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Global Report on Sanitation and Wastewater Management in Cities and Human Settlements

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A UN-Habitat led initiative with support from:

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UN-HABITAT

The Global Report on Sanitation and Wastewater Management in Cities and Human Settlements

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Foreword

We can develop more sustainable and resilient cities and communities by taking a more comprehensive approach to sanitation and wastewater management while encouraging environmental sustainability and preserving public health.

As the world prepares to mark the halfway point in implementing the Sustainable Development Goals, the dramatic and unacceptable figures on sanitation and wastewater are a stark reminder of the enormous challenges still lying ahead. 3.6 billion people, accounting for nearly half of the global population, still lack safely managed sanitation services and up to 494 million people practise open defecation. In addition, over 80% of the world's sewage is discharged untreated into the environment. .

Unsanitary conditions in slums and informal settlements, which currently accommodate over 1 billion people, create a constant threat of disease outbreaks, such as cholera. Untreated wastewater and faecal sludge often enter freshwater bodies, deteriorating water quality and threatening the aquatic ecosystem.

Even more worrying is the lack of critical data on the status of wastewater and faecal sludge treatment globally and at the country level. A figure on the total amount of domestic and industrial wastewater produced and treated globally is lacking. Without such critical data, local service delivery, investment decisions and regulation are not supported by reality.

Lack of data is symptomatic of the challenge of effectively containing, transporting and treating wastewater and faecal sludge. There has been a significant increase in the production of wastewater due to urbanisation and industrialisation, placing an excessive burden on the facilities and technology used for wastewater treatment today. Additionally, for many years, onsite technologies were seen as merely a stopgap measure until sewers could be built, which hindered progress in the management and safe treatment of faecal sludge. This exacerbated inequities in access to safely managed sanitation.

As a result, critical capacity gaps exist. For example, few countries and cities effectively operate treatment plants receiving wastewater and faecal sludge. In addition, while there is abundant knowledge of wastewater treatment technologies and processes, there is significantly less research on faecal sludge treatment. At the same time, the specific technical skills and regulatory and financial arrangements for dealing with wastewater and faecal sludge management (treatment and monitoring) are sub-optimal in many countries.

Despite the considerable obstacles that sanitation and wastewater management present, there are reasons to be optimistic. The seriousness of these concerns is becoming more widely recognised, and initiatives to solve them are gaining traction. Governments, development partners, and other stakeholders are collaborating to develop creative solutions and invest in essential infrastructure and technologies. Furthermore, there is a growing understanding that wastewater can be a valuable resource used in various ways, ranging from energy generation to agricultural irrigation.

We can develop more sustainable and resilient cities and communities by taking a more comprehensive approach to sanitation and wastewater management while encouraging environmental sustainability and preserving public health. Thus, a paradigm shift is taking place at the global level, with wastewater increasingly being viewed as a resource, not a waste stream. In addition, wider and new wastewater applications are emerging, such as epidemiological surveillance, harnessing the potential of wastewater to provide valuable data on transmissible diseases.

This *Global Report on Sanitation and Wastewater Management in Cities and Human Settlements* is a global reference on sanitation and wastewater in urban settings. It takes stock of the sanitation and wastewater management situation, both in terms of service levels and the supporting functions required to enable service provision at scale. The Report also highlights actions being taken by governments, development partners, city planners, utilities, service providers and researchers around the globe.

Further, the Report argues that for countries and cities starting from a low base point in sanitation and wastewater management, clarity is needed on what actions to prioritise and why. It offers a structuring framework supporting such prioritisation by integrating the three core functions of citywide inclusive sanitation - responsibilities, accountability, and resource planning and management. With these foundations in place, supported by strong data management systems, emerging wastewater and faecal sludge management innovations can be fully utilised.

I sincerely thank the Bill and Melinda Gates Foundation and the French Development Agency for supporting this important publication. I hope that the lessons and best practices from the case studies in this report will inform and inspire further research and implementation of promising best-fit approaches in sanitation and wastewater management, resulting in enhanced quality of life while leaving no one and no place behind.

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Mirpur, a low income community in Dhaka, Bangladesh © Yellow Rose

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Acronyms

ABASE	Association of Manual Emptiers of Burkina Faso
ADB	Asian Development Bank
ADERASA	Association of Regulators of Water and Sanitation of the Americas
AFD	Agence Française de Développement
AfWA	African Water Association
AMCOW	African Ministers' Council on Water
AURA	Autoridade Reguladora de Águas (Mozambique)
BOD	Biochemical Oxygen Demand
BOD5	5-day Biological Oxygen Demand
BUKEA	Ministry for Environment, Climate, Energy and Agriculture (Germany)
CACTUS	Climate and Costs in Urban Sanitation
CAPEX	Capital expenditure
CBS	Container-Based Sanitation
CBSA	Container-based Sanitation Alliance
CC	City Corporation
COD	Chemical Oxygen Demand
CO2	Carbon dioxide
CRA	Comisión de Regulación de Agua Potable y Saneamiento Básico (Colombia)
CT/PT	Community & Public toilets
CWIS	Citywide Inclusive Sanitation
DALY	Disability Adjusted Life Years
DANE	National Data Management Entity
DARD	Department of Agriculture and Rural Development
DAWASA	Dar es Salaam Water Supply and Sanitation Authority
DBO	Design-Build-Operate
DGA	Direction Générale de l'Assainissement (Burkina Faso)
DNCC	Dhaka North City Corporation
DONRO	Department of Natural Resources and Environment (Hanoi)
DSCC	Dhaka South City Corporation
DPHE	Department of Public Health Engineering (Bangladesh)
DSIP	Dhaka Sanitation Improvement Project
DWASA	Dhaka Water Supply & Sewerage Authority
EAWAG	Swiss Federal Institute of Aquatic Science and Technology
EBITDA	Earnings Before Interest, Taxes, Depreciation, and Amortization
EDC	Endocrine Disrupting Compounds
EPM	Empresas Públicas de Medellín
EPS	Extracellular Polymeric Substances
ERP	Enterprise Resource Planning
ERAS	Ente Regulador de Agua y Saneamiento (Buenos Aires)
ERSAR	Entidade Reguladora dos Serviços de Águas e Resíduos (Portugal)
ESAWAS	Eastern and Southern African Water and Sanitation Regulators Association
EU	European Union
EWRC	Energy and Water Regulatory Commission (Bulgaria)
EWURA	Energy and Water Utilities Regulatory Authority (Tanzania)
EY	Ernst & Young
FCDO	Foreign, Commonwealth & Development Office (UK)
FSTP	Faecal Sludge Treatment Plant
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GSMA	The Global System for Mobile Communications Association
HH	Household
HIC	High Income Country

HPC	Hanoi People's Committee
HSDC	Hanoi Sewerage and Drainage One-member State Company Limited
HSE	Hamburger Stadtentwässerung
IBNET	International Benchmarking Networking
ICT	Information and Communications Technology
IFI	International Financial Institutions
IMI	Integrated Monitoring Initiative
INSEED	National Institute of Statistics and Economic and Demographic Studies
IRF	Institutional Regulatory Framework
ISUD	Integrated Strategic Urban Development Plan
IWA	The International Water Association
IWK	Indah Water Konsortium
JICA	Japan International Cooperation Agency
JMP	Joint Monitoring Programme
KCCA	Kampala Capital City Authority
KfW	Kreditanstalt für Wiederaufbau
LIA	Low Income Area
LIC	Low Income Country
LG	Local Government
LMICs	Low- and Middle-income Countries
MENA	Middle East and North Africa
MESSD	Ministry of Environment, Sanitation and Sustainable Development (Mali)
MFC	Microbial Fuel Cells
MLG	Ministry of Local Government
MONRE	Ministry of Natural Resources and Environment (Thailand)
MOT	Ministry of Transport (Palestine)
NA	Not Applicable
NACOSTEC	Nakuru Countywide Sanitation Technical Steering Committee
NAWASSCO	Nakuru Water and Sanitation Services Company
NDC	Nationally Determined Contributions
NEMA	National Environment Management Authority (Kenya)
NGB	National General Budget
NSMIS	National Sanitation Management Information System
NWSC	National Water & Sewerage Corporation (Uganda)
ODA	Official development assistance
ODF	Open Defecation Free
OECD	Organisation for Economic Co-operation and Development
OFWAT	The UK Water Services Regulation Authority
ONEE	Office National de l'Électricité et de l'Eau Potable (Morocco)
OPEX	Operating expense
OSS	Onsite Sanitation
ONAS	L'Office National de l'Assainissement du Sénégal
ONEA	Office National de l'Eau et de l'Assainissement (Burkina Faso)
PFAS	Polyfluoroalkyl Substances
POIR	Plan de Obras e Inversiones Reguladas
PPCP	Pharmaceuticals and Personal Care Products
PPIAF	Public-Private Infrastructure Advisory Facility
PPP	Public Private Partnership
PVC	Polyvinyl Chloride
PWA	Palestinian Water Authority
RAJUK	Rajdhani Unnayan Kartripakkha (Bangladesh)
RISA	The Rainwater Management Program for Climate Adaptation
ROI	Return on Investment
RRR	Resource Recovery and Reuse
SanQoL	Sanitation-related Quality of Life
SARS-COV-2	Coronavirus Disease
SCADA	Supervisory Control and Data Acquisition
SCP	Single-cell Protein
SDGs	Sustainable Development Goals

SFD	Shit Flow Diagram
SIAAP	Greater Paris Sanitation Authority
SIP	Slum Improvement Project
SME	Small and Medium-sized Enterprises
SPA	Special Planning Area
SPV	Special Purpose Vehicles
SS	Suspended solids
SUDS	Sustainable urban drainage systems
SV	Sofiyska Voda
TACH	Total Annualised Cost per Household
TDS	Total Dissolved Solids
TLU	Thuyloi University
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
UASB	Up flow Anaerobic Sludge Blanket
UCCRN	Urban Climate Change Research Network
UDIC	Urban Development and Investment Corporations
UK	United Kingdom
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
UN Habitat	United Nations Human Settlements Programme
UNICEF	United Nations International Children's Emergency Fund
UNSD	United Nations Statistics Division
URENCO	Hanoi Urban Environment Company
UN Water	United Nations Water
US	United States
USD	United States Dollar
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
UVW	Association of Water Authorities
VFA	Volatile Fatty Acids
VIMAPRO	Projet Vidange Manuelle Propre
VND	Vietnamese đồng
VTO	Vacuum Tank Operators
WASREB	Water Services Regulatory Board (Kenya)
WB	World Bank
WHO	World Health Organization
WMA	Wastewater Management Authority
WOP	Water Operators' Partnerships
WRA	Water Resources Authority (Kenya)
WSP	Water Service Provider
WSRC	Water Sector Regulatory Council (Palestine)
WSS	Water Supply and Sanitation
WSUP	Water & Sanitation for the Urban Poor
WWTP	Wastewater Treatment Plant
ZEMA	Zambia Environmental Management Authority

Executive summary

There is a need for greater clarity, and better guidance, on what a public service approach to sanitation involves in practice. There are many cities across regions taking effective measures to improve sanitation — but guidance is needed to make universal access a reality.

Sanitation and wastewater management are core to the health and wellbeing of individuals, cities, societies and whole environmental ecosystems. But halfway through the SDG era, and despite being a public good, sanitation continues to lag behind. Governments and intergovernmental organizations still lack critical data on the status of wastewater and faecal sludge treatment, both globally and at the country level. There is a need for greater clarity, and better guidance, on what a public service approach to sanitation involves in practice. There are many cities across regions taking effective measures to improve sanitation — but guidance is needed to make universal access a reality.

Drawing on a mapping of 18 cities across Africa, Asia, Europe and Latin America, this report aims to raise awareness of the critical importance of sanitation in human and urban development. Its target is to shed light on the current situation and the state-of-the-art globally, with specific reference to wastewater and faecal sludge management; and to provide decision makers with guidance on the level and types of action required to drive change.

Bringing sanitation and wastewater management to the heart of the urban development agenda

Halfway to 2030, the world is still facing the tremendous challenge of managing sanitation and wastewater. Nearly half of the world's population lacks sanitation services that are securely managed, preventing the safe treatment and disposal of excreta. Some regions are particularly affected by the crisis: in Sub-Saharan Africa, only one in five people benefit from safely managed services. Even high-income economies are confronted with the challenge of sustaining wastewater management and adapting to changing consumption and production patterns affecting wastewater quality.

This report provides the rationale for a strong and urgent public response to the urban sanitation challenge. Its key premise is that sanitation is a public good, and sanitation services must be organised into public service systems. National and local governments should prioritize sanitation and wastewater as a public service — just like education, health, energy and other services where service authorities have a clear public mandate to ensure service delivery for all. This requires responses that look beyond infrastructure development. Ensuring sanitation systems deliver expected outcomes requires financial planning, both for capital investments and operational and maintenance costs; as well as clear responsibilities, strong accountability frameworks, and capacities for data management to help deliver long term citywide inclusive sanitation.

Recommendations of this report draw on a global review of the state-of-the art of urban sanitation and wastewater management. The report combines insights from academic research on the impacts of sanitation and wastewater management, together with grey literature on processes and best practice. In addition, 18 cities were surveyed through questionnaires on citywide sanitation and wastewater management, including wastewater and faecal sludge treatment plant operators. The global mapping illustrates specific challenges and emerging best-fit approaches related to sanitation and wastewater, providing evidence and underlying rationale for the public policy response proposed in this report. Within this sample, in-depth case studies are provided, led by country-level research for Medellin (Colombia), Ouagadougou (Burkina Faso), Dhaka (Bangladesh), Nakuru (Kenya) and Hanoi (Vietnam).

The costs of inaction on public health, the environment, the economy and the climate

Through the Sustainable Development Goal 6 (SDG 6), the world has set ambitious targets: the nature and scale of investments can be daunting for many countries and cities. But there is evidence that the cost of inaction is even higher.

Poor sanitation and wastewater management is devastating for human health. Untreated wastewater leads

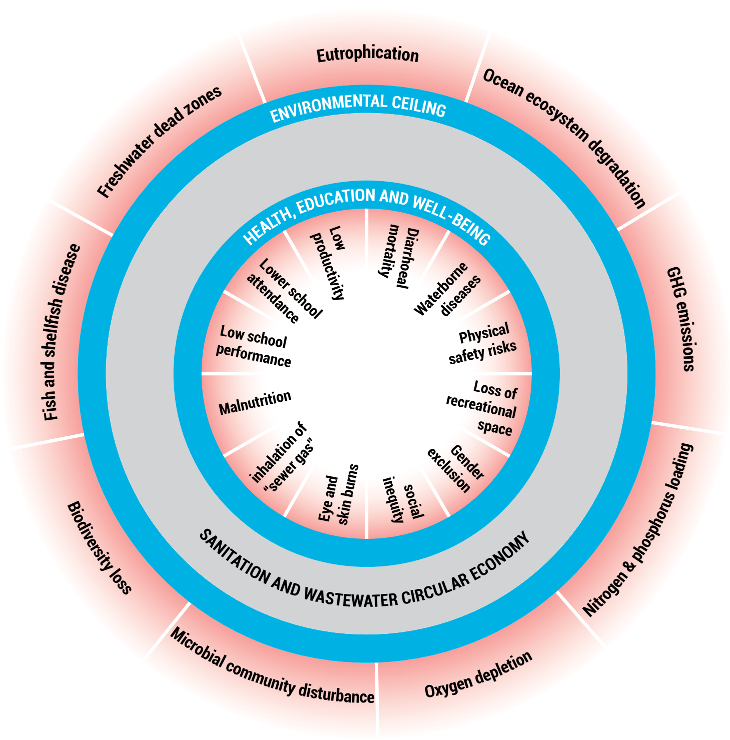
Where quality of life metrics have been applied to assess sanitation impacts, women and girls in particular experience significant gains from sanitation improvements.

to disease such as diarrhoea, cholera, dysentery, typhoid, and polio, and wider infections which can contribute to malnutrition and long term cognitive impairment. A wide range of pollutants present in wastewater such as nitrogen, pathogens, heavy metals, and emerging contaminants like EDCs pose serious health risks to communities and consumers of wastewater irrigated crops. Sanitation workers such as manual pit emptiers are among groups particularly at risk of sanitation-related disease.

Beyond human health, disposal of untreated wastewater and faecal sludge into the environment is a significant threat to life below water and life on land. Poor wastewater management has a plethora of impacts on coastal ecosystems, leading to eutrophication, declining of fisheries, habitat loss and degradation. Freshwater systems are particularly susceptible to sewage pollution because of their proximity to human settlements.

Impacts on health and the environment are root causes of huge economic losses linked to poor sanitation and wastewater management. Economic losses due to lack of sanitation and wastewater treatment are particularly substantial in low and middle income countries (LMICs). In countries in Africa and Asia, malnutrition costs from poor sanitation, which include impaired school performance and delayed entry into the labour market, are an estimated 9 per cent of the gross domestic product (GDP).

Figure 1: doughnut economic model applied to sanitation and wastewater management. Adapted from Raworth, K, 2017



Conversely, the socio-economic benefits of adequate wastewater and sanitation treatment are vast. The global provision of toilets with safely managed faecal sludge services alone is estimated to generate 86 billion USD per year in greater productivity and reduced health costs. And sanitation plays a vital role in improving broader aspects of well-being, including security, dignity and overall quality of life. Where quality of life metrics have been applied to assess sanitation impacts, women and girls in particular experience significant gains from sanitation improvements.

Effective wastewater and faecal sludge management are imperatives for reducing the carbon footprint of the water sector. Recent studies indicate that wastewater and faecal sludge contribute 62 per cent of the water sector total Green House Gas (GHG) emissions, including carbon CO2, methane CH4 and Nitrous Oxide N2O. Emissions relate to the treatment process and to the use of energy, chemical production, and transportation, which form essential parts of wastewater and faecal sludge management processes globally.

Why every city must formulate its own response

While all cities and human settlements face the challenge of sanitation and wastewater management, every city occupies a unique context which defines required public responses. Cities included in the global mapping, vary in their public finance capacity, density, regulatory arrangements, ciimactic conditions, and mix of sanitation services— ranging from Medellin, Colombia (95.5 per cent sewered access) to Ouagadougou, Burkina Faso (only 3.7 per cent sewered access).

As a result, contextual features must determine technology choices and the mix of services provided. How wastewater and faecal sludge management is delivered

will vary considerably between regions and countries and within a city itself. In practice, this disparity in technology choices is already a global reality. While certain world regions depend heavily on sewer networks to contain and transport flushed excreta, most urban dwellers in Sub-Saharan Africa and South Asia rely on onsite sanitation processes. In low income contexts in particular, a menu of services will be required to deliver citywide inclusive sanitation, involving both sewered and onsite approaches. Rather than a technology-driven approach, policy makers and planners should be guided by core principles including cost-effectiveness, inclusion, sustainability and climate resilience.

Rather than a technology-driven approach, policy makers and planners should be guided by core principles including cost-effectiveness, inclusion, sustainability and climate resilience.

Assessing current levels of wastewater and faecal sludge management performance

Recognizing the need for more and better data on wastewater and faecal sludge management, the report presents current levels of performance based on primary data from service authorities in the focus cities, with an emphasis on wastewater and faecal sludge treatment efficiency.

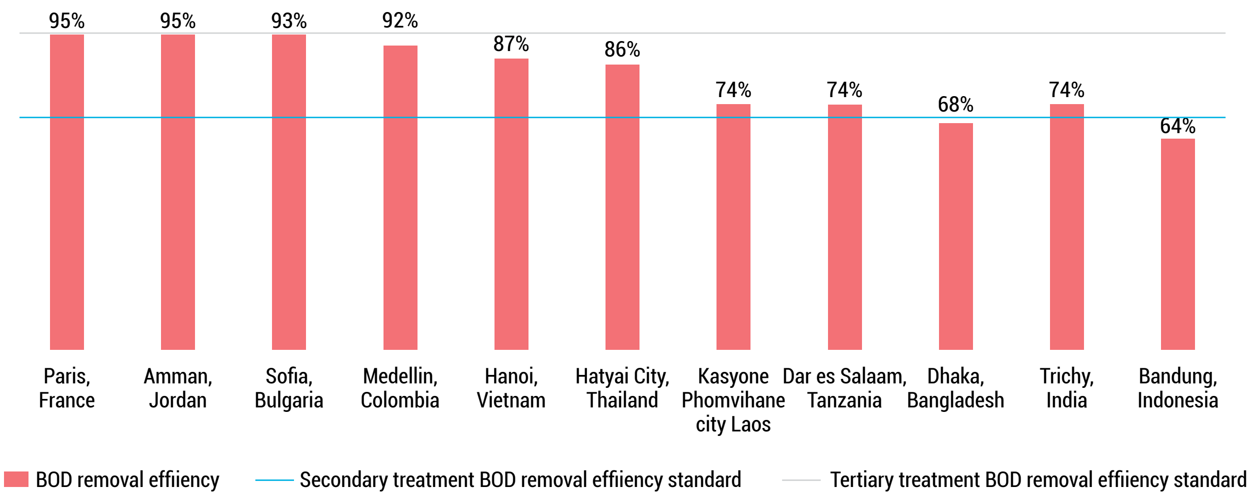
In practice and regardless of technologies used, many cities in LMICs are struggling to manage wastewater and faecal sludge effectively throughout the sanitation service chain. For a number of cities within our sample, these challenges begin at the containment stage and at the challenge of providing access to basic sanitation services.

At the treatment level, there are wide discrepancies in the volume of wastewater treated when mapped against city population size. For example, the volume of wastewater and faecal sludge treated in Dhaka, Bangladesh – one of the largest cities in the world – is at least five times less than volumes treated in Sofia (Bulgaria) or Paris (France), when Dhaka's population is nearly 10 times larger.

Only cities in high income countries were able to meet the Biological Oxygen Demand (BOD) global standard for tertiary treatment. A large majority of cities, including in LMICs, were able to meet the global BOD removal standard for secondary treatment, though two cities failed to meet this standard, according to the self-reported data provided.

Treatment technology is clearly correlated with higher treatment performance. Cities from high income countries included within the global mapping tend to use mechanical treatment processes, such as activated sludge processing, whereas LMICs are reliant on nature-based solutions such as stabilization ponds. In all cities relying on mechanical treatment, BOD removal efficiency of over 90 per cent was achieved. Five of the six cities that reported data on nitrogen and posphorus removal efficiency also met the tertiary treatment standards for these constituents. Availability of financial resources may be the primary factor behind these technology choices. Nature-based solutions have a number of notable advantages, including lower levels of energy consumption and lower

Figure 2: Global Mapping — BOD removal efficiency



To secure sanitation outcomes, policy makers and city planners must move from a de facto situation of various service delivery approaches to controlled planning of services across the sanitation chain.

overall operations and maintenance costs. European cities such as Sofia and Paris are adopting the most cutting edge wastewater treatment technologies, including biological ultrafiltration and UV treatment, at a faster rate than cities in other regions.

There is misalignment in many cities in LMICs between the predominance of onsite sanitation and the low availability of treatment facilities capable of treating faecal sludge. Six cities within our sample were conducting some level of co-treatment of wastewater and faecal sludge, with co-treatment the primary form of treatment in Dhaka and Bandung, where global standards are not currently being met. Four cities – Dar es Salaam, Kampala, Ouadadougou and Hatyai – reported figures for isolated faecal sludge treatment. Current treatment levels for faecal sludge are often challenging to ascertain.

