-1 Url: https://en.unesco.org/sites/default/files/issues_0.pdf

United Nations. (2020). Sustainable Development. Url: https://sdgs.un.org/. Cited on 27-11-2020.

Wals A.E., Brody M., Dillon J., Stevenson R.B. (2014). Convergence between science and environmental education. Science 344, 583–4.

Weinstein, M. (2012). Schools/citizen science: A response to “Th e future of citizen science.” Democracy & Education, 20(1). Article 6. Available at: http://democracy educationjournal.org/home/vol20/iss1/6

World Bank Group. Climate Change Knowledge Platform.Url: https://climateknowledgeportal.worldbank.org/country/ghana/climate-data-projections. Cited on 19-11-2020

Zou, X., Tang, J., Zhao, Y., Wang, T. (2020). Effects of feedback design and dispositional goal orientations on volunteer performance in citizen science projects. Computers in Human Behavior, Volume 107, 2020, 106266, ISSN 0747-5632, https://doi.org/10.1016/j.chb.2020.106266.

Assessing the Impact of Youth Water Education Gap on Water Security in Zaria, Nigeria

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Abstract

This study analyzes the challenges of water insecurity in Nigeria, especially in the Northern part of the country as a result of the gap in water education among youth. There have been different cases of water-borne diseases such as cholera in Zaria with attribution to water poisoning in wells due to lack of education on proper protection of wells. In this investigation, 400 people were engaged in random sampling of data in May 2020 (for a period of 3 weeks). The data is analyzed using Microsoft Excel 2013 software at 95% confidence level. The mean, standard deviation, and student's t-test are computed to ascertain whether the knowledge gap in water education has any impact on water security. The results indicate that 9.25% and 20.75% use borehole and pipe-borne water respectively, compared to about 70% that uses well water. For the well water users, 57.86% draw water from unhygienic, uncovered and cracked-wall wells while 42.14% utilize standard wells. Further analysis shows that 77.75% experience water scarcity during the dry season while 22.25% have sufficient water all year round. Also, an average of 61.625% of the respondents dispose solid wastes and feces near water sources while 38.375% dispose these wastes sustainably. A limited number (13.75%) of the respondents are highly literate in water education, whereas, 30.75% and 55.5% possess basic and zero-knowledge respectively in water education. The P-value (0.726707) greater than 0.05 depicts a possible relationship between the knowledge gap in water education and unsustainable waste management around water sources. Thus, the results of this investigation indicate that the tertiary institutions in Northern Nigeria, most especially Zaria, develop community water education programs to enlighten people on the dangers of water pollution and encourage the youth to become water professionals to tackle these challenges.

Keywords: Water Security, Youth, SDGs, Water Education, Zaria

1. Introduction

The preservation of water quality and quantity is a growing global concern. The World Economic Forum (2015) reports that water insecurity is the largest global risk in terms of potential impact. Specifically, an estimated 785 million of the world population lack basic access to clean drinking water (WHO and UNICEF, 2019) and Sub-Sahara Africa accounts for about 32% (UN, 2016). By 2025, over 1.8 billion people across the globe might be living in countries with complete water scarcity (UNESCO, 2012). Although, Richey et al (2015) have concluded that one-third of the world's biggest groundwater is distressed. This might be a result of increased population growth. Despite the insufficient amount of water, open defecation and poor waste management around water points reduce the universal acceptable quantity of clean water. Generally, water security has been added to a range of security fields such as health, food, energy, environment, political and, economics (Zeitoun, 2011). According to UNESCO-IHP (2012), water security is the capacity of a population to safeguard sustained access to adequate quantities of acceptable quality water and sustained livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political instability. Due to the increased pressure of the human population, unsustainable environmental practices and, high economic development on water availability and standard, education is a vital tool in achieving sustainable development goals (SDG) 6 (Bouchouata et al., 2012).

Water education transcends academic water theories to building bridges between water insecurity and multidisciplinary and interdisciplinary solutions (UNESCO, 2014). It is concisely defined as the teaching and training on water sources, means of supply, and the effects of human activities on its quality. The research conducted by Nagata et al. (2011) indicated that educated individuals handled water better than people with no water background. This was further confirmed by the research from Aboh et al (2015) in Samaru-Zaria where the level of water education was low and contamination of well water was high due to open defecation, poor waste management, unhygienic handling of water containers and inappropriate siting of septic tanks. Also, the strategic importance of water education in mitigating the water-borne epidemic is profound. This is in line with conclusions by Ibrahim et al (2018) after a study at Dutsen-Abba in Zaria on the outbreak of cholera for 3 days which affected 50 people. It was discussed that the epidemic originated from a point source and that well water should be boiled properly before drinking for maintaining good hygiene.