The global mapping underlines that cities in LMICs are generally reporting lower levels of wastewater treatment, and that data may be absent completely for faecal sludge treatment, despite the prevalence of onsite sanitation in these locations. A number of systemic challenges are contributing to this situation and must be addressed to achieve inclusive citywide sanitation – including investment, planning, institutional mandates, regulation and data management.

How can this situation be addressed? The report presents six core recommendations and connected actions, presented below and summarized in Box 1.

1: Invest more, but invest more smartly

To secure sanitation outcomes, policy makers and city planners must move from a *de facto* situation of various service delivery approaches to controlled planning of services across the sanitation chain**.** What does this practically involve, and where will investments come from?

Adopting a phased and cost-sensitive approach to sanitation planning

In the huge investment needs context, city planners' starting point is to adopt cost-optimization approaches. Such approaches include the preparation and adoption of masterplans or investment plans, which clearly set out what planners want to achieve and what long term costs are implied. Although most cities from the global mapping have a masterplan form, the quality varies. To be effective, these tools must be based on a critical assessment of sector governance, financing and regulation frameworks. For example, where the financing framework is overlooked, cities and utilities may propose services that are unaffordable for targeted users. There are global examples of WWTPs out of operation or functioning below capacity due to low connection rates to the sewerage system.

As cities and services develop, the scale of capital investments is reduced, and master plans become less relevant. Long term financial planning to cover all costs remains essential. Utilities in cities of high income countries (such as Paris and Hamburg) use long term business planning to manage investments.

Relative costs and level of services provided by candidate sanitation systems must be carefully assessed at the planning stage. In some cases, lower cost approaches may provide comparable outcomes to more expensive systems. Research suggests that onsite sanitation systems may be more cost effective than a traditional sewerage system in specific contexts. As contexts evolve and population density increases, sewerage systems can then be more affordable, including operational costs.

The approach to sanitation planning must prioritize incremental changes, in which services are gradually upgraded as conditions evolve – including socio-economic conditions. For example, with treatment facilities, low cost technologies involving limited electromechanical equipment can achieve adequate performance and can be upgraded as soon as human and financing resources required for more advanced treatment options are secured.

Identifying the financial resources for investments

Sanitation and wastewater development requires significant public funds. Historically, public funds have been instrumental in developing urban sanitation and wastewater infrastructures. In Europe and the US governments have used their own revenues and also repayable finance (including municipal bonds) to lay out initial capital costs. In developing countries where investments in wastewater are increasing. The Official Development Assistance (ODA) is a major resource for governments seeking to boost access to sanitation and wastewater services. In fact, OECD figures indicate that the share of ODA going to large sanitation systems is gradually increasing, surpassing investments in large water supply systems in 2020.

There are fundamental reasons for integrating water and sanitation initiatives with national and local urban policies, strategies and plans.

There are still untapped instruments public funders can use for sanitation investments. Land value capture instruments — a form of taxation upon land upgrades — remain largely unused across Africa, but have contributed to funding infrastructure at scale in countries like China and Colombia.

Many barriers still exist for private sector investments in sanitation and wastewater and must be overcome. Although in most countries service users bear the brunt of costs - especially when relying on onsite sanitation systems - private sector investments in other segments of the sanitation service chain are scarce, most notably for treatment facilities.

Cost recovery is a major barrier for attracting investments. Among utilities from cities in the global mapping, only four out of 11 generate revenues from wastewater and faecal sludge enabling full cost recovery, and only two recover the full costs of wastewater services. Some utilities benefit from direct (and predictable) subsidies, enabling them to attract private operators in the management of treatment facilities. In many cases, wastewater and faecal sludge management services are not running on a cost-recovery basis and are not receiving any direct subsidy, leading to facilities' disrepair.

There are still important benefits in pursuing private sector participation. Design-Build-Operate (DBO) contracts for WWTPs and FSTPs can be attractive for governments to ensure design is as efficient as possible, since constructors will also be in charge of operations. In many countries, such contracts would have to be paid with public funds, in the absence of cost-recovery tariffs.

2: Integrate sanitation and wastewater management with wider urban development

The urban development sector seldom appreciates the critical role of sanitation and wastewater in improving public health and eradicating poverty and inequality in cities and human settlements. This report argues that integration of sanitation with wider urban development, including slum upgrading processes, is a coherent and necessary response to the challenge of basic service provision in urban contexts. An integrated approach to basic services is fully in line with international strategic commitments, including the New Urban Agenda adopted at the 2016 United Nations Conference on Housing and Sustainable Urban Development (Habitat III) in Quito, Ecuador.

There are fundamental reasons for integrating water and sanitation initiatives with national and local urban policies, strategies and plans. In urban environments, issues such as water access, drainage, health, street design and solid waste management are all inextricably linked. Poor drainage leads to flooding, causing damage to sanitation facilities. Rubbish collected in drainage canals can exacerbate the issue and lead to stagnant water which becomes a breeding ground for disease. Pit latrines and septic tanks cannot be safely emptied if poor road access makes it impossible for emptying services to operate. And low income urban residents may be unable to invest in property improvements, and mandated authorities unable to provide basic services. These interconnections mean unless water, sanitation and solid waste management services are planned together, the risk of service failure is magnified.

What does integration practically involve? The report outlines five key factors drawing from experience in Africa and Asia:

- **High level government commitment to unblocking political and bureaucratic hurdles.** In Asia, a notable example of this commitment is the Government of India's Slum Improvement Project (SIP), implemented across cities in India in the 1980s and 1990s. The project incorporated water, sanitation, solid waste, drainage and road improvements to improve the quality of the city environment, delivering diverse economic and quality of life improvements.

- **Interdisciplinary and multi-sectoral collaboration, supported by the integration of slum upgrading into citywide strategic planning.** In Nairobi in 2017, the informal settlement of Mukuru was declared a Special Planning Area (SPA), due to its unique environmental, health and development challenges, resulting in the formulation of seven sector plans developed by a coalition of 46 organizations. Within the framework of this initiative, Nairobi City Water and Sewerage Company and Nairobi Metropolitan Services successfully piloted simplified sewer systems in Mukuru, as a cost effective way of leveraging the settlement's existing trunk sewer infrastructure.

Place urban development departments at the centre of urban sanitation service planning, to support the pro-poor targeting and expansion of sanitation services at the city level.

- **Placing urban development departments at the centre of urban sanitation service planning,** to support the pro-poor targeting and expansion of sanitation services at the city level. Governments must establish clear mandates, not only for urban sanitation (see Recommendation 3 below), but also for urban development, local government, and housing, among others.

- **Mechanisms for the promotion of community participation in all stages of the planning process**. In Mukuru, a participatory planning process led by Muungano wa Wanavijiji, the national federation of slum dwellers in Kenya, was also central to creation of the Integrated Strategic Urban Development Plan (ISUD), in a process involving consultation with over 100,000 households — making the initiative one of the biggest slum upgrading projects ever attempted.

- **Financial incentives through the creation of integrated funding streams**. Most external funding remains highly siloed within the sanitation sector, and tied to a short-project mode of delivery. Funding streams need to evolve to address integrated slum improvement, encouraging sanitation actors to partner with actors bringing other expertise.

3: Clarify mandates across the sewered and onsite sanitation service chains

In order to provide universal sanitation services, there must be a responsible authority with a clear, legal mandate for inclusive urban service provision. Historically, lack of clarity of responsibilities for urban sanitation and overlaps have been major bottlenecks to service improvements. Across regions, responsibility for urban sanitation service provision, including wastewater management, resides with one of two institutions: the utility, which may be publicly or privately owned; or the local government. Unless responsibilities are clearly laid out between these two institutions, with coordination mechanisms in place where required, there are risks of overlap, which can lead to inaction.

The service jurisdiction of mandated authorities must include informal settlements and low-income areas on city peripheries. This requires sustained attention to shifting city boundaries. Rapid and unplanned urban expansion exacerbates gaps in clear mandates for urban sanitation. Few public utilities have the explicit mandate to serve informal settlements, where onsite sanitation systems prevail. As a result, a *de facto* state of responsibilities such as in Dhaka, where municipalities are in charge of onsite sanitation and utilities are in charge of sewerage services – even though they serve a fraction of the population.

The global mapping demonstrates a number of countries are actively reviewing responsibilities for urban sanitation, recognizing this as a foundation in sector reform. A key trend can be observed in Eastern and Southern Africa, where there is growing regional momentum towards integrating responsibility for sewered and onsite service outcomes with utilities. Within our sample, this can be observed in Nakuru (Kenya) and Dar es Salaam (Tanzania). This shift is also underway in Zambia, where commercial utilities are adopting additional responsibility for on-site sanitation.

There is a general trend toward greater public and private delegated management of wastewater services. When private operators are in charge of operating FSTPs and WWTPs, this is mostly done through operations and management contracts (as in

Vietnam). There are examples of concession contracts for FSTPs (as in Senegal); these require a strong regulatory framework and incentives mechanisms to ensure the FSTP is actually used. In onsite sanitation, the global trend is for the private sector to play a key role in the provision of faecal waste emptying services, with increasing attention being paid to the progressive formalization of these services.

The gender equity gap within sanitation authorities is profound. Greater representation of women at leadership-level will be an asset for governments, local authorities and service providers in achieving sector goals. Evidence indicates that utilities which tap into the female labour force are more profitable, competitive, and sustainable than others. There are still important barriers preventing women from playing a key decision making role, starting with girls facing gender bias in school when pursuing technical degrees; young career-women having to balance greater familial obligations than men; and mid-career women lacking networking opportunities. These barriers exist in many contexts, as demonstrated by only four service authorities within our sample reporting the existence of gender mainstreaming strategies.

Local and regional governments are at the forefront of the water and sanitation management challenge and will be key to reaching global development targets.

Local governments and service providers must be supported in their critical role in the provision of sanitation and wastewater management services. The global mapping of institutional responsibilities affirms that local and regional governments are at the forefront of the water and sanitation management challenge and will be key to reaching global development targets. Many local operators, particularly in LMICs, are struggling to meet current demands, and are enormously challenged by fast-growing populations and the ongoing sprawl of urban areas. Achieving citywide access will require strengthening the institutional capacity of these essential service providers, particularly in LMICs.

4: Allocate financial and human resources to regulation design and enforcement

Regulation is core to a public service approach to urban sanitation. Without effective regulation, mandated authorities cannot be held accountable, in a meaningful but fair way, for the services they provide, and citizens and ecosystems lack protection from the public health and environmental risks posed by inadequate treatment. The importance of effective regulation, coupled with current capacity gaps, highlights the need for greater human and financial resource allocation in this area.

Many countries have a well-developed regulatory framework for sanitation. In Europe, autonomous regulatory agencies play key role in the economic regulation of sewered services. Examples include the Energy and Water Regulatory Commission (EWRC) (Bulgaria) and the UK Water Services Regulation Authority (Ofwat). In other countries, as in France, regulation is performed by several ministries and agencies. In the Eastern and Southern Africa region, Kenya, Tanzania and Zambia offer good examples of rationalized institutionalized frameworks for sanitation. In these instances, there are autonomous regulatory entities with responsibility for economic and technical regulation; and national-level environmental authorities with specific roles in environmental regulation. Although regulation by ministry and regulation by contract can certainly be effective, regulation by agency has been found to be associated with a higher number of regulatory mechanisms and higher-performing regulation in the African context.

In practice, however, economic regulation of sanitation, particularly onsite sanitation, is only nascent in many LMICs. Tariff models are less well-developed for sewerage services, often being set as a per centage of the water bill, without underlying cost calculations. Performance indicators related to sewerage management are also less extensive than for water. In recent years, the regional organization ESAWAS has led the development of a comprehensive regulatory framework for sanitation, which also embeds onsite sanitation. Efforts are ongoing to disseminate this framework in the Africa region and the experience can be useful for other regions.

Environmental regulation, where effective, also provides strong accountability mechanisms for investments in sanitation and wastewater. The enforcement of national treatment standards, licensing permits for WWTPs/FSTPs and discharge permits can incentivise investments where they are needed. In the EU, legislation provides an overarching framework for environmental regulation of wastewater, through the Urban Wastewater Treatment Directive. In Africa, progress has been made in developing standards for environmental regulation in broad terms. All focus countries in the global mapping have developed environmental regulations for discharge of wastewater effluent, although some countries report a gap in the development of such regulations for faecal sludge treatment and discharge specifically. Even where standards exist, current levels of oversight may be suboptimal: many regulatory authorities in LMICs, and some in HICs, lack capacity to conduct spot checks to verify reporting on the quantity and quality of wastewater and faecal sludge treated.

There is an urgent need for governments to invest in data systems promoting service quality and inclusivity.

Finally, where regulations are being formed, it is important they are set to levels feasible within the context, and not too costly to implement, to gradually evolving the regulations in line with socio-economic conditions.

5: Strengthen country-level monitoring capacities and data systems

To strengthen accountability, improve decision making, and increase commitment and investments, service authority performance against their mandate should be monitored through a credible public data system incorporating all sanitation outcomes, both sewered and onsite. There is an urgent need for governments to invest in data systems promoting service quality and inclusivity. The need to invest in timely and credible data and information is one of the five accelerators identified under the UN-Water SDG 6 Global Acceleration Framework.

Such data systems should allow for the public benchmarking of service provider performance across the sanitation service chain. Public benchmarking is a core accountability tool widely practiced by regulators in Europe and Latin America, and by countries such as Palestine, Kenya and Zambia. Where service providers have an explicit mandate for citywide sanitation, data systems should also allow reporting on services to specific communities, including low-income areas.

There are currently data gaps on the state of sanitation services, across the sanitation service chain, especially at city level, which hinder service planning. Many city authorities in developing countries lack information on types of sanitation systems in use, on needed upgrading, what is emptied, etc. This means cities are making investments without data required to plan or manage expected services and ensure inclusion. Lack of data is linked to lack of clear mandates with regards to sanitation services, often considered a "private matter" to be dealt with by households and private operators.

This situation calls for radical strengthening of city and country-level monitoring systems, beginning with enhanced capacity development support and connected resource allocation. Greater capacity development support is required from sector actors to assist countries in taking ownership of data, reporting data, connecting with statistical offices, and using data to make decisions. National and local governments should prioritize not only strengthening data systems but also building local capacity to use information for local decision making. For example, the UN-Water Integrated Monitoring Initiative for SDG 6 (IMI-SDG6) supports countries in monitoring progress towards SDG 6, through a network of monitoring focal points in national line ministries involved in water and sanitation, as well as in national statistical offices. Robust national, municipal and utility-level data collected at the lowest administrative level on a regular basis and disaggregated, wherever possible, is necessary to enable reporting, manage local service delivery, inform investments and support regulation.

Multiple countries across regions are on the path to embracing data systems as a key driver of sanitation service improvements, demonstrating shifts involved in the practice. Within our sample, Colombia, Kenya, Tanzania and Thailand provide strong examples. In recent years, some cities, with support from development partners, have taken important steps towards building the data systems required for citywide inclusive sanitation service delivery, such as Nakuru in Kenya and Lusaka in Zambia.

At the global level, and notwithstanding the challenges involved, there have been notable improvements in data on the status of sanitation services. The UN Water Joint

Monitoring Programme (JMP) initiative, implemented by WHO and UNICEF, does provide a global picture of sanitation services based on the SDG 6.2 monitoring framework, using a combination of national surveys and statistical assumptions. The monitoring system still faces challenges, particularly with estimating, at national level, access to safely managed urban sanitation services – an indicator that is more difficult to track than in rural areas, where septic tanks (which do not systematically require associated services of emptying and treatment) are more prevalent.

Mobile applications are increasingly deployed to support real-time data collection and analysis, which can ultimately be used to strengthen city and national-level data systems.

A specific challenge lies within country-level reporting on wastewater treatment, including industrial, which can help inform the SDG 6.3.1. Globally, only a handful of countries have been able to share data on the quantity of wastewater produced that has received treatment via global reporting systems. There is no global picture available of the volumes of wastewater treated. Though conducted on a small scale, our study demonstrates both the latent potential and the limitations of current monitoring capabilities in this area. In some cases where aggregated national-level data on wastewater treatment is lacking, it was possible to access this data through direct engagement with service authorities. This implies data can be accessed, but conducting studies at larger scale requires comprehensive supporting systems be in place.

As cities look to improve sanitation data systems, digital technologies offer opportunities. Mobile applications are increasingly deployed to support real-time data collection and analysis, which can ultimately be used to strengthen city and national-level data systems. In Togo, for example, the "TogoInfo MICS" application, available and accessible on smartphones, is used by ministries in charge of health, sanitation and water for data updates. Digital infrastructure can generate between three to 34 per cent return on investment, depending on the technology, when used customer data management and billing (Leading Utilities of the World, 2019). Digital technologies also offer opportunities in remote sensing and monitoring, which can improve regulatory compliance and safety.

6: Adopt measures for safe wastewater and faecal sludge valorization

A number of innovations in sanitation and wastewater management are gaining traction, including wastewater reuse, and wastewater-based epidemiology, which played an important role in national responses to the Covid-19 pandemic. With these shifts, there is urgent need for planners and service authorities to adapt their approach to wastewater and faecal sludge management in response to the urgent threat posed by climate change. The report spotlights these innovations, with particular focus on reuse.

Paradigm shifts are occurring as the sector is realizing that wastewater and faecal sludge can be turned into an economic opportunity. Changing the approach to sanitation from waste management to resource recovery could uncover valuable financial gains. Globally, governments and service authorities are only just discovering the extent of this potential – although the use of wastewater to irrigate agricultural land is ancient practice. Many economic sectors are set to benefit from excreta valorization, from industrial production to energy generation, agriculture and the leisure industry. In faecal sludge management, there is movement towards a circular economy for faecal sludge based on renewable resource flows, with container-based sanitation (CBS) providers at the forefront.

Treated wastewater can even alleviate the water crisis. Non-potable treated wastewater can be used for agriculture. Depending on the treatment level, treated wastewater can also be classified as potable, though this requires an environmental buffer before consumption, which can be achieved through aquifer recharge, reservoirs or river discharge. Countries such as Israel are pioneering the reuse of treated wastewater at scale, where the Water Authority master plan aspires to reuse 100 per cent of treated wastewater, supported by economic tools and strict environmental regulation.

Innovations to support climate resilience

Many cities are already adapting and implementing innovative responses to climate change, putting further strains on cities' sanitation services and treatment capacities. Droughts, flooding, and sea level rise are already causing damage to sanitation infrastructure. Resilience to these adverse conditions requires adapting infrastructure design, for instance, elevating sanitation facilities and separating stormwater from wastewater shifting away from combined sewer systems, as well as institutional preparedness through improved planning, regulatory arrangements, capacity building and monitoring. The development of climate-resilient urban drainage systems will be a key part of many cities' responses.: Hanoi and Shanghai offer examples of cities proactively changing approaches to services in urban areas through the introduction of such systems.

Box 1: A call to action

Priority Actions:

1. Cities need to invest more, across the sanitation service chain, and invest smartly, with specific attention to environmental contexts as well socio-economic conditions and climate change risks.

2. Wastewater and faecal sludge management services must be integrated with national and local urban policies, strategies and plans, including slum upgrading processes.

3. Roles and responsibilities with regard to sanitation, from policymaking to service delivery across the sanitation service chain, have to be clarified so that actors have clear delivery mandates.

4. Financial and human resources must be allocated to regulation design and enforcement, necessary incentives for service providers to invest.

5. National monitoring systems for sanitation, wastewater and faecal sludge management services must improve radically, with countries supported in developing credible public data systems incorporating all sanitation outcomes.

6. Cities need to adopt measures for safe wastewater and faecal sludge valorization, even ahead of the full development of sanitation services, to mitigate health and environmental risks associated with this resource.

Enabling Factors:

1. Funding for research in wastewater and faecal sludge management needs to continue and increase, to support the development of technologies and service models adapted to different contexts and resilient to climate change.

2. Peer-to-peer learning and south-south cooperation must be supported to share knowledge and inspire replication of best fit approaches.

Connecting a pipe to main sewer line
Githima, Kenya © Brian Otieno

01

Putting sanitation and wastewater management centre stage

1.1 Bringing wastewater and faecal sludge out from the margins

Halfway to 2030, it is becoming increasingly clear that governments, intergovernmental organizations, research organizations and other practitioners lack critical data on the status of wastewater and faecal sludge treatment, both globally and at the country level.

A necessary companion to the growth of human settlements, wastewater and faecal sludge treatment plants occupy our cities' peripheries, hidden away from our senses. Yet they provide a vital service, without which towns and cities would be unliveable, filled with stench and dangerous pathogens. Untreated faecal sludge and wastewater often find their way into water bodies, deteriorating water quality and threatening whole aquatic ecosystems. The damage untreated faecal sludge and wastewater can cause is not only an environmental concern: heavily polluted rivers are linked to lower economic growth in downstream regions (World Bank, 2019).

Recognizing its importance to sustainable development, United Nations (UN) member countries have set a global target on wastewater treatment. Target SDG 6.3 sets to "halve the proportion of untreated wastewater discharged into water bodies" by 2030. Two complementary indicators have been set to monitor this progress: "the proportion of domestic and industrial wastewater flows safely treated" (Indicator 6.3.1) and "the proportion of bodies of water with good ambient water quality" (Indicator 6.3.2).

Halfway to 2030, it is becoming increasingly clear that governments, intergovernmental organizations, research organizations and other practitioners lack critical data on the status of wastewater and faecal sludge treatment, both globally and at the country level. To date, a figure on the total amount of wastewater (including industrial) produced and treated globally is lacking. Data on 6.3.1 largely relies on reporting by national ministries and institutions, based on questionnaires sent by Eurostat and OECD (for EU Member States and OECD countries) and by UNSD/UNEP (for non-OECD countries). Concerning the total and industrial wastewater flows reported by UN Member States, UN-Habitat has analysed comparable data for 2015, compiled in the 2021 report on progress on wastewater treatment (UN-Habitat and WHO, 2021). In 2015, 42 countries were able to report both generation and treatment of total wastewater flows, representing 18 per cent of the global population, with high-income countries more likely to report. The proportion of industrial wastewater flow could only be calculated for 14 countries, representing 4 per cent of the global population.

Lack of data is symptomatic of the challenge of effectively containing, transporting and treating wastewater and faecal sludge. There has been considerable progress since the first wastewater treatment plant was introduced by Robert Thom in Scotland in the early 18th century. However, there has been a significant increase in the production of wastewater because of urbanization and industrialization, placing an excessive burden on facilities and technology used for wastewater treatment today. For many years, onsite technologies were seen as merely a stopgap measure until sewers could be built, which hindered progress in the management and safe treatment of faecal sludge, and exacerbated inequities in access to safely managed sanitation.

This is an exciting time for wastewater management. At the global level, a paradigm shift is taking place, with wastewater increasingly being viewed as a resource not a waste stream.

As a result, critical capacity gaps exist. For example, few countries and cities effectively operate treatment plants receiving both wastewater and faecal sludge. While there is abundant knowledge of wastewater treatment technologies and processes, there is significantly less research on faecal sludge treatment. At the same time, the specific technical skills as well as regulatory and financial arrangements for dealing with wastewater and faecal sludge management (treatment and monitoring) are sub-optimal in many countries.The limited data available on total and industrial wastewater flows indicates the proportion of flows being safely treated are low, with 32 per cent of total wastewater flows receiving at least some treatment (UN-Habitat and WHO, 2021). Overall, capacity is greater for dealing with water supply than for wastewater and faecal sludge.