However, the vigor with which to implement and sustain this solution lies with the youth. In every nation, they are the most energetic in driving socio-economic change and development (Odoh et al, 2014). There are several definitions of youth. However, there are variations according to country, organization or context. According to the United Nations (1985), a youth is any person between the ages of 15 to 24 years. This tender age bracket is possibly the best for targeting to build expertise in water security. In contrast, Pitti (2017) posit that the adult age reflects the period of becoming a guardian, gaining complete autonomy of making decisions and taking full responsibility of actions. The age of adulthood closely follows that of youth and is taken to be between 25 to 35 years in this paper: same as the age of elderly which is from 36 years above. A study by Grimmette (2014) on the impact of early environmental education, specifically on water, concludes that enlightening young children is more effective than doing so for older groups. The investigation identified education as a strategic tool for establishing environmental consciousness and bringing about a paradigm shift in youth. Since they are often open to learning and receptive towards change, the outcomes of coherent water programs on them include developing interest in water solutions as a means of livelihood, striving to engage personal behavioral changes and introducing sustainable practices to their local communities (Juanita, 2018). Thus, this empowerment on water knowledge entails not only good health and wellbeing (SDG 3) but zero poverty (SDG 1).

Precisely, women and youth in rural and poor urban centers such as Zaria that have strong potentials to enhance water security are often incapacitated due to the knowledge gap. The research by Sule et al (2017) on the epidemiology of cholera outbreak in the 23 local government of Kaduna State showed that Zaria had the second highest numbers in the first peak, 22 cases and 4 deaths. Similarly, Ibrahim et al (2018) in their investigation on the outbreak of cholera in Zaria uncovered that out of 50 recorded cases with 7 deaths, the average age was that of the youth, 20 years, and more women, approximately 68%, suffered more from the epidemic. These people are highlighted as socially vulnerable people in the Hyogo Framework for Action 2005-2015. A step towards minimizing inequality, sustainable development goal 10, is the integration of these people in the water educational process. Furthermore, water education among youth is highly necessary because of its impact on them as future leaders. For instance, in an investigation carried out by WHO and UNICEF (2000), it was discovered that while 54% of the people in Nepal wanted a budget allocation for water and sanitation projects, only 11% of the local leaders supported this. Conclusively, the local leaders were uninformed on the dangers of water insecurity (Pokhrel and Viraraghavan, 2004).

Currently, the United Nation’s SDGs are in the decade of action. The next ten years will be characterized by spontaneous implementation of the United Nations (UN) Sustainable Development Goals. The action plan is to eliminate water insecurity before 2030 using a joint collaboration with the youths. Hence, the capacity development of young people with water education to build resilience, improve water delivery and sustain quality water resources.

2. Materials and Methods

2.1. Study Setting

This study was conducted in Zaria, located at 11^{0}04’N 7^{0}42’E with a population of 695,089 (NPC, 2016). The research setting is filled with indigenous farmers, local and foreign traders and the academia in evenly distrisbuted proportions.

2.2. Study Design

Within Zaria, the required data were obtained mainly from Samaru, Sabongari, and Zaria City while the rest were randomly completed. A total of 400 people were engaged for this study from these three strategic locations and a few others. The survey, though descriptive, gives a comprehensive cross-sectional analysis of a month’s session in May, 2020. Also, the investigation was carried out among people of different age grade to get a conscise view of the youth knowledge gap on water education. However, the youth account for the majority.