This report puts sanitation and wastewater management centre stage. It takes stock of the situation, both in terms of service levels as well as the supporting functions required to enable service provision at scale. The report highlights what we still need to do better in wastewater and faecal sludge management, but also what we need to know better, including in response to global threats such as climate change.

Enhanced action on sanitation and wastewater management is urgently needed. But there are also reasons for optimism. This report highlights actions being taken by governments, development partners, city planners, utilities, service providers and researchers around the globe. Together these examples show clearly that effective responses do exist. This is an exciting time for wastewater management. At the global level, a paradigm shift is taking place, with wastewater increasingly being viewed as a resource not a waste stream. And wider new applications of wastewater are emerging, such as epidemiological surveillance, harnessing the potential of wastewater to provide valuable data on transmissible disease. This report is also a repository for emerging practices, developed to inspire further research and implementation of promising best-fit approaches.

Finally, the report argues that sanitation is a public good, and sanitation services must be organised into public service systems. National and local governments should prioritize sanitation and wastewater as a public service — just like education, health, energy and other services where service authorities have a clear public mandate to ensure service delivery for all. For cities and countries starting from a low base point in sanitation and wastewater management, clarity is needed on what a public service approach to sanitation involves, what actions to prioritize and why. We need a structuring framework which can support prioritization, not an endless list of disconnected ideas. To support this, the report integrates the three core functions of citywide inclusive sanitation — responsibilities, accountability, and resource planning and management. With these foundations in place, supported by strong data management systems, emerging innovations in wastewater and faecal sludge management can be fully utilized.

1.2 Specific scope: wastewater and faecal sludge management in urban contexts

Urbanization intensifies the challenge of wastewater and faecal sludge treatment. Globally, 56 per cent of the population resides in urban areas and over the next fifteen years, the majority of growth will occur in mid-sized cities. Forecasters predict that by 2050, the global urban population will reach 68 per cent (UNDESA, 2018). Africa and Asia alone are expected to add around 25 and 35 million new urban residents per year respectively. In addition, much city expansion is unplanned, and most of the growth taking place is in slums and informal settlements, where one billion people live today. As towns and cities grow, in the context of land scarcity, with high population density and unsecured tenancy is economic activity, generating further wastewater needing to be evacuated and treated to prevent the outbreak of disease and environmental degradation.

This report considers the situation of sanitation and wastewater management in urban contexts globally. As such, it includes a range of urbanization contexts, from small towns such as Changunarayan, Nepal (the cities of tomorrow) to megacities such as Dhaka, Bangladesh. It also considers a range of socio-economic development contexts to capture the many faces of wastewater and faecal sludge management challenges, including prevalence of onsite sanitation facilities, the footprint of the treatment facility, urbanization and industrialization, water stress and emerging pollutants.

Within sanitation, what do wastewater and faecal sludge refer to exactly? Wastewater is the community's water supply collected via a sewer system after it has been utilized for residential, institutional, commercial, and industrial purposes, together with water inflow and infiltration from other water sources (such as stormwater). Faecal sludge is the result of the storage of excreta and blackwater with or without greywater. Unlike wastewater, it comes from onsite sanitation technologies and has not been transported through a sewer. The inclusion of faecal sludge in this report stems from the fact that ~58 per cent of the world's population relies on such systems (36 per cent of the global urban population) (JMP,2022) Box 2 contains the key terminology used in this report, with a full glossary enclosed in Appendix A.

The heart of this report is wastewater and faecal sludge treatment. Within this scope, the report considers the state of the art in terms of treatment technologies and processes and their performance in practice. The report also unpacks institutional, regulatory and funding and financing arrangements that underpin this performance. Industrial wastewater that can be treated in municipal treatment plants is also within the report scope.

Box 2: Key terminology and definitions. Full glossary is provided in Appendix A.

- **Wastewater**: Used water produced by domestic, industrial, commercial, and institutional sources. Stormwater and agricultural runoff are also essential elements of the wastewater management cycle. Water makes up the majority (>99 per cent) of wastewater, with the rest consisting of nutrients, pathogens, and dissolved or suspended organic and inorganic materials. Domestic wastewater is conveyed through a sewer by flush toilets.

- **Faecal sludge**: Undigested or partially digested slurry and resultant solids from the storage or treatment of blackwater or excreta. Faecal sludge has been contained onsite by various technologies such as pit latrines, septic tanks and container-based solutions. In addition to human excrement, faecal sludge may include menstrual hygiene products, flush water, cleaning supplies, bathing or kitchen water, or municipal solid waste.

- **Sanitation systems**: Infrastructure and technologies that deliver sanitation services (both onsite and sewerage services), from containment to treatment.

- **Wastewater and faecal sludge management:** The containment, conveyance, treatment and disposal or reuse of wastewater and faecal sludge.

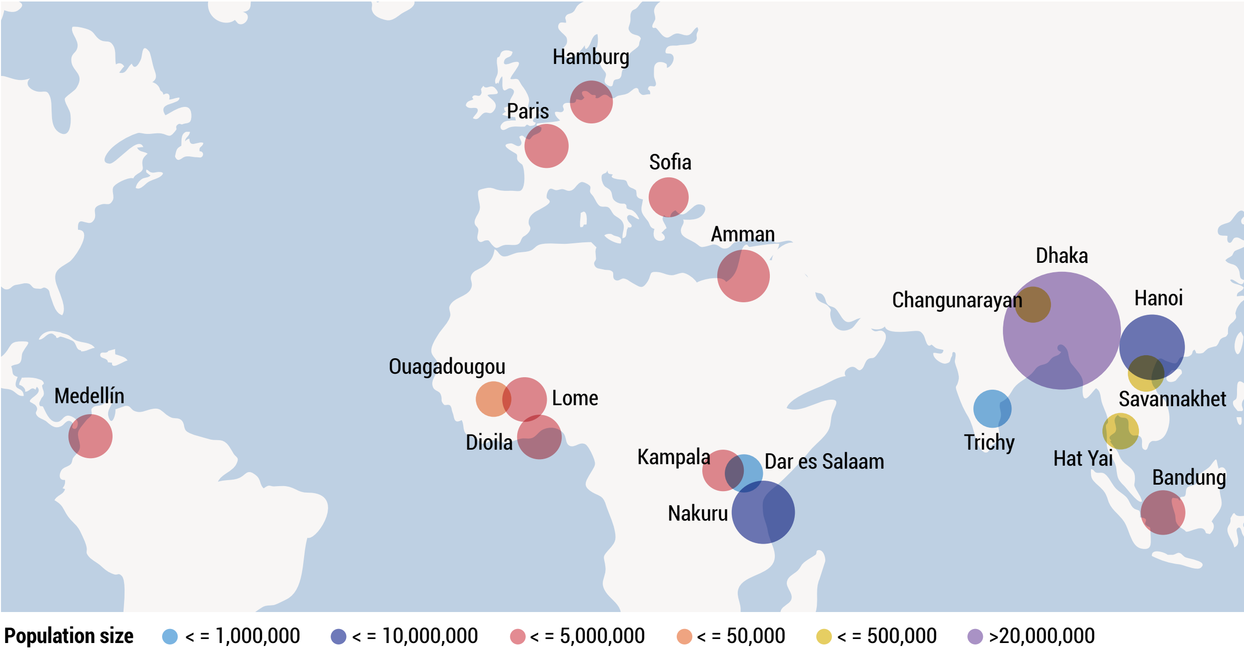
1.3 Methodology: combining theory with the state of the art in practice

As a status report, this document presents the global situation of sanitation and wastewater management in the context of what is known to be "best practice". Findings are therefore the results of a desk-review of academic papers on faecal sludge and wastewater, analyses of grey literature and service providers' reports as well as interviews with service providers in-country. While academic literature is abundant on certain aspects of sanitation and wastewater management, there remain important research gaps, particularly with regards to faecal sludge treatment. An academic lens-only would be unsuitable to capture the state of the art, including best practice regarding institutional, regulatory and financing arrangements, considering the wide variety of urban contexts globally.

Without purporting to do full justice to this varied context, this report draws on a global mapping of the situation of sanitation and wastewater management in 18 towns and cities (Figure 3). Situated in Africa, Asia, Europe and Latin America, these cities were purposively selected, taking into account access to data, and to ensure a diversity of contexts in terms of population size, institutional and regulatory arrangements, and sanitation services — ranging from Medellin, Colombia (95.5 per cent sewered access) to Ouagadougou, Burkina Faso (only 3.7 per cent sewered access).

Data from these cities was collected through desk review and interviews with city authorities and service providers, including wastewater and faecal sludge treatment plant operators, using a common framework. This framework captures both citywide status in terms of access to wastewater and faecal sludge management services (overall access to services as well as institutional and regulatory arrangements) and data on the performance of service providers at the

Figure 3: map of the 18 towns and cities with their respective population size



wastewater and faecal sludge systems level – both technical and financial performance (see Box 3).

For indicators relating to wastewater and faecal effluent quality, treatment systems and treatment performance, analysis is based primarily on the self-reported data of treatment plant operators, supplemented by published regulator and service authority reports where they exist. For indicators such as wastewater volumes and concentrations of wastewater constituents, annual averages have been used for consistency. The authors are indebted to the wide-ranging authorities in focus cities who have engaged so constructively to help bridge the data gap for wastewater and faecal sludge treatment, without which this report would not be possible.

Box 3: Citywide Inclusive Sanitation (CWIS) and study data collection framework.

The Citywide Inclusive Sanitation (CWIS) concept aims to ensure everyone in a city has access to safely managed sanitation by promoting a range of solutions, including sewered and onsite, centralized and decentralized (World Bank). ESAWAS (2021) argue that to achieve the SDGs and to support safe, healthy urban living environments, sanitation services must be organised into public service systems. For systems to function safely, at scale, over time, and inclusively, they must be organised to support three closely related requirements: clear **responsibility**, strong **accountability**, and fit-for-purpose **resource planning and management**.

Data collection for this report was structured to support analysis of the three core functions of CWIS as they relate to wastewater and faecal sludge management. The common data collection framework included indicators on policies, institutional arrangements, regulations and standards (economic and environmental regulation), planning and investment, and financial performance of service providers. Monitoring and data management processes related to wastewater and faecal sludge management were also included as key qualitative indicators, alongside gender inclusion and digitisation within mandated service authorities, as topics of special interest. Together with wider desk review, this data provides the basis for Chapters 5 – 9 of the report.

No less importantly, city authorities and service providers were engaged to provide primary data on wastewater and faecal effluent quality, treatment systems and treatment performance. Through this exercise the report aims to bridge the data gap through a snapshot of current levels of wastewater and faecal sludge treatment at the global level. Together with wider desk review, this data provides the basis for Chapter 4 of the report.

The report synthesises data from the 18 cities with insights from the wider desk review, In this way, the report provides an overview of the wastewater and faecal sludge management situation globally by (i) leveraging data from the global mapping, based on primary data collection from these locations; and (ii) drawing on secondary literature to provide a more complete picture. This desk review provides not only insights into best practice but also additional examples from wider cities and countries.

Cities' status and experience with sanitation and wastewater management provided the opportunity to deep-dive into specific approaches that have been put in place. This deep-dive analysis is presented in "case study" format within the report. An overview of selected case studies and their thematic areas are presented below.

This report is not without important limitations. The experience of 18 cities cannot be taken as fully representative of the thousands of cities worldwide. In some cases, the full set of data could not be obtained — another indicator of how poorly developed data management systems are for wastewater and faecal sludge in many countries. Like other global monitoring processes, parts of the analysis are

Box 4: City-level case studies

For five of the focus cities, the report examines the situation in-depth through detailed case studies. Each case study provides an overview of key elements of wastewater and faecal sludge management in the focus city, looking across the three CWIS functions, and places one key issue under the spotlight, detailing how city authorities are proactively engaging with that aspect of wastewater and faecal sludge management:

***Resource Planning and Management*: Medellin, Colombia**
Medellin is the best performing city for sanitation in Colombia and moving towards 100 per cent sewered sanitation coverage. Key to the city's success has been the effective use of city-level sanitation planning. This case study documents how citywide sanitation advancements have been achieved in Medellin, with a special focus on financing and long-term investment planning.

***Responsibilities*: Ouagadougou, Burkina Faso**
Ouagadougou was the first in Africa to introduce a sanitation surcharge on water bills to help finance sanitation services; while Burkina Faso is the only country in West Africa currently to stipulate access to sanitation as a constitutional right. Key ministries are now engaged in renewed efforts to extend services to informal settlements. This case study focuses on what is required to deliver wastewater and faecal sludge management services at citywide scale from a low base point, highlighting the importance of inclusive mandates.

***Accountability*: Dhaka, Bangladesh**
In Dhaka, there has been notable evolution in institutional responsibilities for onsite sanitation in recent years, following the publication of the Institutional and Regulatory Framework for FSM in 2017. The city faces a massive regulatory challenge in addressing widespread direct discharge of wastewater to open surface drains, an issue which is now gaining increased political momentum. This case study focuses on the complexities of wastewater and faecal sludge management in a megacity context, with a special focus on accountability.

***Data management*: Nakuru, Kenya**
In Nakuru, there is a shared understanding among decision makers of the urgent requirement to bridge the sanitation data gap. This case study details how the mandated service authority in Nakuru is collaborating with the national regulator to develop a new tool to provide the basis for enhanced sanitation data management and informed sanitation investment planning.

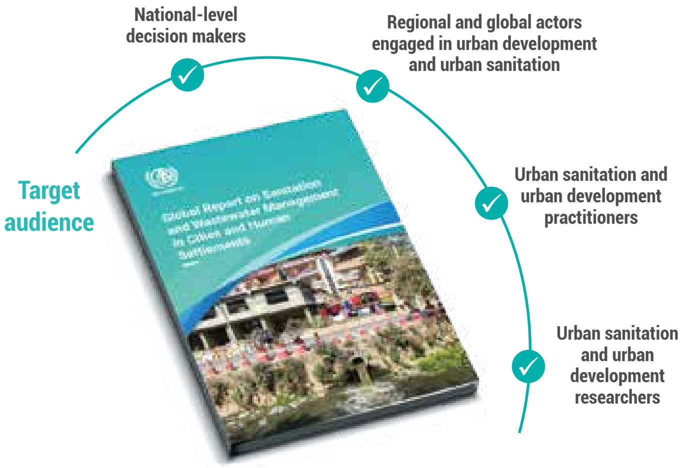
***Climate resilience and emerging innovations*: Hanoi, Vietnam**
This case study explores the emerging innovations now being trialled in Hanoi, with a focus on sustainable urban drainage systems and institutional arrangements for wastewater valorisation for agriculture.

dependent on self-reported data from focus cities, which could not be validated directly. Most likely, important innovative approaches are being implemented to tackle the wastewater and faecal sludge management challenge which have not been captured in this report. This report is only a starting point, aiming to trigger discussions that can reveal these innovations to the wider sector and increase opportunities for knowledge sharing.

1.4 Target audience: from decision makers and service providers to academia

The report provides a reference document on the global situation in wastewater and faecal sludge management, combined with practical and targeted recommendations. The report will be useful for the following core groups:

- **National-level decision makers** involved in urban development and urban sanitation, including relevant national government departments and regulators; policy-makers within relevant ministries; and decision makers within city authorities (for example, Managing Directors of water and sanitation utilities);
- **Regional and global actors engaged in urban development and urban sanitation**, including multilateral institutions, International Finance Institutions (IFIs) and other funding agencies;
- **Urban sanitation and urban development practitioners** seeking to better understand current trends and practices relating to sanitation and wastewater management to include in their planning and programming;
- **Urban sanitation and urban development researchers** seeking reference material to benchmark current practice.



1.5 Structure of this report

Following on from this introduction, **Chapter 2** sets the broad context of this report: it highlights the specific challenges of urban areas, before presenting key features of the 18 focus cities, including population and development status.

Bringing wastewater and faecal sludge treatment from the periphery also means understanding their centrality to environmental and health protection: **Chapter 3** fleshes out the impacts we face when adequate treatment solutions are not in place.

The report then dives into current levels of sanitation and wastewater management performance at the global level. Drawing on primary data from the 18 cities, it charts global levels of sanitation service provision and wastewater treatment efficiency in **Chapter 4**. Turning to financing arrangements in **Chapter 5,** the report takes a closer at planning resource allocation, what systems are potentially cost-effective and what options exist for covering costs. Recognizing the importance of clear responsibilities for urban sanitation**, Chapter 6** explores how mandates for wastewater and faecal sludge management are currently structured at the global level and provides guidance for how institutional frameworks can be strengthened. **Chapter 7** explores the fundamental importance of strong accountability, including environmental and economic regulation of wastewater and faecal sludge management services, before highlighting the practical tools available to regulatory authorities. The issue of data management, critical for sector planning and decision-making, is discussed in **Chapter 8**. The report then presents in **Chapter 9** emerging innovations that could be change makers in wastewater and faecal sludge management, including climate resilience, wastewater and faecal sludge reuse, and wastewater-based epidemiology. Finally, in **Chapter 10**, the report synthesizes key recommendations targeted to stakeholders involved in wastewater and faecal sludge management at the city, national, regional and global levels.

Residential discharge to the river Dhobi Khola (tributary of Bagmati River, Kathmandu, Nepal
© Rajesh Manandhar/UN-Habitat

02

The global challenge of sanitation and wastewater management in urban contexts

CHAPTER IN BRIEF

Urbanization is one of the defining global trends of the 21st century. In this section, we outline the extent of urbanization now taking place, and the implications for sanitation and wastewater management. We then introduce the contextual features of the 18 focus cities for this study. The analysis shows:

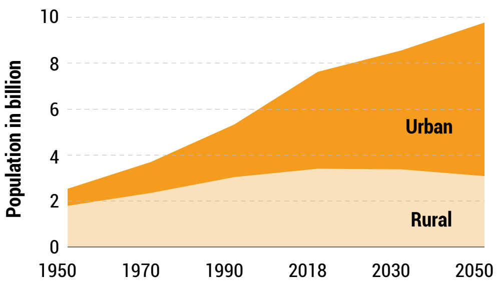
- The world's population will continue to urbanize, with nearly 70 per cent expected to live in cities by 2050. Much of this growth will take place in informal settlements and slums in and around large cities.
- Globally, wastewater and faecal sludge infrastructure has not kept pace with the high demand caused by rapid urbanization. The impacts of this deficit are now being exacerbated by climate change.
- Every city has different characteristics, which define their needs and the combination of responses required. Population density, water access, and financial resource levels are key variables influencing the mix of sanitation options appropriate to individual cities within our sample.

2.1 The global urban shift

The world has seen a rapid shift toward urbanization in recent decades. Today, more than half of the world's population live in urban areas. The global urban population increased fourfold from an estimated 0.8 billion in 1950 to an estimated 4.2 billion in 2018 (Figure 4) (UNDESA, 2018). The world's population is projected to continue to urbanize, with 68 per cent expected to live in cities by 2050.

Africa and Asia have joined Europe and the Americas as highly urbanized regions. Almost 90 per cent of urban growth is now occuring in Asia and Africa (UNDESA, 2018). Sub-Saharan Africa in particular is witnessing strong urban growth (4 per cent per year). Giant countries like Nigeria (206.1 million people) and the Democratic Republic of Congo (89.5 million) are predicted to have their urban population double in the next two

Figure 4: Urban and rural population 1950-2050



Source: UNDESA, 2018

Poor wastewater management, ranging from non-existing treatment systems to ineffective discharge, causes air, water, and soil contamination.

decades. South Asia is another urbanization hub, with countries like Bangladesh and Vietnam witnessing close to 3 per cent annual growth rate.

Today, the world's 33 megacities, each with a population of more than 10 million people, are home to roughly one-eighth of the world's population (UNDESA, 2018)**.** Since 1990, the number of megacities has tripled, concentrated in only 20 countries with the majority located in Asia. In 2018, China alone had six megacities and ten cities with populations ranging from 5 to 10 million. According to projections, by 2030, there will be 43 megacities, the majority of which will be in developing countries, with nearly half of the top 30 largest urban areas located in low- or lower-middle-income regions.

Large and small cities also play a key role in global urbanization. Nearly half of the world's urban residents live in settlements with less than 500,000 people. Another 22 per cent of the global urban population live in cities of 1 to 5 million inhabitants. In some regions, and Sub-Saharan Africa in particular, urban growth is occurring in smaller towns and cities with a population range of 100,000 to 500,000. Over the next decade, the majority of the world's urban population will continue to reside in small cities.

Rapid rural-to-urban migration has led to the development of large informal settlements or slums in and around large cities. An estimated 20 per cent of the world's urban population live in slums and unplanned urban settlements (UNDESA, 2018**)**. The majority of slum dwellers reside in three regions: Eastern and South-Eastern Asia (332 million), Central and Southern Asia (197 million), and Sub-Saharan Africa (189 million) (United Nations , 2018). Slum areas typically lack access to basic services, with inhabitants also affected by lack of security of housing tenure (Box 5). In many countries, the formalization of slums is politically contested, contributing to lack of financial resource allocation, lack of infrastructure and lack of basic services in these areas.

2.2 Sanitation infrastructure development: an urbanization challenge

Urbanization places ever greater pressure on urban infrastructure development, including water and sanitation. As cities grow in population, so does the total amount of water required and consumed, which increases the volume of wastewater produced. Annual demand for municipal water in the world's major cities is expected to rise by nearly 80 billion cubic metres by 2025, from around 190 billion cubic metres per year in 2012 to around 270 billion cubic metres per year (McKinsey Global Institute, 2012).

Managing wastewater is a major challenge for cities of all sizes, from megacities to small towns. Cities generate massive volumes of wastewater. Poor wastewater management, ranging from non-existing treatment systems to ineffective discharge, causes air, water, and soil contamination. Untreated or inadequately treated wastewater contributes to contamination of drinking water and increased levels of

Box 5: What is a slum?

UN Habitat define a "slum household" as one in which the inhabitants suffer one or more of the following 'household deprivations':

1. Lack of access to improved water source
2. Lack of access to improved sanitation facilities
3. Lack of sufficient living area
4. Lack of housing durability
5. Lack of security of tenure

Informal settlements are usually seen as synonymous of slums, with a particular focus on the formal status of land, structure and services.

Source: UN Habitat (2006).

infection and disease transmission. Finding space in cities to build new treatment plants or upgrade existing ones can be challenging. Due to noise and odour concerns, there may be public opposition to development near residential areas.

Globally, wastewater and faecal sludge infrastructure has not kept pace with the high demand caused by rapid urbanization. While cities in high-income countries frequently struggle with service quality – due to high operation and maintenance costs and deteriorating infrastructure – leading to environmental degradation, low and middle-income countries are struggling to expand wastewater services for all. In slum areas, few access wastewater management services, with populations often relying on informal service providers, posing health and environmental hazards. Secondary cities, which are fueling the bulk of urban growth, are lagging behind in urban development, resulting in significant discripencies between primary and secondary towns globally.

Aerial view of sewage treatment plant in Swindon taken by CAA approved operator
© Shutterstock

Today, climate change is exacerbating the impact of inadequate wastewater and faecal sludge treatment infrastructure. Urban populations are particularly vulnerable to climate change because of their size and density. For instance, concrete and asphalt surfaces in urban areas reduce infiltration, resulting in fast surface run-off that can increase flash floods and landslides. These events can damage urban infrastructure, hinder access to basic services, and threaten livelihoods. As well as being heavily impacted, cities are a key contributor to climate change. An estimated 70 per cent of global CO2 emissions come from urban areas, primarily from transportation and buildings (UCCRN, 2018). Wastewater management also contributes to greenhouse gas (GHG) emissions. There is a relative lack of data on global emissions linked to sanitation, with some estimates suggesting the contribution of onsite sanitation systems is circa 377 Mt CO2e/year, accounting for 4.7 per cent of the total anthropogenic CH4 emission, with India and China as major contributors, and excluding emissions from other sanitation systems (Cheng et.al, 2022). A whole-systems analysis of greenhouse gas emissions from citywide sanitation in Kampala, Uganda, suggests sanitation may represent more than half of total city-level emissions (Johnson et al, 2022).

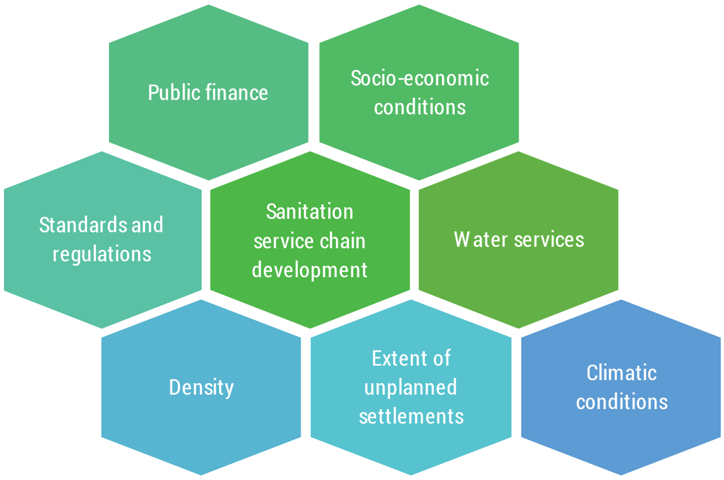
Box 6: "The Great Stink" and the introduction of large-scale sewerage systems

In Europe, high industrialization and urbanization rates throughout the eighteenth century brought with them a greater understanding of the importance of waste and wastewater disposal. The principle followed at first was to assume "the solution of pollution is dilution" (Angelakais et.al, 2018). Prior to the invention of the modern sewerage systems with associated treatment plants, the approach to wastewater management consisted mainly in directing wastewater onto water bodies, with the view that small amounts of sewage discharged into flowing water initiates a self-purification process. However, densely populated areas generate volumes of sewage such that dilution alone is ineffective to prevent pollution – and stench. In London, "the Great Stink" of August 1858, when the smell of untreated human waste discharged in the river Thames became untenable for members of Parliament and inhabitants, prompted the start of works for wastewater management in the city. This started with the construction of sewers. The first contemporary method of treating wastewater emerged in the 19th century. After that wastewater treatment appeared necessary prior to disposal from sewers. Centralized sewage treatment plants started to be built from the 19th century, primarily in the United Kingdom and the United States. Instead of directly being discharged into a nearby water body, sewage was first processed to remove pollutants using physical, biological and chemical processes.

2.3 Key features of the focus cities for this report

While all cities face the challenge of wastewater and faecal sludge management, every city has different characteristics, which define their needs and the combination of responses required. These characteristics are captured in Figure 5 below and relate to a combination of of socio-economic and environmental features as well as access to sanitation and water services, among others.

Figure 5: factors influencing current and potential city-level responses to the sanitation challenge



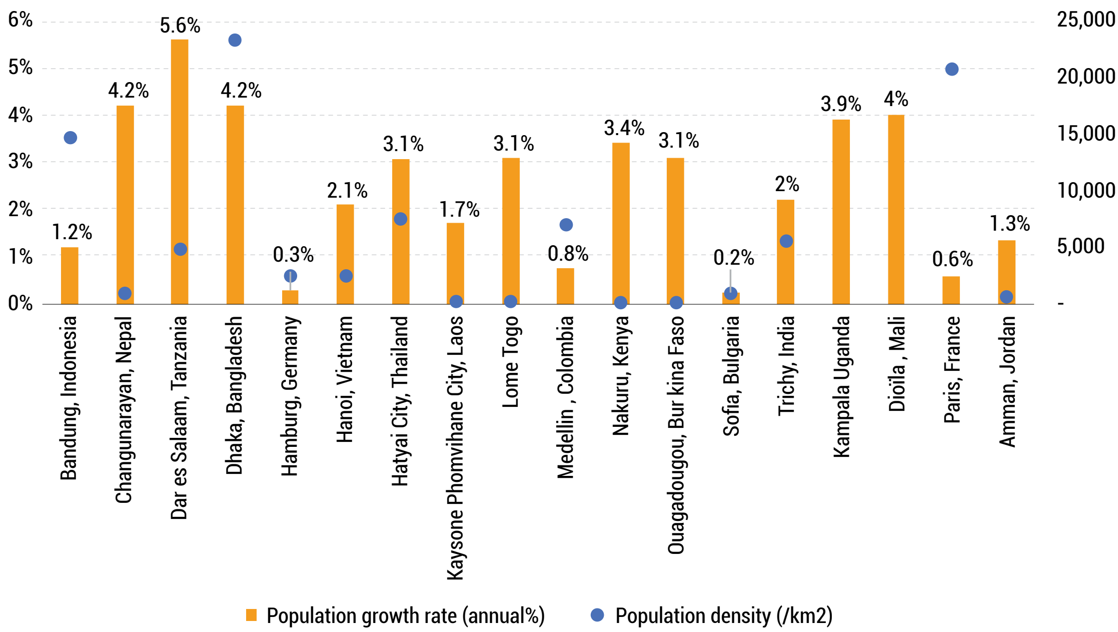
Source: Authors.

This section outlines some of these key contextual features for the 18 focus cities of the global mapping.

First of all, some cities are still in the process of rapid expansion. Five of the 18 cities have an annual growth rate above 3.8 per cent. Dar es Salaam in Tanzania tops all cities with a rate of 5.6 per cent (Figure 6). Cities with such fast growth rates have to rapidly adapt services and respond to basic needs such as access to toilets and sewer connections. Cities' expansion also calls for careful planning of wastewater and faecal sludge management systems on the basis of future demand.

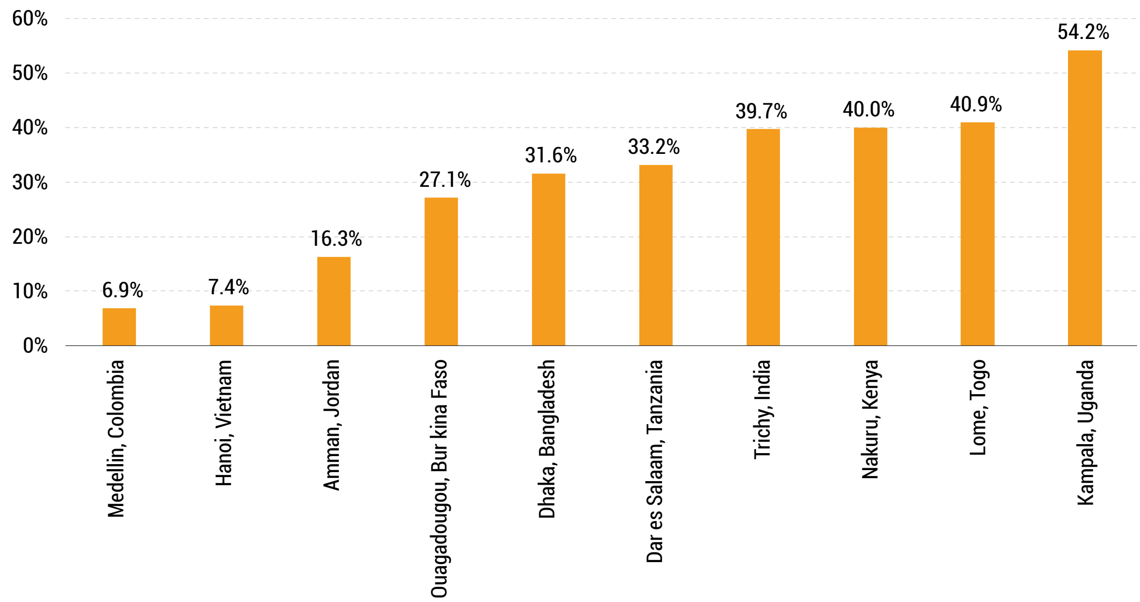
Population density is also an important factor in determining approaches to sanitation service provision. High density can justify the development of sewers and WWTPs: for example, sewered sanitation can be an appropriate response in low-income contexts where cities are primarily developing vertically, with a predominance of multi-storey buildings. However, high density can also result from the expansion of informal settlements and slums, as in the case of Dhaka, Kampala and Trichy, for example (Figure 7). The development of conventional sewers can only occur in the context of whole slum upgrading.

Figure 6: Population growth rate and density of the 18 focus cities



Source: Reported figures from national sources.

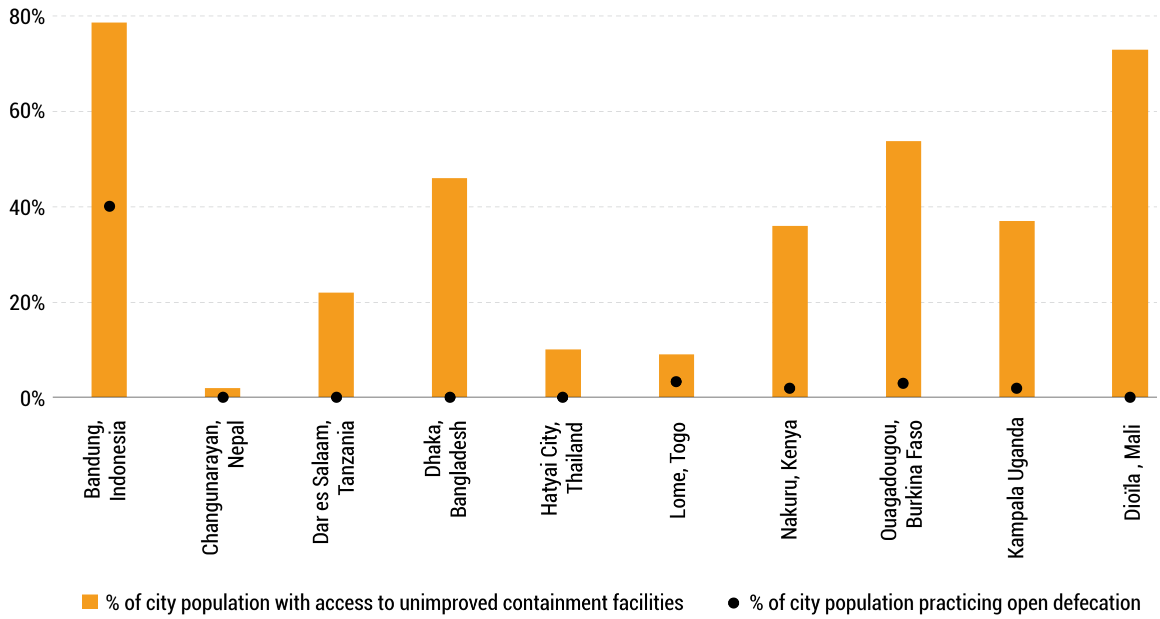
Figure 7: Percentage of city population living in slums in select focus cities



Source: UN-Habitat Data Analytics Section.

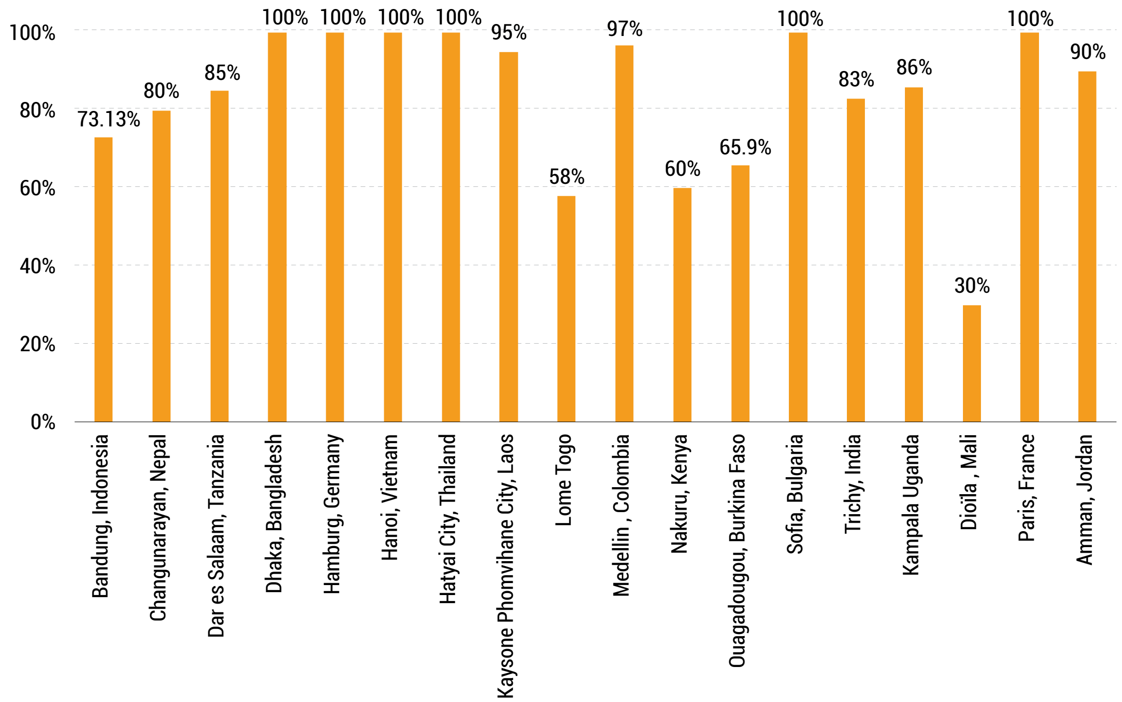
Many focus cities face the challenge of achieving universal access to basic sanitation facilities. Some cities still need to tackle open defecation, as in Kampala, Ouagadougou, Lomé and Bandung. Others may have eradicated the practice but face the issue of poor toilets, which may be difficult to service. For these cities, the challenge of wastewater and faecal sludge starts from the point of containment (see also Chapter 4).

Figure 8: Percentage of the focus cities' population practicing open defecation and using unimproved toilets



Source: Reported figures from national sources.

Figure 9: Total population connected to the water network in the focus cities



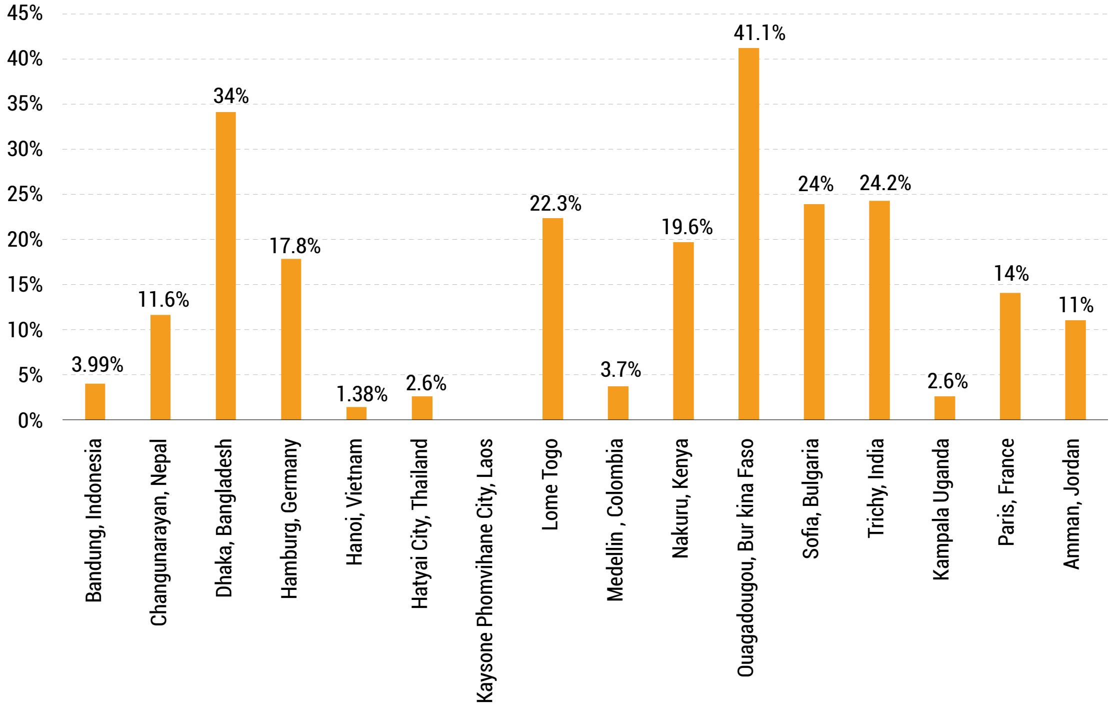
Source: Reported figures from national sources. A full list of sources is provided in Appendix D.

Access to water is critical in determining which sanitation options are feasible. Pour-flush toilets, for example, require a reliable water supply. Here there is considerable variation within our sample. Six focus cities report 100 per cent coverage, including the three European cities, which also have full sewered coverage; but also three cities in Asia (Dhaka, Hanoi and Hatyai). In the African focus cities, coverage ranges from 86 per cent in Kampala to 30 per cent in the commune of Dioila, with Lome, Nakuru and Ouagadoudou each around 60 per cent coverage (Figure 9).

Worker inside sewer tank, Nakuru, Kenya © Brian Otieno

Finally, and critically, cities and their populations face different financial constraints. In Ouagadougou for example, over 40 per cent of the population live below the national poverty line, many of whom reside in informal settlements (see Ouagadougou case study). At city and country level, limited financial resources mean that low-cost technologies need to be prioritized, where these options can still provide an effective service. As discussed in Chapter 4 and Chapter 7, such low-cost options do exist and need to be better integrated in service planning. At the household level, there is considerable variation in ability to pay for services, and correspondingly, the portion of costs which city authorities and planners can expect to recover from services users themselves (in charges and tariffs). The issue of cost-recovery is discussed in Chapter 7.

Figure 10: Per centage of focus city populations living below the national poverty line



Source: Reported figures from national sources.

Conclusion

The 18 cities included in this study represent a diversity of contexts in terms of population growth, income level, and current levels of access to water supply and safely managed sanitation. These contextual features will be critical in shaping the approaches adopted to ensure effective wastewater and faecal sludge management. The options available to decision makers, and now being implemented in the focus cities, are outlined from Chapter 4 onwards. But irrespective of the context and the approach taken, it is critical that national and city authorities take action to prioritize these services, for reasons set out in Chapter 3.

The man taking photo of mass dead fish
on West Lake (Ho Tay), Hanoi, Vietnam
© Shutterstock

03

The impacts of poor sanitation and wastewater management

CHAPTER IN BRIEF

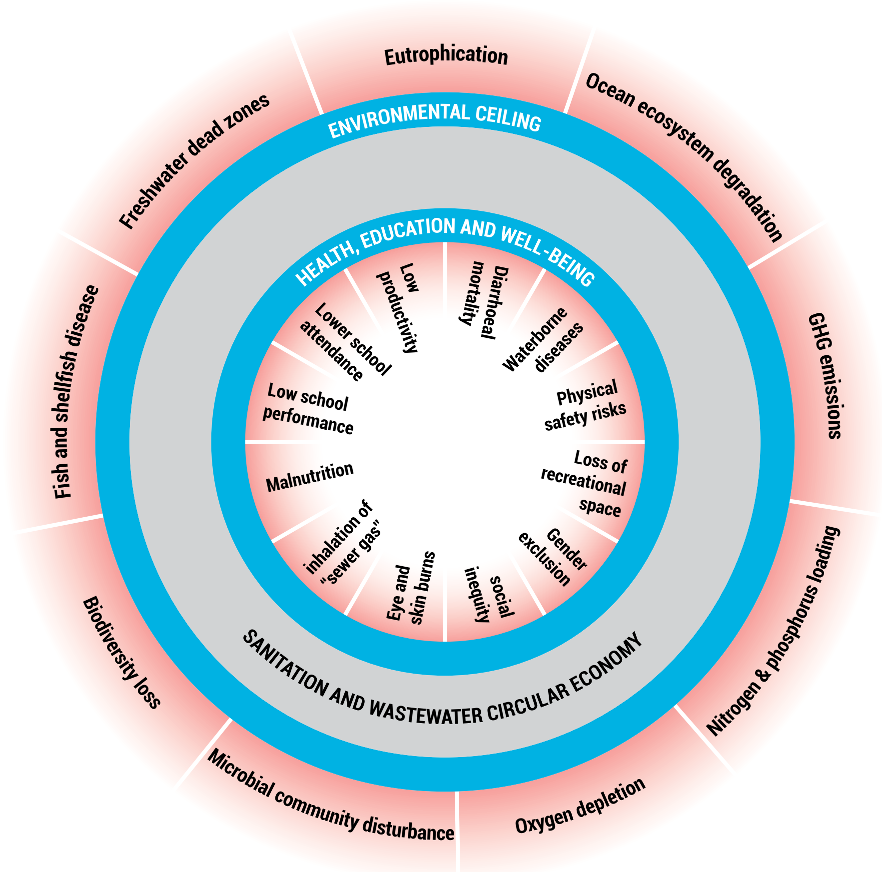
This Report argues that greater attention is urgently required at the global level to improve sanitation and wastewater management. Why is this issue so important? In simple terms, because poor sanitation has hugely detrimental impacts on public health, environments and economies. The vast potential gains to be made from improvements largely outweigh the cost of inaction.

- Poor sanitation and wastewater management creates major **health risks** from water-borne pathogens, and is associated with reduced water quality and disease spread.
- Key **environmental impacts** from untreated wastewater include ecosystem damage due to oxygen depletion in receiving waters from the biodegradation of organic matter; and the eutrophication of waters resulting from excessive inputs of nutrients present in wastewater.
- Taken together, these environmental and health impacts exert a huge toll on **economic activity**, including through loss of workdays and income.

Sanitation and wastewater management impacts directly on human and environmental flourishing. Figure 11 presents these impacts holistically through adaptation of the established doughnut economic model. Applied to sanitation and wastewater management, the doughnut consists of two concentric rings: a social foundation, focused on health, education and well being; and an environmental ceiling, focused on protecting earth's life-supporting systems. Between these two sets of boundaries lies a doughnut-shaped space that is both ecologically safe and socially just, characterized by the balanced and sustainable use of resources to optimize human and environmental outcomes, here conceived as the sanitation and wastewater circular economy.

Below the diverse impacts of inadequate sanitation and wastewater management are unpacked, with a focus on health, environmental and socio-economic aspects.

Figure 11: The impacts of poor sanitation and wastewater management



Source: Authors, adapted from Raworth, K, 2017.

3.1 Health impacts

Globally, health conditions and diseases caused by inadequate WASH account for 1.6 million deaths every year, and 105 million disability adjusted life years (DALYs). Of these, 829,000 deaths are due to diarrhoeal disease.

The disease burden of inadequate sanitation

The impacts of poor wastewater and faecal sludge management on human health can be devastating. Perhaps first among these impacts is **diarrhoea**, a leading cause of disease and death among children under five years of age in low- and middle-income countries (WHO & UNICEF, 2020). This includes **cholera** — an acute diarrhoeal disease associated with exposure to untreated wastewater — and other waterborne diseases such as dysentery, typhoid, and polio.