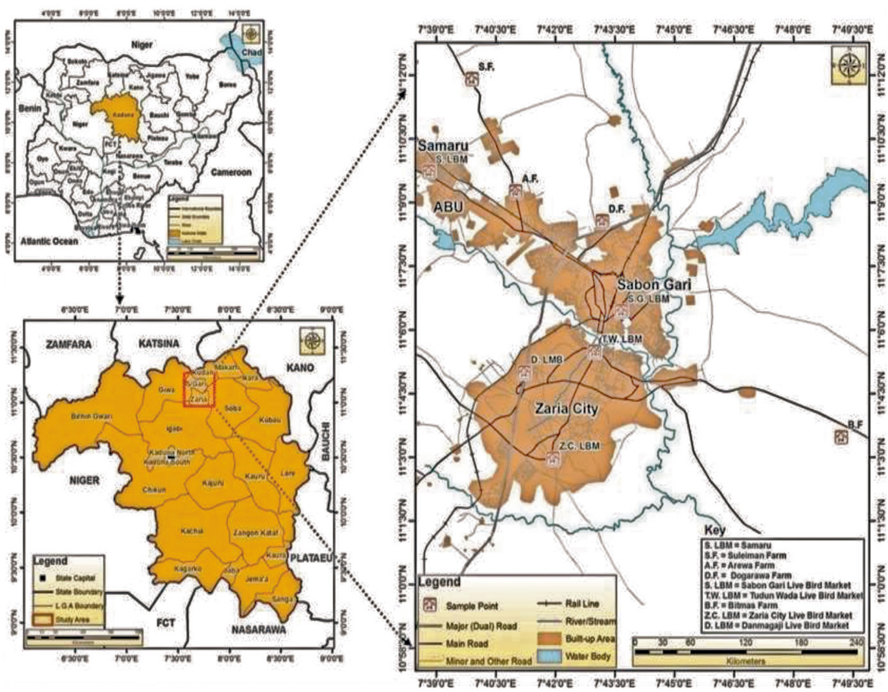

Figure 1: Map of the Study Area (Extracted from Hamisu et al, 2016)

2.3. Size Sampling

In determining the sample size, the statistical method of Krejcie and Morgan (Krejcie and Morgan, 1970) was used. Mathematically,

$$n = \frac{X^2NP(1-P)}{d^2(N\text{-}1) + X^2P(1-P)} \qquad (1)$$

Description; N = Sample Size, X^2 = Chi-square value of 1 degree of freedom at the desired confidence level, N = Population, P = Population proportion, d = degree of accuracy

The approximate Zaria population of 695,089 (NPC, 2016) was used to get the required sample size. At a confidence level of 99% and a 5% degree of accuracy, a sample size of 383 was obtained through interpolation. However, this figure was rounded off to 400 to ensure even assessment of the three strategic locations and the other random areas with at least 75 respondents and above from each region.

A two-stage sampling technique was used in this investigation. From the 23 local government areas of Kaduna State, Zaria was selected because it hosts the majority of the tertiary institutions in the state. Furthermore, the three strategic locations of Samaru, Sabongari and Zaria city were picked inside Zaria. These areas have a unique settlement style. Specifically, Samaru is dominated by literates due to the presence of Ahmadu Bello University, Nigerian College of Aviation Technology, Division of Agricultural College and Nigerian Institute of Leather and Science Technology, Sabongari constitutes majorly of settlers who are business people, and Zaria city is predominantly filled with indigenes, mostly local Hausa farmers.

2.4. Inclusion and Exclusion Criteria

This study was conducted on consenting youth, adults and the elderly. Precisely, consent was a high priority before assessing the knowledge gap of the interviewees. Majorly, only women who declined consent due to their cultural believes were excluded from the survey.

2.5. Preliminary Data Collection Arrangement

Prior to the field survey, the district heads of Samaru, Sabongari and Zaria City were duly informed to facilitate any support from them. Following this, a research team comprising of one community youth leader from each of these areas and one National Youth Service Corps (NYSC) member, was formed and the team was adequately informed on the mode of data collection.

2.6. Data Collection and Management

For this investigation, relevant literature was reviewed. Questionnaires administered and close-ended one-on-one interviews were conducted as the main techniques of data collection. Section 1 captures the socio-demographic characteristics of the interviewees such as age, gender, marital status and educational qualification. The second section gives detailed information on water availability, their sources and mode of sanitation. Section three gives the sanitation coverage. Finally, the fourth section gives an overview of the water knowledge and the proximity of septic tanks, open defecation and dump sites to water sources The study was carriedout via oral consent from the respondents, irrespective of age, gender or status. Also, they were assured of confidentiality on the data obtained from them.

The data obtained were analysed using Microsoft Excel 2013; data were cleaned and errors such as spellings and units of years and distance were adequately checked for and corrected.

Also, coding and categorization were used to group data for easy evaluation. Generally, the data were analyzed using regression analysis and t-test. The essence of the t-test is to establish if a relationship exists between the knowledge gap of the youth and the water insecurity, at a confidence level of 95%.