Eliminating open defecation is associated with reduced prevalence of infectious disease, improved nutrition, improved cognitive development, and improved wellbeing, especially for women and girls (WHO, 2018). By contrast, lack of safe sanitation is associated with a wide range of **neglected tropical diseases**, such as soil-transmitted helminth infections, schistosomiasis and trachoma, which account for a significant burden of disease globally (WHO & UNICEF, 2020).

Infections caused by inadequate sanitation commonly lead to malnutrition and stunting among children (WHO, 2018; Root, 2022; Bhave, Naik and Salunkhe, 2020; UNESCO, 2020). Stunting has been found to affect one quarter of children under five years of age globally, through mechanisms including repeated diarrhoea, helminth infections and environmental enteric dysfunction related to unsanitary conditions, leading to poor physical and cognitive development (WHO & UNICEF, 2020).

Globally, health conditions and diseases caused by inadequate WASH account for 1.6 million deaths every year, and 105 million disability adjusted life years (DALYs). Of these, 829,000 deaths are due to diarrhoeal disease. Sixty per cent of the overall diarrhoea burden, 13 per cent of the burden from acute respiratory infections, 16 per cent of the burden of protein-energy malnutrition, 43 per cent of the schistosomiasis burden,

Table 1: Disease burden[1] linked directly or indirectly to inadequate sanitation, 2016

Disease	Deaths	DALYS (Disability adjusted life years)	Population-attributable fraction
Diarrhoeal diseases	828,651	49,774	0.60
Other diseases and conditions			
Soil-transmitted helminth infections	6,248	3,431	1
Malnutrition[2]	28,194	2,995	0.16
Trachoma	<10	244	1
Schistosomiasis	10,405	1,096	0.43
Lymphatic filariasis	<10	782	0.67
Total other diseases	**44,848**	**8,548**	**NA**

Source: WHO & UNICEF, 2020.

[1]Disease burden estimates and population-attributable fraction are presented for WASH combined. Disease burden estimates are for LMICs; diarrhoea include disease burden in high-income countries.
[2] Includes disease burden of protein–energy malnutrition and consequences in children < 5 y

80 per cent of the malaria burden and 100 per cent of both the burden from soil-transmitted helminth infections and trachoma burden are attributed to inadequate WASH (Prüss-Ustün, et al, 2019). Table 1 provides an overview of key health outcomes that are at least partly attributable to inadequate sanitation and the associated disease burden.

A number of vulnerable groups are particularly at risk of sanitation-related disease. In urban contexts, these include the residents of **informal settlements** and migrant communities, who are more likely to practice open defecation due to inadequate public facilities. Those living in low-lying areas, and downstream from effluent outlets, are also more likely to be exposed to disease originating from inadequately treated wastewater. Safe sanitation is vital in **health centres**, to reduce exposure to infections for pregnant women and newborns, which may lead to adverse pregnancy outcomes, sepsis and mortality (Benova, Cumming & Campbell, 2014).

Traditional toilet in Viet Nam. Underneath toilet they raise fish © Shutterstock

Sanitation workers such as manual pit emptiers are at very high risk. A meta-analysis of occupational health outcomes among sanitation workers found this group to at increased risk of gastroenteritis and respiratory conditions (Oza et al, 2022). Wider reported physical and medical conditions directly associated with sanitation work include cholera, typhoid, hepatitis, polio, cryptosporidiosis and schistosomiasis, as well as eye and skin burns resulting from exposure to toxic waste and gases (World Bank, ILO, WaterAid, and WHO, 2019). As outlined by WHO, sanitation workers may be exposed to ‘sewer gas’ produced during the breakdown of faecal sludge — composed of hydrogen sulphide, methane, nitrogen, carbon dioxide and ammonia — the inhalation of which can have fatal consequences (WHO, 2018).

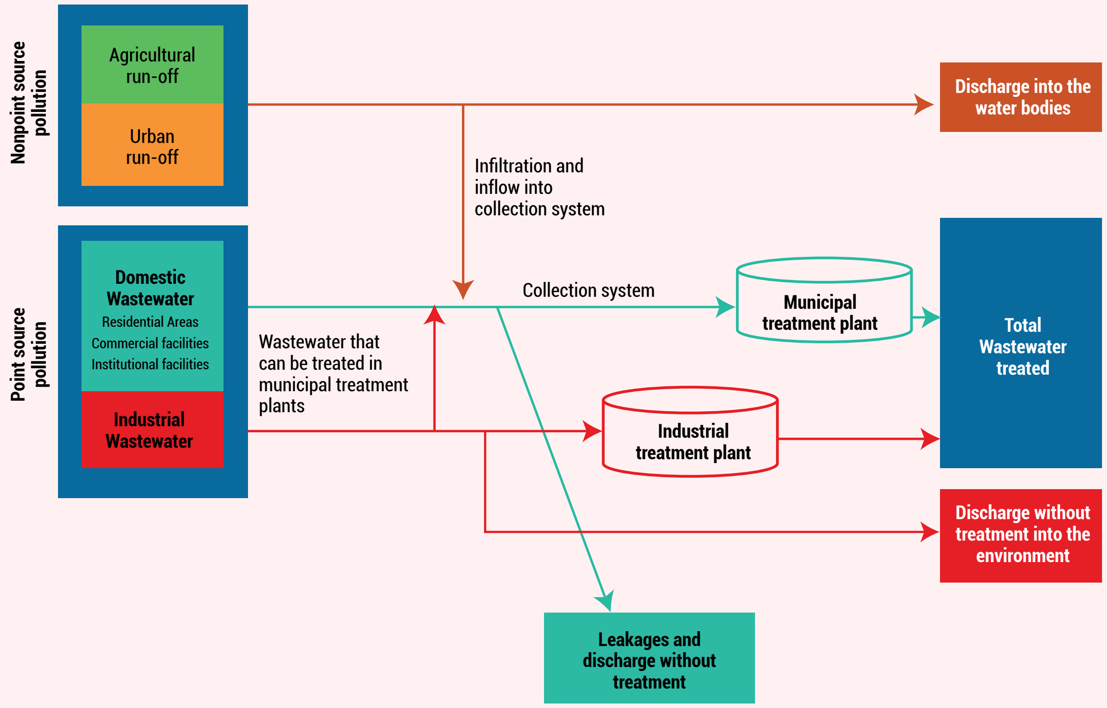
Box 7: **Sources of pollutants carried by wastewater**

Figure 12 presents wastewater flows, distinguishing between water pollutants originating from point and non-point sources:

- Point-source pollution reaches water from a single sewage discharge pipeline or channel, typically originating from domestic or industrial activities.

- Non-point source pollution enters the body of water from broad, unconfined areas. For instance, surface runoff from farms is a non-point source of pollution that introduces fertilizers, pesticides and animal waste into nearby streams. Urban stormwater drainage, which may carry grit materials, oil, grease and toxic chemicals from motor vehicles, is also considered a non-point source of pollution.

Figure 12: Wastewater flows



Source: Authors

Chemical exposure risks associated with inadequate sanitation

Infectious disease is the most significant and most quantified health risk resulting from inadequate sanitation and wastewater management. A number of chemical compounds pose health risks. First among these are nitrogen and phosphorus, key wastewater constituents explored in **Chapter 4**. Known and emerging health risks associated with chemical compounds present in wastewater are summarized below. A summary of wastewater characteristics is provided in Box 8.

- **Nitrogen**: If not removed properly from wastewater, nitrogen and phosphorus can cause toxic algal blooms and eutrophication in receiving waters (see **Section 3.2**). Human exposure to nitrogen compounds can also occur through contaminated drinking water from both public systems and private wells. Some potential health issues caused by nitrate exposure include reproductive problems, methemoglobinemia, colorectal cancer, thyroid disease and neural tube defects (Ward et al., 2018; Van Grinsven et al. 2006). Babies are most at risk for being contaminated by nitrates, which may induce methemoglobinemia or blue baby syndrome.

- **Endocrine-disrupting compounds (EDCs):** Industries such as pulp and

An emerging contaminant of concern, microplastics have been found widely present in sewage samples globally.

paper, tannery, distillery, textiles and pharmaceuticals are considered major sources of EDCs (Haq and Raj, 2019), as well as wider complex organic and inorganic pollutants. These industrial wastewaters can end up combined with the municipal sewage system, and if not appropriately treated, increase the level of EDCs in municipal wastewater. Conventional wastewater treatment plants have not been designed to remove EDCs and other micropollutants. For example, during wastewater treatment by activated sludge process, EDCs can be transferred from sewage to sludge because of their hydrophobic properties (Guo et al., 2016). EDCs have been linked to reduced fertility (Matuszczak et al., 2019; Vessa et al., 2022) and increased cancer risk (Diamanti-Kandarakis et al., 2009; Calaf et al., 2020). Children are more susceptible to EDC exposure compared to adults (Wee and Aris 2022).

- **Microplastics**: an emerging contaminant of concern, microplastics have been found widely present in sewage samples globally (Lyare et al, 2020). A critical review of micoplastics removal in wastewater treatment plants found that secondary and tertiary WWTPs remove an average of 88 per cent and 94 per cent of microplastics, respectively. Microplastics can become airborne during the application of wastewater treatment sludge in agriculture, increasing human exposure to these particles through inhalation (Revel et al. 2018). The actual measure of human exposure to microplastics can only be estimated by body fluids analysis. Studies on this area are still scarce (Udovicki et al. 2022) but a WHO systematic review of microplastics in drinking water suggests current levels do not exceed the level of concern for human health (WHO, 2019).

- **PFAS:** Further chemical compounds originating from domestic and industrial wastewater are per- and polyfluoroalkyl substances (PFAS), the collective name for a large group of fluorinated compounds. PFAS are extremely persistent in the environment, and have been reported found in water, food, and air worldwide (Fenton et al. 2021). Some of the health impacts caused by these substances identified by the European Environment Agency (2019) with high certainty include thyroid diseases, increased cholesterol levels, liver damage, kidney cancer, testicular cancer, and various developmental issues affecting unborn children.

In **Chapter 4**, we explore current levels of treatment for nitrogen and phosphorus as key wastewater constituents for which data is available. It is important to note that many of the wider emerging compounds outlined above are not yet regulated (Rogowska et al. 2020). Some countries prioritize different compounds, indicating concentration and risk levels of these chemicals may vary due to different production, consumption habits and detection methods (Yang et al. 2022). Further research is required to better understand the level of risk to human health posed by contaminants such as microplastics (see **Chapter 9**).

Open drain in Dhaka, Bangladesh © Green Ink Media

Box 8: Wastewater constituents and their potential health and environmental impacts

Wastewater is characterized by its physical, chemical, and biological composition**.** As we explore in **Chapter 4**, measuring and understanding these characteristics will help determine the most appropriate treatment techniques for meeting discharge requirements. Below we summarize the key constituents of wastewater and their connected impacts.

An important physical characteristic of wastewater is its total solids content, which can be divided into total dissolved solids (TDS) and total suspended solids (TSS) (TSS are solids in water that a filter can trap). Other important physical characteristics include turbidity, colour, temperature, odour and conductivity. **Suspended solids** are constituents of concern in wastewater treatment. When untreated wastewater is discharged into the aquatic environment, suspended solids can lead to the development of sludge deposits, may decrease water's natural dissolved oxygen levels, and increase water temperature, threatening aquatic biota.

The chemical constituents of wastewater are typically classified as inorganic and organic. The concentrations of different inorganic and organic elements are constituents of concern in wastewater treatment as they may significantly impact the use of water. The primary constituents of concern are **nitrogen, phosphorus and heavy metals**. Nitrogen, phosphorous and traces of metals are necessary for biological growth, and sufficient levels are required to make the wastewater treatable. If these nutrients and metals are discharged into water bodies, they might lead to serious problems such as eutrophication, oxygen depletions, and toxicity to aquatic ecosystems. The presence of nutrients and metals in excessive quantities will also interfere with the beneficial uses of water because of their toxicity to humans.

Organic constituents are of great significance in treating, disposing and reusing wastewater. The most widely used parameter that measures aggregate organic matter is the **5-day Biological Oxygen Demand** (BOD5). BOD tests measure the dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter. This test is used to measure the treatment process's efficiency and determine compliance with discharge regulations. **Chemical Oxygen Demand** (COD) is another method of measuring the organic pollutant in water and wastewater[i].

Finally, the biological characteristics of wastewater are of critical importance in the control of diseases caused by pathogenic organisms. Pathogenic organisms found in wastewater are excreted by humans and animals. They can be classified into four broad categories: bacteria, protozoa, viruses and helminths. The survival of those pathogenic organisms in the water can be of great concern in the management of diseases such as typhoid, dysentery, diarrhoea and cholera. However, bacteria and other microorganisms have extensive and fundamental roles in the decomposition and stabilization of organic matter, both in nature and in wastewater treatment plants.

i While the BOD test uses a population of microorganisms to replicate what would happen in a natural stream over five days, the COD test uses a strong chemical oxidizing agent to chemically oxidise the organic material in the wastewater sample.

Health risks posed by unsafe agricultural reuse of wastewater and faecal sludge

In **many countries, especially LMICs, treatment of wastewater and faecal sludge used for irrigation and/or as fertilizer for agriculture is not closely monitored, and may be absent entirely.** There is emerging work on the use of wastewater and other sanitation end products for crop irrigation and fertilization, which has significant potential to improve food security and water conservation. However, there is a risk of adverse health impacts through pathogen exposure (WHO, 2006) if reuse is not effectively regulated. Currently the majority of cropland depending on wastewater flows is situated in around 70 countries with generally low levels of wastewater treatment, including (for example) China and India (UNEP, 2017). It has been estimated that the use of untreated wastewater for urban and peri-urban agriculture accounts for about 11per cent of all irrigated croplands (Thebo et al, 2017).

The wide range of contaminants and organic pollutants present in untreated wastewater are posing serious health risks to farmers, communities and consumers of wastewater irrigated crops (Dickin *et al.*, 2016; Damania *et al.*, 2019). Adegoke et al. (2018) have documented impacts associated with wastewater irrigation including diarrhoeal disease, food-borne disease outbreaks, and harmful antibiotic residues in wastewater reuse and irrigated soil (Adegoke *et al.*, 2018). For instance, in Vietnam, a focus country for this study, exposure to untreated agricultural wastewater was associated with skin disease including dermatitis and fungal infections (Dickin *et al.*, 2016; Adegoke *et al.*, 2018).

Both low-income and high-income nations still have cities that suffer from severe contamination of surface water caused by the disposal of untreated wastewater into water bodies.

There are a number of resources and tools which can support mitigation of these risks. These include Sanitation Safety Planning, a tool to help sanitation system operators to minimize health risks of their system (WHO 2016), the implementation of which provides assurance to the public and operators of system performance based on risk assessment and management. The requirement for improved safeguards to unlock potential safe wastewater and faecal sludge valorization is explored further in **Chapter 9**.

3.2 Environmental impacts

The disposal of untreated wastewater and faecal sludge into the environment is a significant threat to ecosystems below water and on land (Fayomi et al., 2019; Wear et al., 2021). Key environmental impacts of this practice can range from those affecting water sources such as groundwater contamination and surface water pollution, to the negative impacts on biodiversity (Thomas et al., 2018). Wastewater input from sewered and septic sources impact natural habitats globally due to contaminants like nutrients, pathogens, endocrine disruptors, suspended solids, and heavy metals found within sewage (Wear & Thurber, 2015). Below we summarize three key environmental impacts resulting from disposal of untreated wastewater and faecal sludge in turn.

Pollution of coastal ecosystems

Poor wastewater management has a plethora of impacts on costal ecosystems, leading to eutrophication, declining of fisheries, habitat loss and degradation. Sewage is in fact the largest source of coastally derived pollution (Wear & Thurber, 2015). For example, Tuholske et al (2021) have identified that 58 per cent of coral with hotspots of exposure in China, Kenya, Haiti, India and Yemen and 88 per cent of seagrass beds with hotspots of exposure in Ghana, Kuwait, India, Nigeria and China are exposed to wastewater nitrogen input (Tuholske *et al.*, 2021). Wear et al (2021) present that poorly treated wastewater is as equal a threat as overfishing to **coral reefs**, exerting notable impacts including the inhibition of reproductive output and growth, disease, bleaching, algal overgrowth or dead zones, and low oxygen levels leading to the death of coral (Wear & Thurber, 2015) (Wear *et al* 2021). **Oyster reefs**, extremely valuable for their ability to filter out toxic contaminants, are depleting due to coastal pollution: disposal of sewage contents in the ocean are causing death in oyster embryos and have shown impacts on the reproductive capabilities of oyster species (Wear et al., 2021).

Pollution of freshwater ecosystems

Freshwater systems are particularly susceptible to sewage pollution because of their proximity to human settlements. Both low-income and high-income nations still have cities that suffer from severe contamination of surface water caused by the disposal of untreated wastewater into water bodies. In India, for instance, severely polluted rivers increased dramatically with the human population increase (Wear et al., 2021). An estimated 46 per cent of rivers and streams and 35 per cent of lakes are polluted by sewage or fertilizer run-off in the US. Pollution from textiles production is particularly significant in Africa (Hepworth et al., 2021).

In heavily polluted freshwater bodies, oxygen depletion and EDCs are leading to dead zones and disease in fish and shellfish. Around a million animals and plants are facing extinction from poor wastewater management and excessive water extraction, with freshwater species especially suffering the greatest recent decline in numbers (84 per cent since 1970) (UNESCO, 2020). Sewage borne contaminants in juvenile salmon (Meador et al., 2016), heavy metal occurrence in predatory fish (Saha et al., 2016), and white pox disease in the most habitat-forming coral in the Caribbean are some of the documented cases resulting from increased sewage pollution in water bodies (Wear et al., 2021).

Pollution of terrestrial ecosystems

Terrestrial ecosystems, wildlife and species diversity are also significantly impacted by the disposal of untreated wastewater. The dispersion of treated or untreated wastewater effluent and sludge in the terrestrial environment — including forests, marsh lands, open waters and estuarine systems — is a common practice globally, including Europe, US and China (Manzetti and van der Spoel, 2015), resulting in the gradual accumulation of toxins and persistent organic compounds in the environment (Wear et al., 2021), which are also accumulated by plants and wildlife living around contaminated water. In India for example, high concentration of zinc, nitrogen and lead were found in soil, vegetation and milk sourced from near a sewage-polluted area, raising concerns for both humans and the wildlife (Wear et al, 2021). In addition, sludge pollution on the surface of wetlands is leading to decreased plant quality, impacting food sources and essential habitats for animals, birds and insects, and leading to biodiversity loss and reduced long term survival chances of exposed species (Manzetti and van der Spoel, 2015; Wear *et al.*, 2021).

Emerging contaminants including EDCs, heavy metals, pharmaceuticals and pathogens are of concern to wildlife and natural habitats as well as public health (Wear et al, 2021). Antibiotics in particular, when discharged in the water bodies, contaminate the aquatic environment, distorting the structure and functioning of microbial communities in soil and water ecosystems (Fayomi et al., 2019). For example, Diclofenac, an anti-inflammatory drug, is only 40 per cent removed by WWTPs and can persist in rivers and streams for weeks to months (Fayomi et al., 2019).

Impacts on climate change

Effective wastewater and faecal sludge management are imperatives for reducing the carbon footprint of the water sector.

Effective wastewater and faecal sludge management are imperatives for reducing the carbon footprint of the water sector. The impacts of wastewater and faecal sludge management on climate change through greenhouse gas emissions are summarized below. The countervailing influence of climate change on sanitation is discussed in Chapter 4. Innovations in climate-resilient sanitation are discussed in Chapter 9.

Wastewater reuse, treatment and reclamation alone has been estimated to cause an average of 56 per cent of the GHG emissions in the water industry globally every year (Tram et al, 2014). This contribution is in the form of A) onsite GHG — carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O) — which are directly related to wastewater and faecal sludge treatment processes; and B) offsite GHG (CO2 and CH4), resulting from energy use, chemical production and transportation, which form essential parts of wastewater and faecal sludge management processes globally (Bani Shahabadi et al, 2009). In total, wastewater and faecal sludge treatment is estimated to produced 257 million tonnes CO2 equivalent every year, while emissions from onsite sanitation (not removed) amount to 267 million tonnes.

Nitrous oxide, known to be three times more potent than CO2, accounts for more than 37 per cent of wastewater emissions. Methane, mostly emitted by faecal sludge stored in onsite facilities (such as septic tanks), is also emitted in the wastewater transport and treatment process. Global methane emissions from onsite sanitation solutions were estimated to form 4.7 per cent of global anthropogenic methane emissions in 2020, with emissions from networked sanitation solutions at a similar level (Cheng et al, 2022). Among onsite sanitation technologies, "wet" containments, receiving both faecal sludge and grey water, are the most susceptible to emitting methane. Nitrous oxide emissions are mostly a consequence of nutrient removal in the biological treatment process.

Emerging research suggests that transport and treatment improvements and more adapted faecal sludge containment storage can help reduce emissions. For example, a 2022 analysis of greenhouse-gas emissions from citywide sanitation in Kampala found containment contributes about 77 per cent of sanitation emissions, and improving containment technologies and practices would contribute significantly to reduction of GHG emissions for sanitation in the city (Johnson et al, 2022).

3.3 Socio-economic impacts

The negative impacts of poor wastewater and faecal sludge management are felt across different regions, sectors and socio-economic population groups worldwide. Below we summarize some of the key socio-economic impacts associated with inadequate sanitation.

Core economic impacts

At the global level, the cost of poor sanitation was estimated at USD 222.9 billion in 2015, up from USD 182.5 billion in 2010, contributed by the factors of mortality, productivity, healthcare, and access to sanitation (Lixil, Oxford Economics and WaterAid, 2016). A 2016 review of the costs of poor sanitation found Asia pacific has the highest economic burden of poor sanitation overall, with considerable disparities between regions (Lixil, Oxford Economics and WaterAid, 2016). A 2012 WHO study assessed the economic costs of not investing in water and sanitation in 135 low and middle-income countries, estimating economic losses equivalent to 0.5 per cent to 3.2 per cent of gross domestic product (GDP) between regions, or 1.3 per cent globally, with the highest impact in Sub-Saharan Africa (WHO, 2012). Conversely, the economic benefits of adequate wastewater and sanitation treatment are significant. A WaterAid report revealed the prospect of boosting the global economy by trillions of dollars with universal access to clean water, toilets, and hygiene over the next two decades (achieved by 2030 and maintained through 2040) (Water Aid, 2021). The global provision of toilets with safely managed faecal sludge services alone is estimated to generate USD 86 billion per year in greater productivity and reduced health costs (WaterAid, 2021). Similarly, improved health care services and productivity in LMICs are evaluated to generate USD 1.4 trillion to USD 1.6 trillion each year (Chaitkin *et al.*, 2022).

The global provision of toilets with safely managed faecal sludge services alone is estimated to generate USD 86 billion per year in greater productivity and reduced health costs.

Economic costs are disproportionately felt by poorer communities. The health of these communities is particularly impacted by lack of sanitation (WHO & UNICEF, 2020), which can result in comparatively higher healthcare costs; and poor and marginalized groups are also more likely to live 'downstream', making their communities disproportionately affected by other people's unmanaged faecal waste. Poor sanitation acts as a barrier to school attendance and enrolment in many countries, with poorer communities again disproportionately affected (WHO & UNICEF, 2020).

Economic losses resulting from sanitation vary widely across countries but are substantial in LMICs. In Ghana and Pakistan, for example, the economic costs of malnutrition from poor sanitation, which include impaired school performance and delayed entry into the labour market, amount to 9 per cent of the gross domestic product (GDP) (Van Minh and Nguyen-Viet, 2011); in India. Economic losses resulting from poor sanitation have been estimated at over 6 per cent (Singh et al, 2014). Aside from diarrhoea-related mortality, millions of people globally are unable to maximize their economic productivity due to sickness and disease caused by poor sanitation. Billions of hours of labour are lost every year, with an estimated cost of USD 16.5 billion to the global economy in reduced productivity (Lixil, Oxford Economics and WaterAid, 2016). By contrast, safe sanitation leads to multiple productivity gains, including having more productive time and spending less time seeking sanitation facilities (WSUP, 2021).

Economic impacts also include losses to key sectors such as the tourism industry (Van Minh and Nguyen-Viet, 2011**).** For example, in South Tarawa, an island nation in the central Pacific Ocean, poor waste management practices, combined with inadequate water supply, have resulted in the visible degradation of seaside areas, making them unclean, unappealing, and unsafe for swimming, resulting in an important decrease of tourists since 2010 (Asian Development Bank, 2013).

Costal and freshwater eutrophication also have global negative economic consequences. These impacts of poor wastewater management are linked to increasing public health costs, loss of biodiversity, losses in commercially important fisheries, decreases in waterfront property values and loss in tourism revenue (McCrackin *et al.*, 2016). For example, the estimated economic cost from freshwater eutrophication in England and Wales is USD 105-160 million annually (Pretty *et al.*, 2003). Similarly, Dodds et al. (2009) estimated that the freshwater eutrophication in the US costs USD 2.2 billion annually, mostly due to decrease in property and recreation value, but also due to threats towards endangered species and impacts on drinking water (Dodds *et al.*, 2009). Pollution of nearby freshwater sources can also compel authorities to source water for domestic and industrial use from far-flung sources, incurring significant extra costs.

Wider socio-economic impacts

In addition to health and economic impacts, sanitation plays a vital role in improving broader aspects of well-being, including security, dignity and overall quality of life. These wider and fundamental impacts of sanitation, extending beyond traditional and narrower focus on health impacts, are gaining increasing attention in the literature (Scar et al, 2018). A broader conception of the impacts of safe sanitation has been supported by the introduction of new evaluative frameworks, such as the SanQoL framework (Sanitation-related Quality of Life), which aims to measure user perceptions of sanitation quality such as feelings of safety, privacy and disgust (Ross et al, 2021).

Women, girls and vulnerable groups are disproportionately affected by inadequate sanitation. Lower school attendance linked to poor sanitation affects girls in particular, especially after puberty, when their need for menstrual hygiene management may not be addressed; while poor access to sanitation can expose vulnerable groups, and particularly women and girls, to violence and harassment. People with disabilities also suffer additional affronts to their dignity from a lack of appropriate sanitation services, with inaccessible toilets leaving them more susceptible to disease, and at greater risk of abuse (WHO & UNICEF, 2020).

Recent studies have shown that women and girls experience vast gains in quality of life when sanitation access is improved. For example, quality of life metrics were used to measure the user-perceived impact of a shared sanitation intervention in Maputo (Ross et al, 2021) and an evaluation of user satisfaction with Clean Team, a container-based sanitation service in Kumasi, Ghana — in both cases to striking effect. The Clean Team Evaluation revealed that customers experienced substantial quality of life gains after adopting the service, in comparison with their previous use of existing public toilets; importantly, while women were less satisfied than men with public toilets, access to the Clean Team service closed the gender gap completely (Tidwell et al, 2021).

Recommendations:

Monitor the impact of untreated wastewater discharge and faecal sludge on environment and biodiversity, promoting enhanced understanding of how pollutants in wastewater and faecal sludge impact soil, marine and aquatic ecosystems.

Support research to develop more cost-effective treatment processes for emerging pollutants and microplastics.

Support further research to generate and update estimates of greenhouse-gas emissions from sanitation systems globally, building on recent studies.

Old town waste water treatment plant, Nakuru, Kenya

04

Wastewater and faecal sludge management performance

CHAPTER IN BRIEF

At the global level, there are significant data gaps in country-level reporting on wastewater and faecal sludge treatment, which can help inform SDG 6.3.1. This chapter first situates wastewater and faecal sludge treatment within the wider sanitation chain, before presenting findings from primary data collection in the focus cities on wastewater and faecal sludge treatment. While findings represent a small sample, the analysis shows:

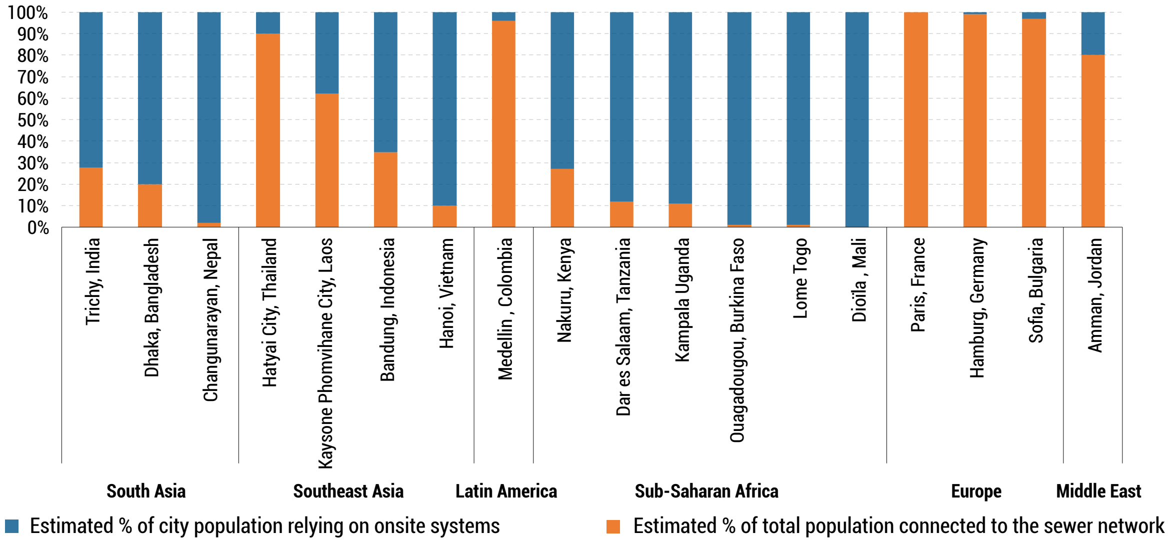
- There is misalignment in many cities in LMICs between the predominance of onsite sanitation and the low availability of treatment facilities capable of treating faecal sludge. Current treatment levels for faecal sludge are challenging to ascertain.
- There are wide discrepancies in the volume of wastewater treated when mapped against city population size.
- A majority of cities were able to provide data on BOD and COD concentrations in wastewater influent, with generally higher concentrations in high-income countries. Fewer cities were able to provide concentration levels for nitrogen and phosphorus.
- Cities in high-income countries tend to use mechanical treatment processes, whereas LMICs are reliant on nature-based solutions. Treatment technology is clearly correlated with higher treatment performance.
- However, a large majority of cities, including in LMICs, were able to meet global standards for secondary treatment. Only cities in high-income countries meet the global standard for tertiary treatment.

4.1 Current global estimates for wastewater and faecal sludge management across the sanitation service chain

Global estimates of safely managed sanitation

How wastewater and faecal sludge management is delivered varies considerably across regions and countries, and within cities. Certain regions depend heavily on sewer networks (offsite sanitation) to contain and transport their flushed excreta, and some form of sewage coverage is common in large cities around the world. Onsite sanitation is widely used globally, and most urban dwellers in Sub-Saharan Africa and South Asia, especially the urban poor, rely on onsite sanitation services (OSS). The global mapping carried out for this report showed the proportion dependent on OSS rises to 99 per cent and 89 per cent in the capital cities of African countries, Togo and Uganda, respectively, and 98 per cent and 90 per cent in

Figure 13: Global Mapping - percentage of city populations served by sewered and onsite sanitation systems



Source: Reported figures from national sources. A full list of sources by city is provided in Appendix D.

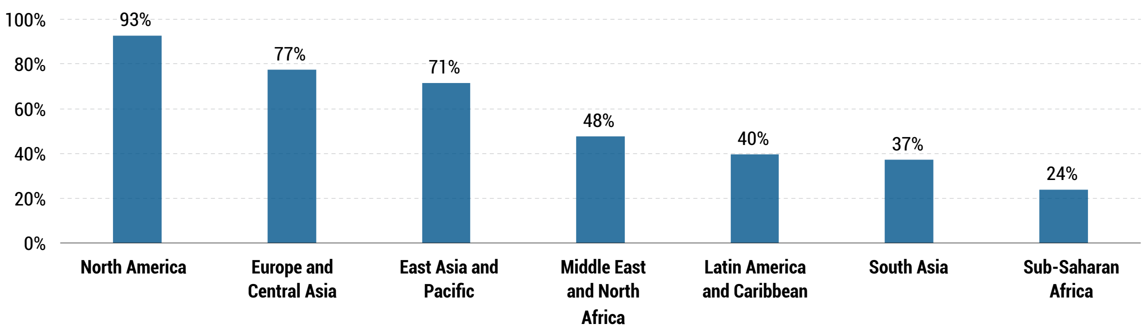
Changunarayan and Hanoi, respectively (Figure 13). In these cities, the management of faecal sludge containment, transport and treatment need to be planned in order to protect human health and the environment.

Regardless of whether onsite or off-site sanitation is used, wastewater and faecal sludge are not effectively managed throughout the sanitation service chain in many cities. As a result, there are widespread geographic disparities in the proportion of sanitation service levels globally. Recent estimates from the WHO/ UNICEF Joint Monitoring Programmes (JMP) indicate that 38 per cent of the urban population lacks access to safely managed sanitation services (see Box 9 for definition), with 43 per cent of this population residing in low and middle-income countries (WHO/ UNICEF JMP, 2022) (Figure 14).

Estimating global levels of wastewater treatment

Even when the city's human waste is safely contained and transported, national estimates and global figures point towards significant variance in the level of treatment prior to disposal. Although data on wastewater is limited at the continental and global levels, estimates for wastewater can be derived from the SDG 6.3.1 monitoring tool. The UN Habitat and WHO 2021 report on the state of wastewater includes data from using the OECD/Eurostat and UNSD databases. In this reporting system, the total treated wastewater refers to volumes that are treated by municipal, industrial, and independent treatment facilities (including septic tanks). Data from non-OECD/Eurostat countries are collected through a UNSD/UNEP Questionnaire on

Figure 14: Safely managed sanitation coverage by region



Source: WHO / UNICEF JMP, 2022.

Box 9: Definition of safely managed sanitation services

WHO/UNICEF defines safely managed sanitation services, as service that meets the following three criteria:

1. People should use improved sanitation facilities which are not shared with other households.
2. The excreta produced should either be:
   - Treated and disposed of onsite.
   - Stored temporarily and then emptied and transported to treatment off-site.
   - Transported through a sewer with wastewater and then treated off-site, and
3. Human waste needs to be safely managed across the entire sanitation service chain

Source: WHO / UNICEF JMP 2022.

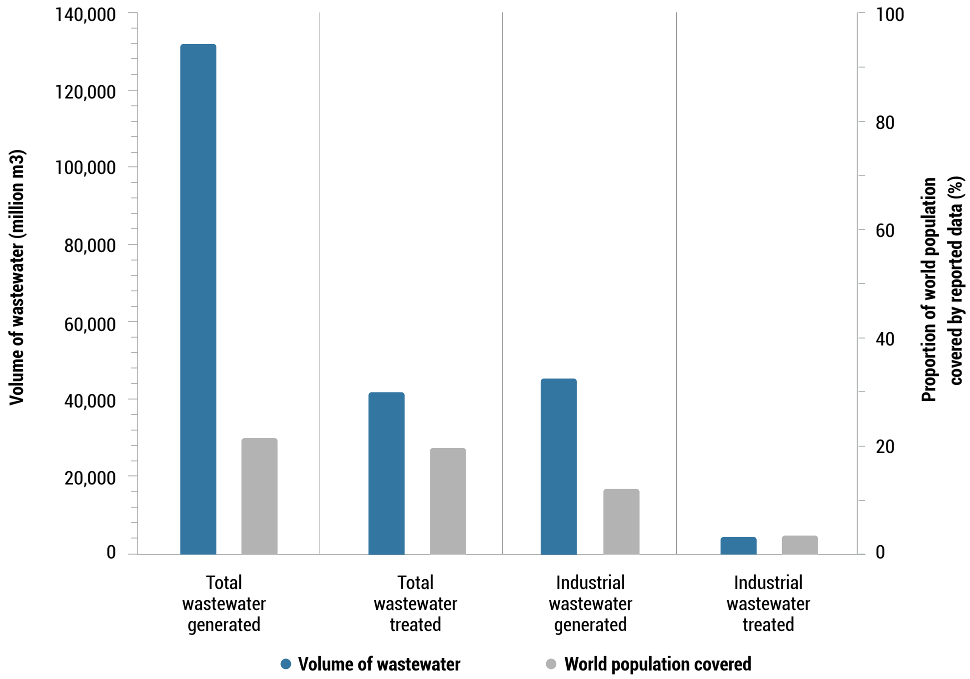
Environment Statistics. The questionnaire is sent to around 165 countries. The average response rate for each data collection cycle has remained roughly 50 per cent, and there remain challenges with the comprehensiveness and quality of the data. According to this report:

- Only 32 per cent of wastewater generated (including industrial wastewater) by 56 countries (131,871 million m^3 in 2015) representing 22 per cenr of the population is reported to be treated; and

- With regard to industrial wastewater alone, only 32 countries have made available figures in 2015 (45,311 million m^3 for those countries); only 15 countries have reported the volume of wastewater treated (4,296 million m3 for the 15 reporting countries) (Figure 15).

Other methods and estimates confirm that a large part of wastewater produced globally is disposed of untreated. Jones et al. (2020) present the first global assessment of spatially explicit wastewater production, collection, treatment, and reuse in 2020 by systematically combining all existing data sources. The study estimates that 359.4×10^9 m^3/year of wastewater is produced globally. Of this volume, 63 per cent and 52 per cent are collected and treated, respectively, with approximately 84 per cent of collected wastewater undergoing a treatment process.

Figure 15: Total and industrial flows of wastewater generated and treated in 2015



Source: UN-Habitat (2021): Progress on wastewater treatment.

Wastewater reuse is estimated at 11 per cent of the total volume of wastewater produced.

Estimating global levels of faecal sludge treatment

Quantification of city-level faecal sludge treatment is particularly challenging, because it cannot be assumed that all sludge generated will be adequately collected and transported. Many containment systems are closed when full and never used again, or never need to be emptied due to the containment technology. In addition, since onsite systems are often built informally, there may be no official record of how many or what sort of systems exist on a city-level scale. There may also be a lack of reliable data on the frequency of desludging; and estimating the amount of faecal sludge to be transported to treatment facilities must consider that vacuum trucks do not always completely empty the sanitation containment system.

Cities are implementing measures to upgrade and improve their combined sewer systems.

Compared to wastewater, faecal sludge management is in its early stages, and there are insufficient national and global figures on quantities of faecal sludge safely treated. Extensive research into wastewater treatment optimization has resulted in advanced empirical and fundamental models. This experience is not directly transferable to faecal sludge management. To date, there are still insufficient national figures on the quantities and characteristics of faecal sludge generated at the city level; similarly, the characteristics of faecal sludge are not monitored prior to treatment. Increased publication of empirical observations will contribute to a better understanding of faecal sludge characteristics and allow for more accurate calculations.

4.2 Collection and conveyance

Wastewater

For the removal of wastewater and stormwater by sewered systems, three types of collection systems are used: conventional collection systems, storm collection systems and combined collection systems. When separate collection systems are utilized for wastewater collection (conventional collection systems), wastewater flows consist of three major components: domestic wastewater, industrial wastewater, and infiltration/inflow. When a combined system is used, wastewater flows include these three components as well as stormwater.

Combined sewer systems appear to be widely present across many cities. For example, they are used in eight out of 12 cities of the global mapping carried out for this report. When combined sewer systems were first installed in London in 1855, they were a significant advancement over the urban cesspool that overflowed whenever it rained. When an excessive amount of rainwater is added to the flow of raw sewage, combined sewers typically overflow. A major disadvantage of combined sewers is that they often lack the capacity to handle the increasing amounts of stormwater runoff that are generated by urbanization and climate change. As a result, many cities are facing challenges in managing their combined sewer systems and preventing overflows. Changunarayan and Hatyai for example, which receive particularly high annual rainfall, must pay special attention to the potential for overflow and floods since their combined sewer system accounts for 67 per cent and 100 per cent of their overall sewage network respectively (Figure 17).

To address these challenges, cities are implementing measures to upgrade and improve their combined sewer systems. This can include separating the stormwater and sewage into separate pipes, increasing the capacity of the sewer system, and implementing green infrastructure such as rain gardens and permeable pavements to reduce the amount of stormwater runoff. In recent years, a general trend can be observed toward separate sewer systems, with previously combined systems even being "re-separated" in some cities. The global mapping data (Figure 17) shows no visible correlation between the type of sewer in use and annual rainfall — implying there may be a need for some cities to update their systems to better reflect local climactic conditions.

Faecal sludge

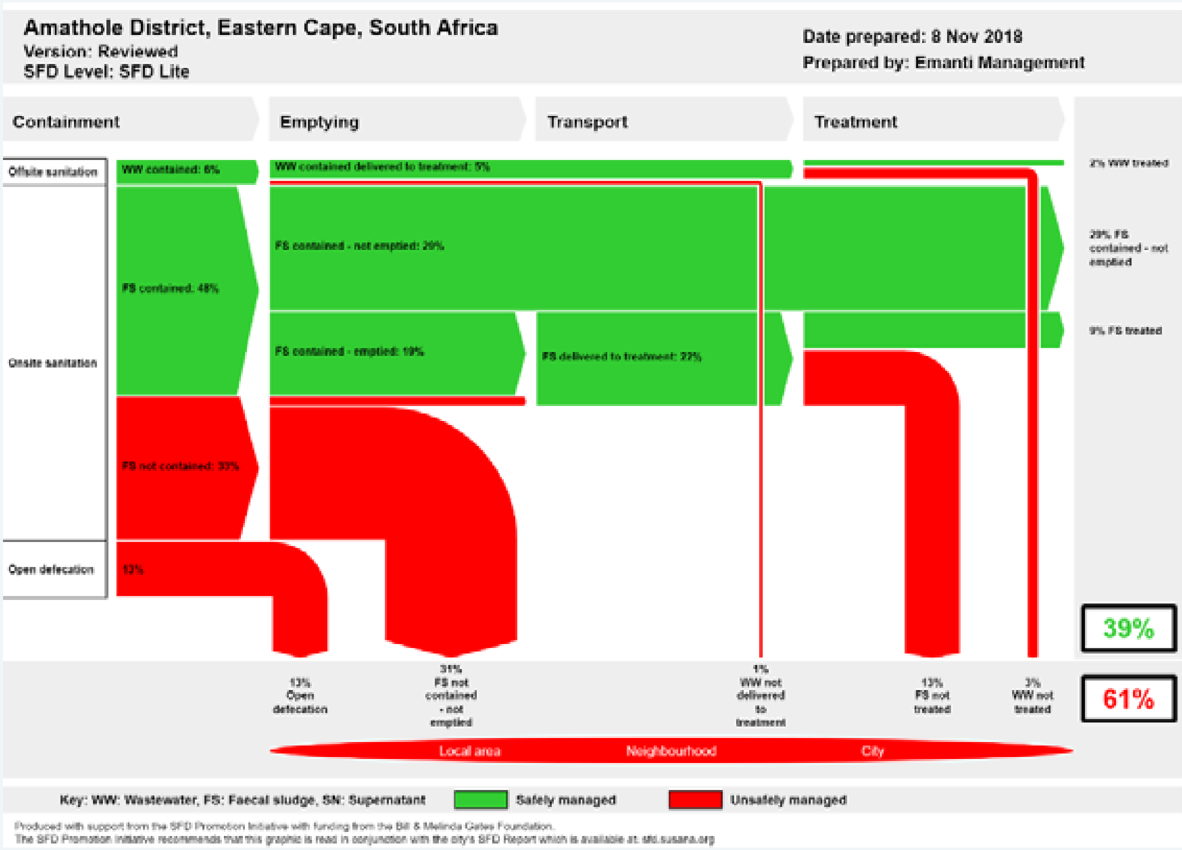
In low-income areas, human waste is generally collected and contained in pit latrines or septic tanks. Pit latrines are the most basic and one of the most widely used forms of sanitation technology (Tilley et al, 2014). Once full, pit latrines need to

Box 10: Shift flow diagrams: a tool for mapping faecal sludge and wastewater flows throughout the sanitation chain

Shift Flow Diagrams (SFDs) are a useful tool that shows faecal sludge and wastewater flow throughout the sanitation chain in a specific geographical location. The initiative is supported by the Bill and Melinda Gates Foundation and is implemented by a number of organizations, including the Sustainable Sanitation Alliance, the Centre for Science and Environment and EAWAG. 240 SFDs in 229 cities worldwide are available on the following website: https://sfd.susana.org/about/worldwide-projects

In the Eastern Cape example shown in Figure 16, an estimated 33 per cent of faecal sludge is not safely contained, posing environmental and health risks from this first stage of the sanitation service chain. A portion of the faecal sludge safely contained and transported still finds its way untreated into the environment. The SFD further indicates that in Eastern Cape the major contributor to untreated wastewater and sludge is onsite sanitation.

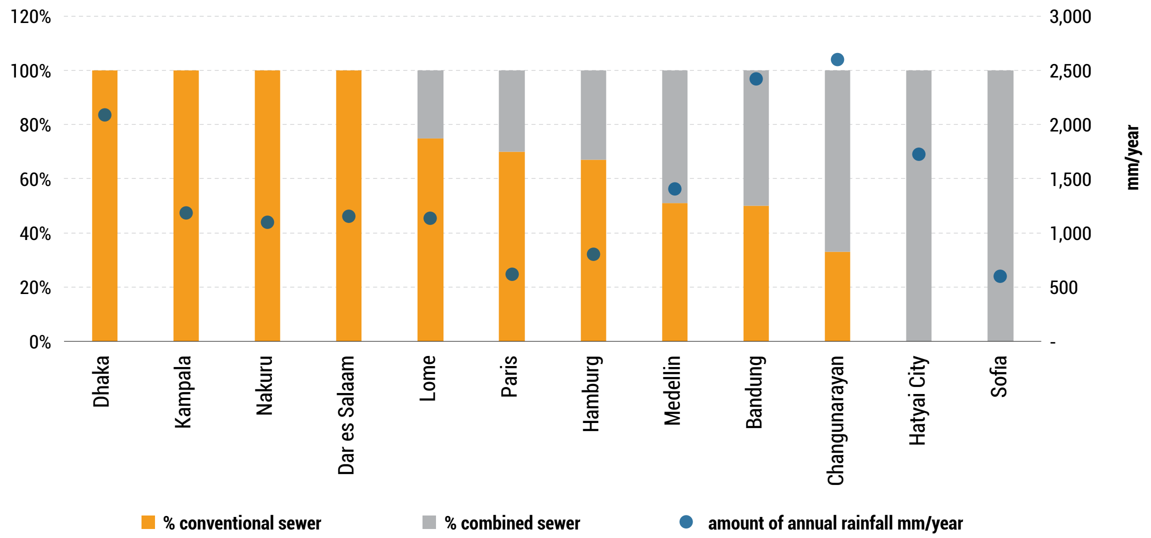
Figure 16: SFS Eastern Cape, South Africa



Source : https ://sfd.susana.org/about/worldwide-projects

be emptied or closed and rebuilt. Septic tanks — watertight chambers made of concrete, fibreglass, PVC or plastic, through which blackwater and greywater flows for primary treatment (Tilley et al, 2014) — are also widely applied at the household level, due to their low capital cost, lack of energy requirements, small land area requirements, and relatively low operation and maintenance costs. Due to low efficiency in removing pathogens, solids, and organics, the sludge and effluent require additional treatment. Because the rate of accumulation exceeds the rate of decomposition, regular desludging is required, generally once every three to five years.