3. Results

Table 1 shows the socio-demographic characteristics of the respondents. Samaru community produced the highest respondents at about 30.5%, followed by Sabongari with 25.75%, Zaria City has 19.75% and the other random areas have 19.75%. The females and males are both 37.74% and 62.25% respectively. The youth and adult account for 40.5% and 27.75% individually, whereas the elderly is 31.75%. Similarly, 29.5% completed primary school as the highest educational qualification, 32% only have secondary education, 11% attended a tertiary education, 9% did adult education and 18.5% have no basic education. Furthermore, the status of 27.75% of the respondent depicts that they are students, 15.5% are business people, 19.25% are farmers, 20.5% are civil servants and 13% are into various crafts.

Lastly, 20%, 13%, 27.5% and 39.5% have lived within Zaria for less than 10 years, between 11-20 years, within 21-30 years and above 30 years respectively.

Table 1: Socio-demographic characteristics of respondents

Description	Number	Percentage (%)
Location		
Samaru	122	30.5
Sabongari	103	25.75
Zaria City	96	24
Others	79	19.75
Total	400	100%
Gender		
Male	249	62.25%
Female	151	37.74%
Total	400	100%
Age (Years)		
Youth (15-24)	162	40.5%
Adult (25-35)	111	27.75%
Elderly (36-Above)	127	31.75%
Total	400	100%
Marital Status		
Married	235	58.75%
Single	155	38.75%
Divorced	10	2.5%
Total	400	100%
Highest Educational Level		
Primary	118	29.5%
Secondary	128	32%
Tertiary	44	11%
Adult Education	36	9%
Uneducated	74	18.5%
Total	400	100%
Status/Occupation		
Student	111	27.75%
Business	62	15.5%
Farming	77	19.25%
Civil Servant	82	20.5%
Craftsman	52	13%
Total	400	100%

Description	Number	Percentage (%)
Period of Stay in Zaria (Years)		
1-10	80	20%
11-20	52	13%
21-30	110	27.5%
Above 30	158	39.5%
Total	400	100%

As shown in Table 2 which provides information on water sources and sanitation facilities, a total of 70% consumes well water, 20.75% use pipe-borne water and 9.25% utilize borehole. A breakdown indicates that 29.5% take water from standard wells devoid of cracked walls and have covers while 40.5% consume water from substandard wells. The statistics on water availability indicates that only 77.75% of the water sources have water during the rainy seasons, in contrast to 22.25% having water during both raining and dry seasons. Additionally, respondents with simple pit latrines that have covers were just 12.25% in comparison to 35.25% whose simple pit latrines lacked covers and VIP latrines and water closets accounted for 16.5% and 8.25% respectively whereas 27.75% indulged in open defecation due to absence of sanitation facilities. Also, Table 3 gives the sanitation coverage; about 37% had improved sanitation but unimproved sanitation and open defecation were 35.25% and 27.75%, respectively.

On the other hand, Table 4 covers the level of water education and waste depots around water sources. About 13.75% of the study subjects are highly-knowledgeable, 30.75% possess little awareness and the percentage with no water education is 55.5%. Again, 61.75% have their fecal sludge locations within 16m of water sources and 38.25% situated theirs far way. Similarly, 61.5% dispose of solid wastes around 30m to water points and 38.5% deposit wastes at distant locations.

Table 2: Water sources and Sanitation facilities

Description	Number of respondents	Percentage (%)
Water source		
Standard well (covered and un-cracked walls)	118	29.5%
Sub-standard well (uncovered and cracked walls)	162	40.5%
Total	280	70%
Pipe borne water	83	20.75%
Borehole	37	9.25%
Total	400	100%
Availability of water		
Raining season only	311	77.75%
Both raining and dry season	89	22.25
Total	400	100%
Sanitation Mode		
Simple pit latrine with cover	49	12.25%
Simple pit latrine without cover	141	35.25%
VIP latrine	66	16.5%
Water closet	33	8.25%
Open defecation	111	27.75%
Total	400	100%

Table 3: Sanitation coverage

Improved Sanitation		Unimproved Sanitation		Open defecation	
Type	Frequency	Type	Frequency	Type	Frequency
Water Closet VIP latrine Simple pit latrine with cover	33 66 49	Simple Pit latrine without cover	141	Open Fields/Bushes	111
Total **Percentage**	**148** **37%**		**141** **35.25%**		**111** **27.75%**

The data in Table 5 show the average sustainability for this study. The knowledge of waste management around water sources is limited. This fact holds true especially in rural or semi-urban areas like Zaria. In this survey, an average of 61.625% have a sustainable waste culture and 38.375% manage wastes unsustainably. The last table gives a detailed analysis of the water education level on the closeness of waste depot to water sources. The t-test value (-0.34976) and p-value (0.726707) > .05 at a confidence level of 95% (-0.1719723 to 0.120024) shows that a relationship exists between the level of water education and closeness of waste/fecal deposition sites to water sources.

Table 4: Water educational level and distance of solid/fecal waste disposal unit from water source

Description	Number of respondents	Percentage (%)
Level of water education		
Highly-knowledgeable	55	13.75%
Little awareness	123	30.75%
No water education	222	55.5%
Total	400	100%
Closeness of pit latrine/ soak away/ open defecation sites to water source		
Below 16m	247	61.75%
Above 16m	153	38.25%
Total	400	100%
Closeness of dump site to water source		
Below 30m	246	61.5%
Above 30m	154	38.5%
Total	400	100%

Table 5: Average number of respondents with sustainable and unsustainable waste ways

Average number disposing waste	Calculation	Percentage (%)
Unsustainable	$\frac{61.75 + 61.5}{2} = 61.625$	61.625%
Sustainable	$\frac{38.25 + 38.5}{2} = 38.375$	38.375%

Table 6: Analysis of educational levels on water issues and closeness of waste depot to water source

Variable	95% confidence level	df	t-value	P-value
Level of water education Closeness of septic tank/ soak away/ open defecation to water source	-0.1719723 to 0.120024	398	-0.34976	0.726707

4. Discussion

From this study, 82.5% of the people possess at least, a primary education and 18.5% have no basic education. Thus, a good number of people are educated, are able to speak, write and comprehend the English language. However, they lack knowledge about the effect of open defecation and unsustainable disposal of wastes on water quality. An average of 61.38% unsustainable waste disposal methods confirms this observation. This study shows a similar outcome with that of Alfa et al (2018) conducted at Oforachi in Kogi State, Nigeria. From their report, 48% of people defecate in the open, sometimes within proximity to Ofu River which serves as the main drinking water source for more than half of the populace. Also, the number of females is more than one-third of the total participants, connoting that more women are gaining interest in joining the data collection and solution process for water security planning. This applies to the number of youths and young people too.

The 37% of people who have improved sanitation facilities is low when compared to a combined 63% who have unimproved sanitation and openly defecate. More so, the 30.75% and 55.50% each having little to no water knowledge will require a comprehensive water program. Generally, the youth demographic is high. Hence, investing in water education for them will yield a high dividend on water security.

5. Conclusions

From this survey, it is clear that the level of youth knowledge on water problems in Zaria is low. Consequently, this study recommends that since they have a significant population and energy in Zaria, they should be given water education through the academic institutions, vocational schools, and other non-formal means to first increase their environmental consciousness and extend to their local communities and secondly to develop their creativity and wild imagination to become water professionals such as researchers, engineers, technologists, managers and policy analysts to tackle the water insecurity.

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The author declares that there were no conflicting or competing interests. Also, the funding was directly on the author.

Definition of Abbreviations

WHO	World Health Organization
UNICEF	United Nation International Children Education Fund
UN	United Nation
UNESCO	United Nations Economic, Scientific and Cultural Organization
UNESCO-IHP	United Nations Educational Scientific and Children Organization Intergovernmental Hydrological Programme

References

Aboh E. A., Giwa F. A., and Giwa A. (2015). Microbiological assessment of well waters in Samaru, Zaria, Kaduna State, Nigeria. *Annals of African Medicine.* Available from: http://www.annalsafrmed.org/text.asp?2015/14/1/32/148732

Alfa M. I., Daffi R. E., and Ajibike M. A. (2018). Assessment of sanitation and water supply coverage in a rural community of Kogi State, Nigeria; *Asian Journal of Environment and Ecology*. 6(4): 1-8, 2018; Article no.AJEE.41602 ISSN: 2456-690X

Grimmette K. A. (2014) The Impacts of Environmental Education on Youth and their Environmental Awareness. *Environmental Studies Undergraduate Student Thesis, University of Nebraska – Lincoln*. http://digitalcommons.unl.edu/envstudtheses/135

Hamisu T. M., Kazeem H. M., Majiyagbe K. A., Sa'idu L., Jajere S. M., Shettima Y. M., Baba T. A., Olufemi O. T., Shittu I., and Owolodun O. A. (2016). Molecular screening and isolation of Newcastle disease virus from live poultry markets and chickens from commercial poultry farms in Zaria, Kaduna state. *Sokoto Journal of Veterinary Sciences*. DOI:10.4314/sokjvs.v14i3.3

Hyogo Framework for Action 2005-2015 (UNISDR 2007): Building the Resilience of Nations and Communities to Disasters. *Extract from the Final Report of the World Conference on Disaster Reduction* (A/CONF.206/6). United Nations International Strategy for Disaster Reduction.