Figure 17: Global Mapping — type of conveyance and annual rainfall in select cities



Source: Reported figures from national sources. A full list of sources by city is provided in Appendix D.

Septic tanks require careful design to provide effective containment and primary treatment. A well-designed septic tank consists of a watertight chamber(s), fully lined on all four sides and the bottom to leakproof contamination of ground water. Poorly designed septic tanks can result in frequent desludging, leakage, and disposal of unsafe septic tank effluent directly into the environment, causing pollution and health risks. In urban India for example, 72 per cent of septic tanks discharge poorly treated wastewater directly into stormwater drains (Dasgupta, Agarwal and Mukherjee, 2021). This is also a widespread issue in cities such as Dhaka (see **Dhaka case study**), and results in the contamination of groundwater and water resources. Similarly, 40 per cent of the total onsite sanitation system of urban Bhutan lack soak pit systems (Dorji et al., 2019). Even though certain innovations have been developed, septic tanks are not particularly robust in areas with flooding threats and/or high-water tables. The technological features and treatment capacity of septic tanks are explored further in the next Chapter.

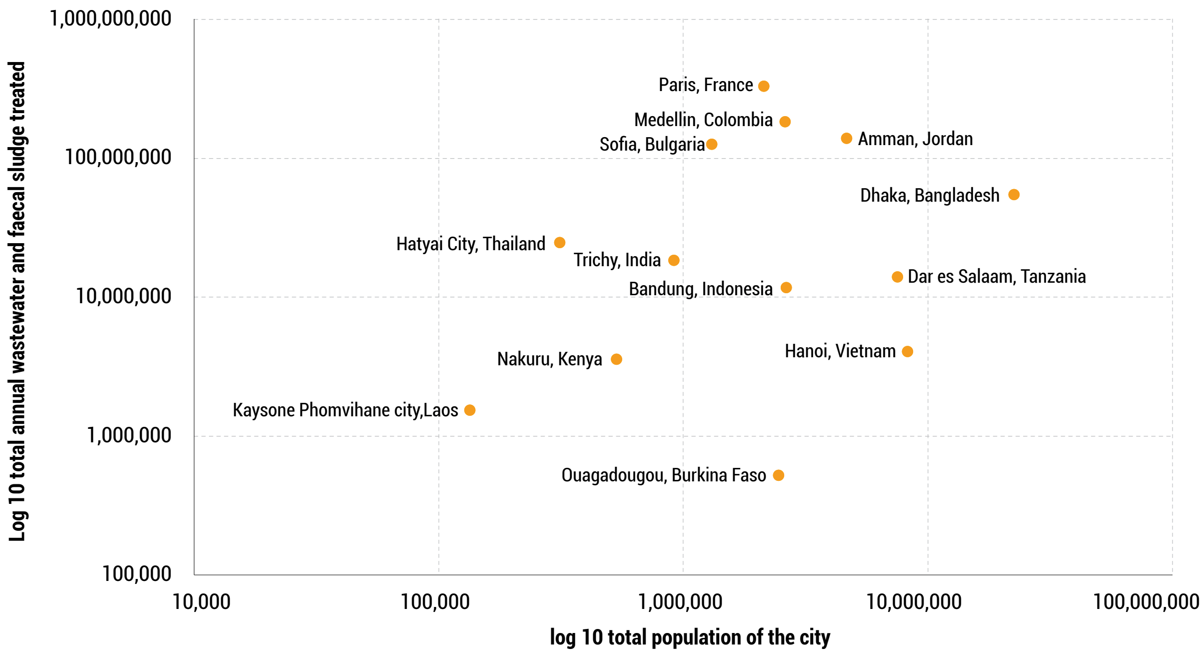
Manual emptiers and vacuum tank operators have a critical role to play in the safe conveyance of faecal sludge from pit latrines and septic tanks to treatment sites. The development of sustainable service models for desludging, and effective regulation of these services, are core components of safely managed sanitation. These issues are explored in Chapters 6 and 7 respectively.

4.3 Wastewater and faecal sludge treatment performance: results from the Global Mapping

As outlined above, there is a significant data gap at the global level in understanding current levels of wastewater treatment. This gap is still greater for faecal sludge. In the following sections, we present data from our focus cities relating to wastewater quantity, wastewater quality and treatment efficiency at the city level. We focus on wastewater because of challenges in obtaining precise data on the properties of faecal sludge in the focus cities.

It is important to underline that despite the paradigm shift toward Citywide Inclusive Sanitation (CWIS) - which promotes both onsite and sewered solutions - there remains a mismatch between prevailing sanitation technologies and treatment facilities provided. Although most Sub-Saharan and Southeast Asian cities rely on onsite sanitation, the majority of cities in those regions have more WWTPs than FSTPs**.** Dedicated FSTPs exist in only four cities included in the global mapping (Hat Yai, Dar es Salaam, Ouagadougou and Kampala). In Dar es Salaam, for example, 88 per cent of the population relies on onsite sanitation, but there are only three small faecal sludge treatment facilities, treating only 25 m^3/d of faecal sludge. In certain cities, faecal sludge is dumped into the existing wastewater treatment plant, which may increase

Figure 18: Global Mapping — total volume of wastewater and faecal sludge treated mapped against the relative size of the city



Note: Cities such as Amman, Paris, Sofia, Medellin, and Kaysone only have WWTPs, while Dhaka, Bandung, and Trichy have cotreatment plants and Hanoi, Hat Yai, and Dar es Salaam have both FSTPs and WWTPs.

Source: Reported figures from national sources. A full list of sources by city is provided in Appendix D.

pollutant concentration not accounted for when designing the system, eventually jeopardizing sewage treatment.

Quantities of wastewater generated and treated

Deriving accurate estimates for the quantity of wastewater produced is essential for adequately sizing treatment plants. Developing reliable estimates at the city level can be challenging, as outlined in Box 11. Figure 18 plots the total volume of wastewater and faecal sludge treated against the relative size of the city. This enables a population-based comparison of cities: for example, Dhaka, the largest of the 13 cities to provide data on quantity of wastewater and faecal sludge treated, had a lower volume treated compared to Paris, Amman, Sofia, and Colombia. The graph demonstrates that while Paris is not the most populated metropolitan, it has the highest treatment volume among the 13 cities. A log10 scale was adopted to provide a clearer view of the data.

Quality of wastewater influent

Treatment options are primarily determined by the characteristics of wastewater, the intended use of the treated effluent (disposal or recycling), as well as financial resources available. In **Chapter 3** we outlined the key constituents of wastewater. Below we present primary data on the concentrations of key constituents, such as BOD, COD, nitrogen and phosphorus, in wastewater influent in the focus cities.

The social, demographic, and economic properties of a city population have an important impact on wastewater quality. Wastewater quality in high-income countries can differ from low-income countries with regard to specific parameters. The widespread use of industrial and cosmetic products in high-income countries has resulted in the emergence of new pollutants. Many LMICs are now home to some of the most polluting industries, and in many cases, these highly toxic industrial wastewater are being treated at municipal facilities.

Box 11: methodological approaches for estimating wastewater and faecal sludge generated and treated

In principle, estimating annual **wastewater volumes produced** can be generated from an analysis of A) population data and B) estimates of per capita wastewater flow rates. Wastewater collected from municipal areas consists of wastewater generated from residential, commercial, institutional, and industrial units located within the city limits. When there is a lack of wastewater flow rate figures from various sources, estimating those flow rates can be based on water consumption estimates, and national estimates of the per centage of water converted to wastewater. Apart from accounted water supplied that will be converted to wastewater, the following quantities are considered while estimating the wastewater volumes generated: additional water infiltration and rainwater in combined sewers; and subtraction due to water losses. On average about 60-90 per cent of water consumption becomes wastewater.

Primary data collection for this study focused predominantly on wastewater and faecal sludge treatment facilities. We were unable to collect sufficient data on each city's commercial, institutional, and industrial units to be able to compute reliable estimates for the total wastewater generated in each city. While it would be possible to estimate the residential flow rate from household units (i.e. domestic wastewater), this would be unrepresentative of the total volume. Some cities depend on combined sewers, which largely increases the amount of wastewater that needs to be treated at wastewater treatment plants. Generating such city-level estimates is achievable, but requires a level of in-depth investigation specific to each focus city beyond the scope of this study. Conversely, city-level faecal sludge quantification is challenging and cannot be computed based on estimations.

Measuring **quantities of wastewater treated** is often performed onsite by the operator of the wastewater treatment plant. Taking into account the co-treatment facilities in Trichy, Nakuru, Bandung, and Dhaka, we were able to collect this data from 13 cities. The treatment plant operators and the most recent facility report provided the daily volume of wastewater and faecal sludge treated in each city. These numbers, because they are based on volumes the operator measures daily on-, are considered to be reasonably reliable for wastewater. There may be a margin of error for volumes of faecal sludge treated: faecal sludge plants, unlike wastewater treatment facilities, lack flow control to track and measure incoming volumes. Truck volumes should ultimately be used to determine how much faecal sludge is discharged from a facility, but very few treatment plants adopt this measure.

Organic matter and macro-pollutant levels are currently the most closely monitored wastewater parameters globally. From the global mapping, we were able to collect information on the Biological oxygen demand (BOD) and/or Chemical oxygen demand (COD) levels from almost all wastewater treatment facilities; only treatment plants in 6 cities provided data on Total Nitrogen (TN) and Total Phosphorus (TP). This may be closely linked to the level of treatment that these facilities are designed to provide (box 6): not all treatment facilities, particularly those in LMICs, are designed to remove TN and TP. The global mapping demonstrates that in most cases, and especially in LMICs, some parameters are not monitored.

In order to present pollutant concentrations in focus cities of the global mapping, we computed the weighted average of each parameter provided by treatment plants in the city. It should be noted that pollutant concentrations in wastewater vary between and within cities. Taking Paris as an example, the influent TN concentration was 10.6 mg/L at the Seine centre treatment plant while it was 66 mg/L at the Seine aval treatment plant.

The 'strength' of raw wastewater is frequently determined by its BOD and COD. Strong wastewater is defined as having BOD and COD levels greater than 750 mg/L and 1500 mg/L, respectively (Ducan, 2013). The strength of the wastewater varies with sources and can be influenced by the type of wastewater network used, water consumption, and the amount of organic waste produced per person per day. Similarly, the composition of TN and TP varies with sources. Most industrial wastewaters contain more heavy metal pollutants and less nitrogen or phosphorus than other types of wastewater (Ting, et.al, 2012). The levels of Total Nitrogen (TN) and Total Phosphorus (TP) in raw municipal

Box 12: What do we mean by treatment level?

The term "wastewater treatment" remains frequently used to refer to any type of wastewater treatment, regardless of the level of treatment. This issue creates substantial challenges for data monitoring and calls for more precise use of treatment terminologies. This is particularly important when monitoring progress in low- and middle-income countries, where primary treatment is still predominant (where WWTPs exist). In many low- and middle-income countries, proper disposal of sewage sludge remains a pressing treatment issue.

These treatment levels are clearly defined based on the EN 1085:2007 as follows:

- **Preliminary treatment:** consists of the removal of wastewater constituents such as grit and grease that may cause operational and maintenance problems during the treatment process.

- **Primary treatment:** entails the removal of suspended solids and organic matter from the wastewater, in which the BOD of the wastewater is reduced by at least 20 per cent before discharge and the total suspended solids of the incoming wastewater are reduced by at least 50 per cent. Typically achieved through physical and/or chemical processes.

- **Secondary treatment:** involves the removal of biodegradable organic matter, suspended solids, and, in some cases, nutrients from the wastewater in which the BOD and COD are reduced by at least 70 and 75 per cent respectively, typically achieved through biological treatment with a secondary settlement.

- **Tertiary treatment:** removal of residual dissolved and suspended materials (after secondary treatment) in which the BOD and COD are reduced by at least 95 and 85 per cent, respectively. Additionally, following a tertiary treatment, at least one of the following efficiencies should be achieved: (i) nitrogen removal of at least 70 per cent; (ii) phosphorus removal of at least 80 per cent; (iii) microbiological removal achieving a faecal coliform density of less than 1000 in 100 ml (ibid).

wastewater are generally around 15 to 90 mg/L and 5 to 20 mg/L respectively.

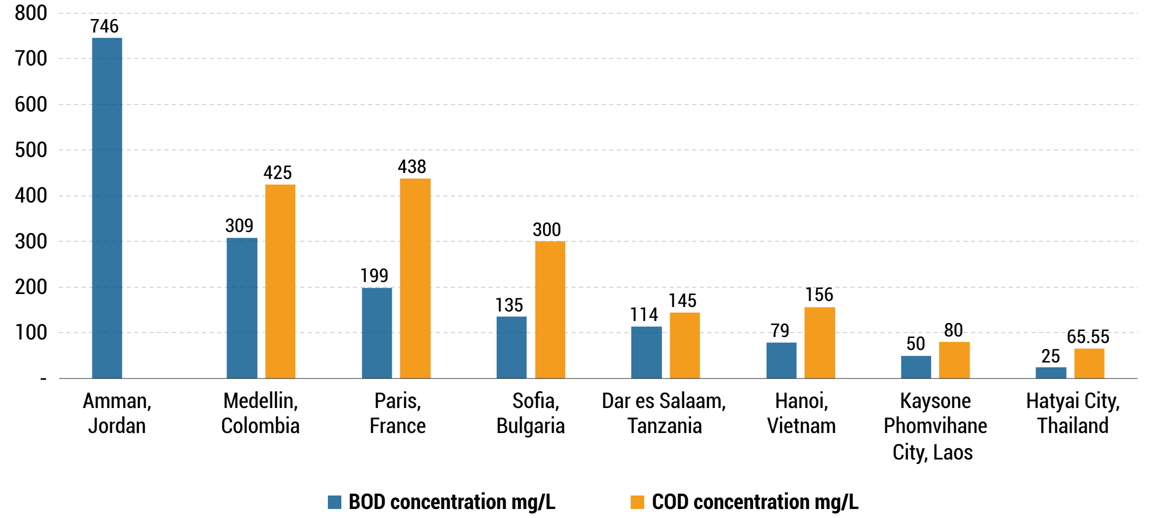
Figures 19 and 20 presents average concentrations of key pollutants in wastewater influent in the focus cities. We see that Amman, for instance, reports relatively high BOD levels in its influent wastewater, reaching 1112 mg/L of COD at one of the treatment plants (As Samara wastewater treatment plant). This could be due, among other factors, to Amman's low water consumption relative to middle and high-income countries; but many other factors may be contributing and low water consumption alone appears unlikely to be the sole contributor, given the mapping also demonstrates that despite lower water consumption, concentrations are typically lower in LMICs, for example in Dar es Salaam.

Seasonal changes can have a significant impact on influent volume and characteristics. For instance, wastewater flow rates during the summer can be stable and will typically follow a log-normal distribution, but daily flow rates during the winter cannot be predicted using either an arithmetic or a log-normal distribution. The main causes of this are infiltration and inflow in collection or containment. In some cases, appropriate measures should be taken to reduce infiltration. An equalization tank, which can regulate the flow and characteristics of wastewater and buffer out variations in the influent flow rate and characteristics of wastewater, can also be installed. In general, as the treatment facility's capacity increases, the observed variability in flow rates tends to decrease.

Wastewater treatment efficiency

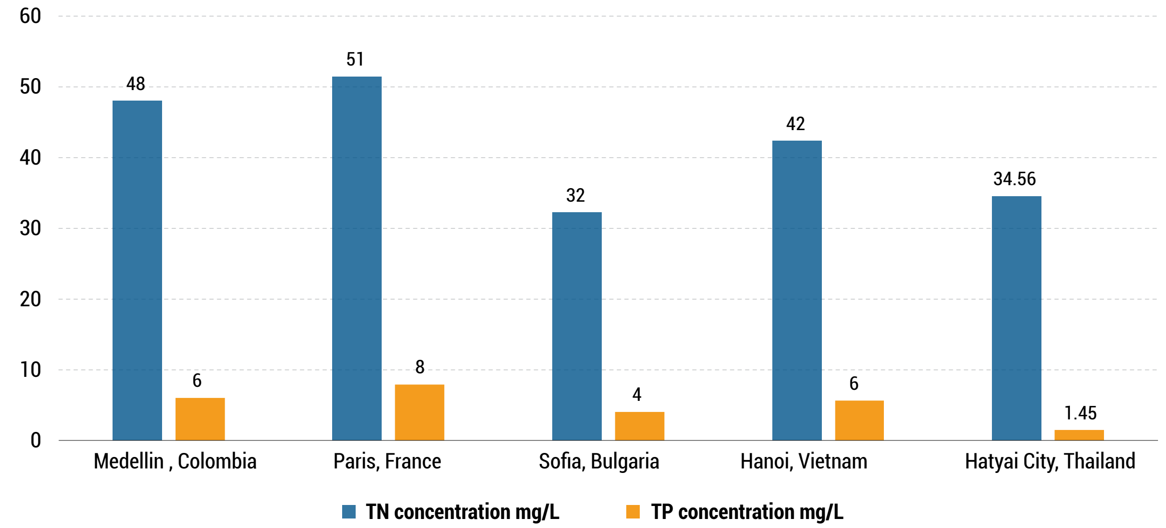
Wastewater collected from municipalities and communities must ultimately be discharged back into the environment after treatment or recycling. Significant scientific and technological advances have paved the way for a variety of treatment processes that can meet a wide range of discharge standards. The selection of treatment options is primarily determined by the type and amount of contaminants in the wastewater, the intended use of the treated effluent (disposal or recycling), as well as financial resources available. In this

Figure 19: Global Mapping — BOD and COD concentrations in wastewater influent



Source: Reported figures from wastewater treatment plant operators. A full list of sources by city is provided in Appendix D.

Figure 20: Global Mapping — TN and TP concentrations in wastewater influent



Source: Reported figures from wastewater treatment plant operators. A full list of sources by city is provided in Appendix D.

section we explore the efficiency of pollutant removal in the focus cities.

The global mapping demonstrates that cities in high-income countries tend to use mechanical treatment processes, whereas LMICs may be reliant on nature-based solutions. Medellin, Sofia, Amman and Hanoi have reported using an activated sludge process for wastewater treatment, while WWTPs in Paris are based on biofiltration processes. Conversely, Dar es Salaam, Hatyai City, Bandung and Ouagadougou have reported using stabilization ponds for wastewater treatment (for more information on treatment technologies, refer to Appendix B). Availability of financial resources may be the primary factor behind these technologies, given that nature-based solutions require lower costs of operation and maintenance, particularly in terms of energy consumption. In addition, lower volumes of wastewater production and higher availability of land makes it simpler for some cities to implement these solutions. The application of nature-based solution in colder regions is particularly difficult due to harsher winters, reduced field and construction windows, and complicated logistics. The mapping also demonstrates that European cities such as Sofia and

Paris are adopting the most cutting-edge wastewater treatment technologies, including biological ultrafiltration and UV treatment, at a faster rate than cities in other regions.

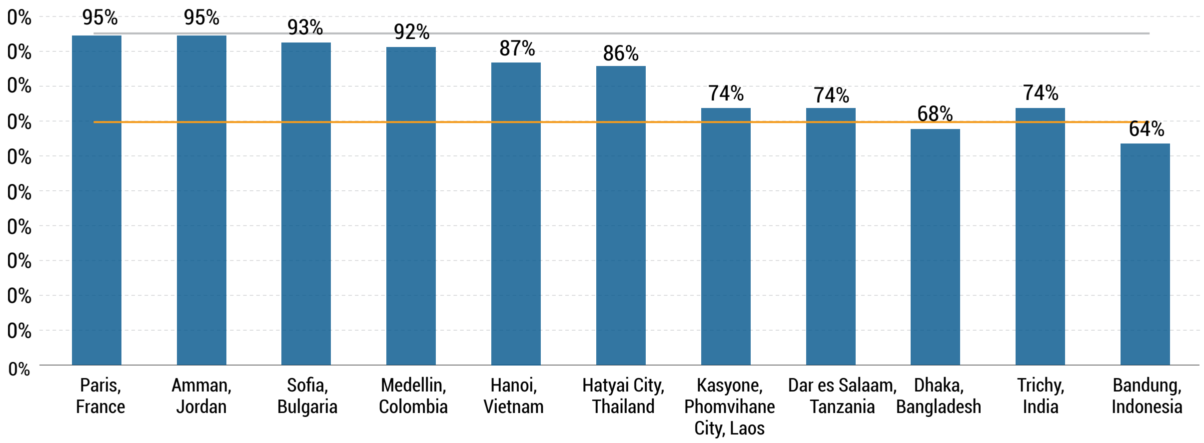
The treatment technology translates into the plant's treatment performance. The treatment performance of a WWTP can be evaluated by measuring the levels of various contaminants before and after treatment. This can include measuring levels of BOD, COD, TN and TP. The plant's performance can also be evaluated by monitoring its ability to meet regulatory standards for discharge. Although each country may have its own discharge standards, this study adopted the standards used by Eurostat for comparison (EN 1085:2007). As outlined by these standards, where the BOD and COD levels are reduced by at least 70 per cent and 75 per cent, respectively, the plant has accomplished secondary treatment standards. If BOD and COD levels are decreased by at least 95 and 85 per cent, respectively, and nitrogen and/or phosphorus levels are lowered by at least 70 per cent and/or 80 per cent, respectively, the plant has achieved effective tertiary treatment, which is now regarded as the highest degree of treatment. Tertiary treatment is predominantly used in high-income countries, although not all high-income countries use tertiary treatment at scale.

For cities able to provide the data, the available reporting indicates an acceptable level of BOD removal efficiency (Figure 21). While treatment performance is typically higher in high-income cities, all cities, except for Dhaka and Bandung, had an efficient treatment that met the secondary treatment global standard. In cities that rely on mechanical treatment, a greater efficiency performance of more than 90 per cent was achieved, as well as a TN and TP removal efficiency that meets the tertiary treatment standards (with the exception of Medellin).

Performance appears less strong where cities have in place co-treatment systems for wastewater and faecal slusge. This is the case in Dhaka, Bandung and Trichy, for example. While there are opportunities for co-treating faecal sludge and wastewater, the outcome may not meet the desirable level. Faecal sludge has different characteristics from wastewater and cannot be treated in a similar way. Studies have also indicated that if executed with proper dosage and monitoring protocols, co-treatment can be an effective strategy for cities which have excess capacities in their wastewater treatment plants and which serve only a limited sewered population, with several cases in India, including in Chennai, where co-treatment has been a major success.[1] An essential recommendation for co-treatment is dewatering faecal sludge and sending the liquid fraction to be treated with wastewater and the solid fraction to be treated with sewage sludge.