Ibrahim B. S., Mohammed Y., Usman R., Okon U. A., Katchy U. I., and Olufemi A. A. (2018). Outbreak of cholera at Dutsen-Abba Ward Zaria local government area, Kaduna State Nigeria 2015: the importance of hygienic practices. *International Journal of Community Medicine and Public Health* 4:1473-8 doi:10.11604/pamj.cp.2018.8.9.591 (www.ijcmph.com)

Jardioui Y., Elachqar A., Kaddari F., and Ijjali M. (2015). Education: Essential Approach for a Better Water Management. *Procedia Social and Behavioral Sciences*, 191, pg 896-899 doi:10.1016/j.sbpro.2015.04.429

Juanita A., (2018) Water Youth Network, lesson from a workshop on Adavancing Towards the Water Security Agenda by UNICEF, WHO/PAHO with the support of the Colombian government and facilitated by CAWST https://www.wateryouthnetwork.org/advancing-towards-the-water-security-agenda/

Krejcie R. V., and Morgan D. W. (1970). Determining sample size for research activities. Educational and psychological measurement. 30(3):607-610.

Nagata J. M., Valeggia C. R., Smith N. W., Barg F. K., Guidera M., and Bream K. D. (2011). Criticisms of chlorination: social determinants of drinking water beliefs and practices among the Tz'utujil Maya. *Revista Panamericana de Salud Pública (Pan American Journal of Public Health),* 29: 09-16. ISSN: 1680-5348

Nigeria Population Council, 2016. Fact sheet (Internet), (cited 2020 January 8). Available on http://www.popcouncil.org/research/Nigeria

Odoh R., Eugene H., and Innocent E. O. (2014). Role of the youths in national development. Singaporean Journal of Business Economics and Management Studies Volume 3, No. 2. DOI:10.12816/0007349

Pitti, I. (2017). What does being an adult mean? Comparing young people's and adults's representations of adulthood Journal of Youth Studies, 20(9), 1225 – 1241 doi://.org/10.1080/13676261.2017.1317336

Pokhrel D., and Viraraghavan T. (2004) Diarrhoeal diseases in Nepal vis-à-vis water supply and sanitation status Journal of Water Health, 2 (2): 71-81 https://doi.org/10.2166/wh.2004.0007

Richey A. S., Thomas B. F., Lo M. H., Reager J. T., Famiglietti J. S., Voss K., Swenson S., Rodell M. (2015) Quantifying renewable ground water stress with GRACE, Water Resour., Res., 51. 5217 – 5238. Doi:10.1002/2015WR017349

Sule I. B., Yahaya M., Aisha A. A., Zainab A. D., Ummulkhuthum B., and Nguku P. (2017). Descriptive epidemiology of a cholera outbeak in Kaduna State, Northwest Nigeria 2014, The Pan African medical journal 27 doi:10.11604/pamj.2017.27.172.11925

UN, 2016. The sustainable development goals report. New York: United Nations; 2016.

UNESCO, 2012. The United Nations World Water Development Report 4. Paris, France: World Water Assessment Programme.

UNESCO, 2014, UNESCO's Intergovernmental Scientific Cooperative Programme in Hydrology and Water Resources.

UNESCO-IHP, 2012. Final Report. 20th Session of the Intergovernmental Council. Paris, 4-7 June, 2012. Paris, France: UNESCO.

United Nations, 1985. Secretary General's report to the General Assembly, A/40/256.

WHO and UNICEF, Joint Monitoring Programme, 2019. Progress on drinking water and sanitation. https://www.who.int/news-room/fact-sheets/detail/drinking-water

WHO, 2015. Progress on drinking water and sanitation: 2015 update and MDG assessment.

World Economic Forum, Global Risks 2015, 10th Edition (World Economic Forum, Geneva, Switzerland, 2015).

Zeitoun M. (2011) The Global Web of National Water Security, Global Policy 2(3): 286-296 https://doi.org/10.1111/j.1758-5899.2011.00097.x

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