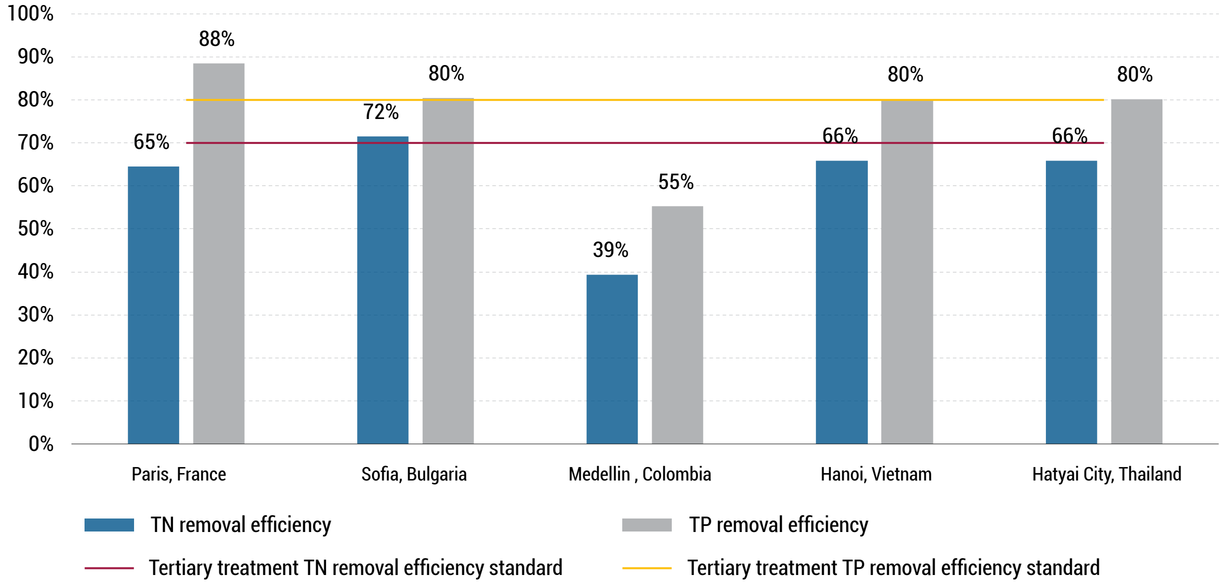
1 See https://www.fsmtoolbox.com/assets/pdf/143._Chennai_Nesapakkam_STP_case_study.pdf

Figure 21: Global Mapping — BOD removal efficiency



Source: Reported figures from wastewater treatment plant operators. A full list of sources by city is provided in Appendix D.

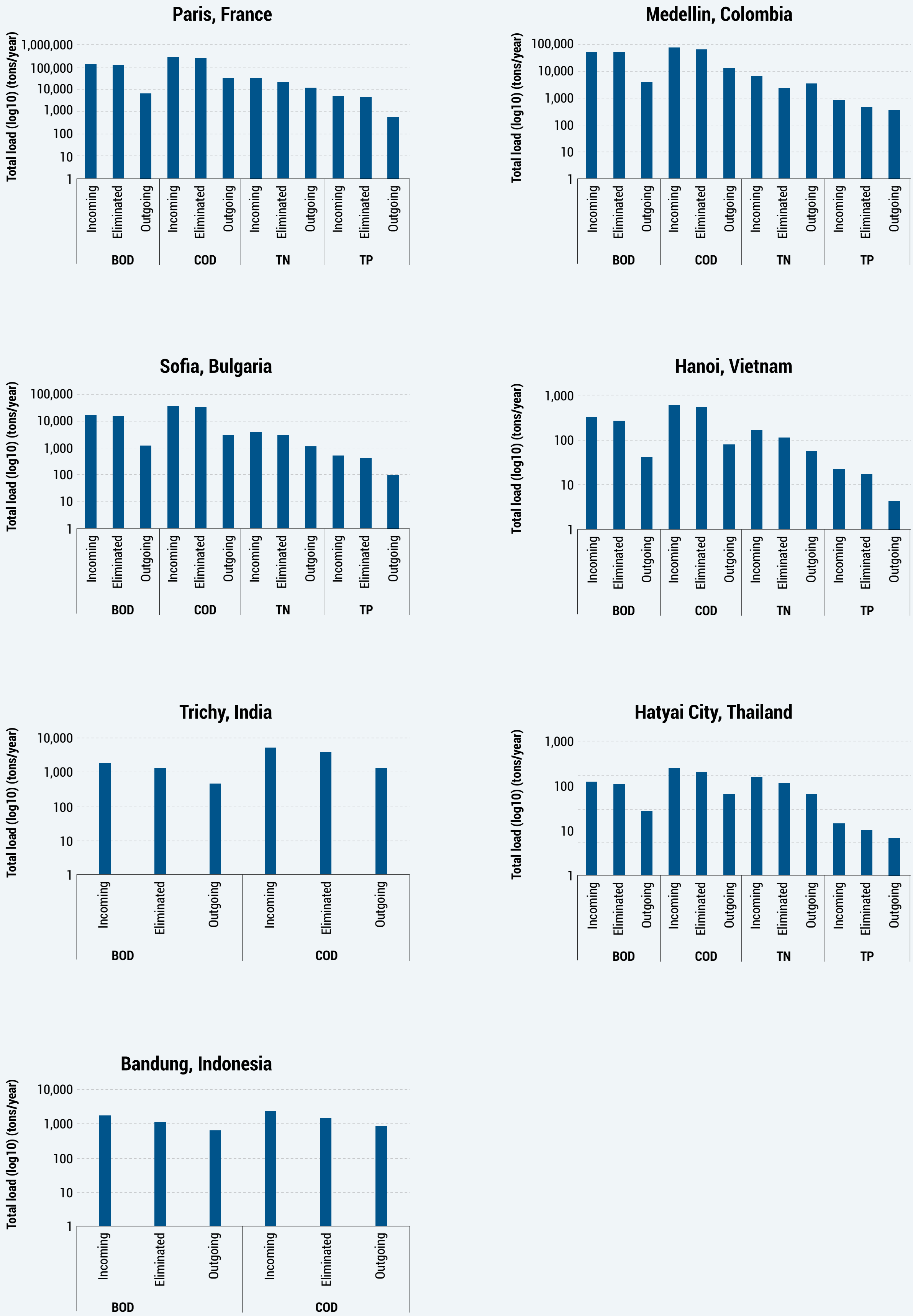
Figure 22: Global Mapping — Nitrogen (TP) and Phosphorus (TP) removal efficiency



Source: Reported figures from wastewater treatment plant operators. A full list of sources by city is provided in Appendix D.

Old town faecal sludge treatment plant, Nakuru, Kenya © NAWASSCO

Box 13: **Global mapping - examples of pollutant loads from focus cities**



Wastewater treatment plant operations

A critical component of wastewater and faecal sludge management performance is the effective operation and maintenance of treatment plants. This connects strongly to issues of financing and responsibilities, which are explored in subsequent chapters. Below we provide an introductory summary of key challenges in this area.

WWTP and FSTP functionality is exposed to inherent variability, due to the presence of living microorganisms and the mixed reliability of mechanical systems. A critical component analysis of the plant can be developed to guide regular maintenance and repair of critical components, as well as the implementation of backup systems or alternative treatment technologies to ensure that the plant can continue to operate in the event of a failure or disruption.

Such variability makes plant operation and performance challenging and expensive, but also calls for technical and engineering expertise. Weak capacity to operate and manage plants, poor working conditions which make it difficult to recruit and retain skilled workers, and inadequate training programmes are all significant barriers to the efficient management of wastewater treatment plants in low-income countries.

Although there is limited evidence regarding the functionality of the plants in most low-income countries, a review by WaterAid (2019) revealed that a significant portion of plants worldwide are either not functional or only partially functional. In Mexico, for instance, the review found 95 per cent were not functioning, with high per centages also in Ghana (80 per cent), India (54 per cent) and Vietnam (33 per cent). Out of the selected cities in the global mapping, Bojongsoang (Bandung) and North Thang Long (Hanoi) treatment plants were operating at 13 per cent of total capacity respectively, while Airwing (Dar es Salaam) WWTP was not fully operational.

One useful mechanism to help service authorities address these limitations and challenges are water operators' partnerships (WOP). WOPs can help utilities in low- and middle-income countries leverage the knowledge and experience of other organizations to improve their operations (Box 14).

Box 14: Water Operators Partnerships

WOPs can take many different forms, but they typically involve technical assistance, training, and other support to help utilities operate more effectively and provide reliable, high-quality services to their customers. This can help utilities stay at the forefront of developments in the water sector and to learn from the successes and failures of other organizations. Another benefit of WOPs is that they can help foster a sense of collaboration and cooperation within the sector. By working together, water utilities can build relationships and trust with one another, which can facilitate sharing of information and resources and help overcome common challenges. In addition, WOPs can help to support the development of new technologies and approaches to water management. This can help to advance the state of the art in the sector and to support the development of more effective and sustainable management practices.

WOPs are prevalent in the water sector, but somewhat less frequent in the sanitation sector. A good example is the seven-year WOP between the Syndicat Interdépartemental pour l'Assainissement de l'Agglomération Parisienne (SIAAP, the sanitation utility of greater Paris) and the Office National de l'Électricité et de l'Eau Potable (ONEE, the national water, sanitation, and electricity utility for Morocco). The WOP supported the development of the skills of ONEE staff, facilitated a detailed assessment of needs to improve the mentee's performance, transferred expertise, and allowed for the decentralization of new skills within ONEE (SIAAP, 2021).

A further example from the global mapping is the long term partnership between Miyahuna, Jordan's largest water utility, and three German water supply and sanitation companies (Hamburg Wasser, Lead Partner; hanseWasser, Bremen; and Netze BW Wasser, Stuttgart). Under the partnership, knowledge transfer in the area of WWTP energy efficiency is a current focus of cooperation (source: https://www.utility-platform.de/en/partnerships/hamburg-wasser-miyahuna-llc-water-company).

4.4 Climate change impact on wastewater and faecal sludge performance

As outlined previously, climate change is a pre-eminent global threat which is already having a significant impact on sanitation and wastewater management. We close this chapter with a summary of the key mechanisms through which climate change is impacting wastewater and faecal sludge management performance. Innovations in climate-resilient sanitation are discussed in **Chapter 9**.

There is increasing evidence of the challenges being posed by climate change to wastewater and faecal sludge management worldwide. Howard et al. (2016) have identified five key climate-related hazards that pose the greatest threat to sanitation services: floods, droughts, windstorms, storm surges and sea-level rises. Wet weather increases have an especially negative impact on wastewater infrastructure in the form of sewer flooding which causes sewer backups, and combined sewer overflow discharges which result in pollution. Wet weather increases can also cause flooding and overflow of treatment plants (Campos and Darch, 2015).

Two men cleaning the sewer at night on a street in Ho Chi Minh City, Vietnam
© Shutterstock

Temperature rise and extreme heat have increased the risk to public health for the over 700 million users of inadequate onsite pit sanitation facilities globally, over half of these living in urban areas (Mikhael et al., 2021). Temperature likewise plays a decisive role in some wastewater treatment processes, especially nature-based solutions (Abdulla and Farahat, 2020).

Anthropogenic activities have significantly increased the frequency and length of droughts, a trend which is expected to continue further due to climate change. In severe drought conditions, influent flows decrease and the contaminant concentration of the effluent increase significantly, aggravating wastewater treatment processes (Anne-li, 2020). Water scarcity leads to reduced dilution of contaminants such as salts, nutrients and other pollution, causing reduced treatment efficiency, corrosion, and blockages of the treatment systems (Hughes et al., 2021). The Mediterranean region (including southern Europe, northern Africa, and western Asia) is predicted to be most affected (Mikhael et al., 2021). Droughts may limit the ability to operate and manage water-intensive sanitation systems.

In addition, anthropogenic warming has led to an increase in the occurrence, magnitude and volume of heavy precipitation events or rainfall globally (Mikhael et al., 2021). This is problematic because onsite sanitation facilities, which the majority of the world population is still dependent on, are particularly vulnerable to flooding (Mikhael et al., 2021) with a risk of contamination of ground drinking water sources due to flood events. Increased rainfall can cause overflow, blockages and breakages, power outage, and damage of the soil structure on various wastewater treatment systems (Hughes et al., 2021).

In the UK, recent flood events have highlighted the vulnerability of essential wastewater services to disruption from rainfall and flooding. Research by the UK Water Industry concluded extensive modifications are already needed to network infrastructure to mitigate this trend (Campos and Darch, 2015). During the UK summer floods in 2007, hundreds of wastewater treatment plants were flooded and put out of action as sewers in many places were overwhelmed by runoff (ibid). Pollution of this type affects wastewater treatment, storage, and conveyance for technologies and hardware worldwide (Abdulla and Farahat, 2020). Similarly, in another HIC, New Zealand, there is a clear trend of wet areas getting wetter, dry areas getting drier and, on average, an increase of rainfall in the west and decrease in the east (Hughes et al., 2021), similarly putting sanitation infrastructures and processes at risk.

Finally, sea levels are expected to rise worldwide because of climate change, especially in tropical and subtropical regions. Sea-level rise has been estimated to be on average 2.6 mm per year since 1993. Global average sea levels could rise by as much as 6 feet by 2100 (Mikhael et al., 2021). A rise of only 1.6 feet by 2070 puts 150 million people globally and USD 35 trillion assets at risk in 20 of the world's most vulnerable and fastest growing port cities (De Almeida and Mostafavi, 2016). As sea levels rise, coastal communities will experience flooding and the sanitation infrastructure in these areas will experience damage and inundation, with coastal cities especially experiencing backflows of wastewater into homes and linked sewerage networks (Mikhael et al., 2021).

Recommendations

- Re-examine combined sewer systems to consider the negative impact of sewage overflows in large urban areas. This is particularly critical in the context of increased rainfall caused by climate change.
- Develop appropriate, affordable, and enforceable standards and guidelines to guide technical design of treatment processes (see Chapter 7).
- Increase the use of nature-based solutions such as wetlands, waste stabilization lagoons, biological filters, and anaerobic digestion (e.g. UASB), instead of energy intense technologies such as activated sludge.
- Promote the construction of low footprint, cost-effective faecal sludge plants. Decentralized faecal sludge treatment plants, supported by sustainable operations and maintenance, have an important role to play in supporting the long-term financial viability of pit emptying services (see Chapter 9).
- Develop reliable, empirical, field-based methods for characterizing and estimating faecal sludge at scale. Because of the high variation and variability of faecal sludge generated, quantification and characterization studies will be required at the local level and based on requirements specific to each location.

Big sedimentation drainages on sewage water recycling station © Shutterstock

05

Resource planning and management

CHAPTER IN BRIEF

A major hurdle in the development of sanitation and wastewater management services is the availability of financial resources. At the same time, reports abound on the number of wastewater treatment plants that have been constructed worldwide but are dysfunctional or not functioning at all. How can this situation be improved? This chapter synthesizes findings from the global mapping and wider literature on the planning, costing and financing of sanitation services. The analysis shows:

- Effective long-term investment planning, based on sound socio-economic assessments, must be the starting point.
- Alongside sanitation-specific plans and strategies, wastewater and faecal sludge management must be integrated within wider urban development plans where these are being developed.
- Cost-effective technologies should be considered, with attention to cost-recovery.
- Tariffs remain an issue, with few utilities and cities able to base tariffs on the costs of services.
- Government will have to bear the brunt of investments in sanitation and wastewater as they require significant capital investments with limited opportunities of cost-recovery.
- There is a role fo the private sector, but private sector participation will still require government transfers; there are opportunities to tap into the private sector to improve services efficiencies.
- Official Development Assistance (ODA) is an important source of funds for sanitation and wastewater.
- Meeting the costs of sanitation and wastewater investments will require governments to tap into other domestic resources, including land value capture.

5.1 Balancing master planning and financial viability

Master plans are traditional planning tools used in the water and wastewater sector to determine investment requirements. Master plans are normally long term planning documents that take into account demographic changes and other anticipated evolutions in the city's environment. Well-designed master plans are built based on extensive surveys of physical as well as socio-economic conditions. They provide investment costs, with an implementation timeline, including for priority projects. They can provide the basis for business planning (for utilities) or government programmes, and for attracting external investors. Most cities and utilities included in the global mapping for this report do have a masterplan for wastewater, with some plans also including faecal sludge management.

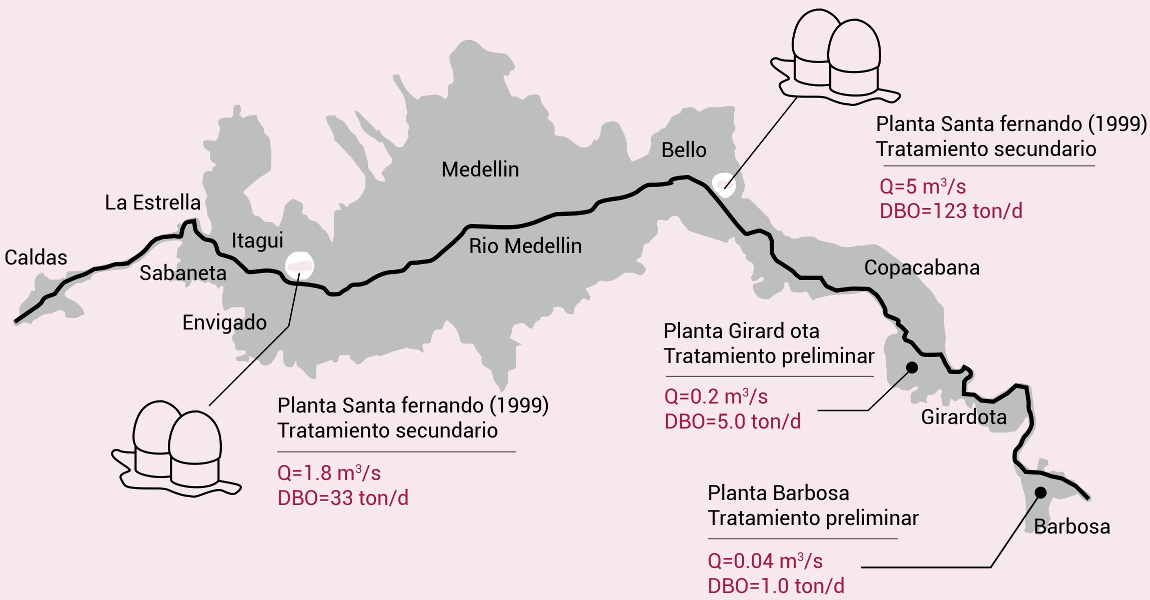
Rather than adopting master plans, some utilities have developed their business plans based on investment plans targeting specific outcomes. This is the case of Medellin (Colombia), where a specific investment programme was prepared to protect the Rio Medellin (Medellin River) (Box 15). It is important to note that this programme was focused on the objective of improving the water quality of Medellín River and was not developed based on the service access perspective. The incentive behind

Box 15: Long term planning for wastewater in the Metropolitan Area of the Aburrá Valley, Colombia

Long term planning has driven the successful service delivery of safely managed sanitation services in the Metropolitan Area of the Aburrá Valley (including Medellin, in Colombia). Wastewater treatment plants that have been recently built were initially planned more than 40 years ago. Long term planning has given the Empresas Públicas de Medellín (EPM), the public utility in charge of wastewater, a clear pathway with reachable objectives, resulting in efficient resource allocation over the years.

In 1982 EPM commissioned the development of a long-term planning instrument to improve the water quality of Medellín River and its tributaries: *Programa de Saneamiento del Río Medellín y sus Quebradas Afluentes*. This plan sets clear actions for EPM, including infrastructure to be built. Based on the projections of wastewater generated in a long term scenario, the plan identified the need to build four wastewater treatment plants to ensure acceptable water quality levels (See Figure 23). The plan was costed, and the resources mobilized through concessional loans provided by the Interamerican Development Bank. As of today, two of these four wastewater treatment plants have been constructed and are now operating. The remaining two are planned to be completed by 2027 and 2028.

Figure 23: Illustration of wastewater treatment plants planned as part of Programa de Saneamiento del Río Medellín y sus Quebradas Afluentes in 1982.



In addition to this specific plan, the environmental and economic regulators in the region mandate the development of other planning instruments to guide investments and ensure the protection of surface water bodies. Figure 23 shows the planning instrument hierarchy and its interrelation. In particular, the CRA requires that service providers have a Plan of Works and Investments (*Plan de Obras e Inversiones Reguladas*, POIR), to plan for investment in works, expansion, optimization of operation and maintenance and innovation to maintain and improve key service delivery indicators. The POIR must be prepared for a ten and twenty-year horizon. Additionally, EPM has four-year and annual investment plans. Finally, CORANTIOQUIA (the regional environmental corporation) requires a plan to ensure adequate discharge management to water bodies.

Source: Authors, based on data shared by EPM.

Alongside sanitation-specific master plans, there is growing awareness of the value of integrating sanitation with other basic services as part of integrated urban development plans.

this comprehensive plan was to improve the water quality of a river that traversed the Metropolitan Area. To improve Medellín's river quality, sanitation service delivery had to increase, and wastewater treatment had to be ensured.

Although master plans can provide an investment framework, they also carry risks of focusing too narrowly on specific infrastructure and technologies. Many cities and utilities struggle to fully implement their plans in parts due to the lack of financial resources required for specific technologies. For example, until recently most master plans almost exclusively focused on sewer systems and WWTPs, with little attention to onsite sanitation and implications for conveyance and treatment of these services, or even the development of water services, still lagging in many parts of the city.

A critical gap in master planning has been poor attention to sector governance, financing and regulatory frameworks. For example, where the financing framework is overlooked, cities and utilities may propose services that are unaffordable for targeted users. Many utilities have faced reluctance of households to pay for a sewer connection. Examples of such cities are Lusaka (Zambia) and Dhaka (Bangladesh) (see also Chapters 4 and Chapter 5). The result is the production of plans which cannot be implemented in their entirety. A World Bank review found that, in one project in Cambodia, only 20 per cent of eligible households had connected to the sewer network; under a project in Brazil, only 30 per cent of households had connected; and through a project in Uruguay, under 40 per cent of targeted households had connected to the sewers, resulting in five of the eight treatment plants remaining inoperational (Gambrill et al. 2020).

The integration of appropriate technologies throughout cities' boundaries - up to peri-urban and informal settlements where they exist – has been a key driver in the development of the Citywide Inclusive Sanitation approach to planning. In 2019, Nakuru County in Kenya developed a "Countywide Strategic Sanitation Plan" with a vision to 2030. The strategic plan proposes approaches to tackle sanitation (including wastewater and faecal sludge management) throughout the county, including peri-urban and rural areas. As a result, the plan recognizes the need for a mix of technologies, including both onsite and sewered, and for "soft" components such as behaviour change and supply side development. The Nakuru plan remains a high-level strategic document providing an overall vision with strategic directions – critical to generate political buy-in – rather than a detailed, costed and actionable planning document. Another example of a citywide plan is the Kampala City-Wide Inclusive Sanitation Improvement and Financing Strategy. This strategic document provides specific costed service delivery objectives from containment to treatment. Kampala's plan has been developed based on prior feasibility studies and master plans.

These experiences indicate that the production of an implementable citywide or area-wide inclusive master plan requires:

- Extensive buy-in from and consultations with all stakeholders involved in sanitation service delivery;
- Analysis of the city or area's socio-economic context to determine demand, willingness to pay and the affordability threshold;
- Analysis of technological options, combining findings from current and projected demand and technical feasibility studies taking into account national service delivery standards; and
- Analysis and identification of communication and community engagement activities that facilitate plan implementation.

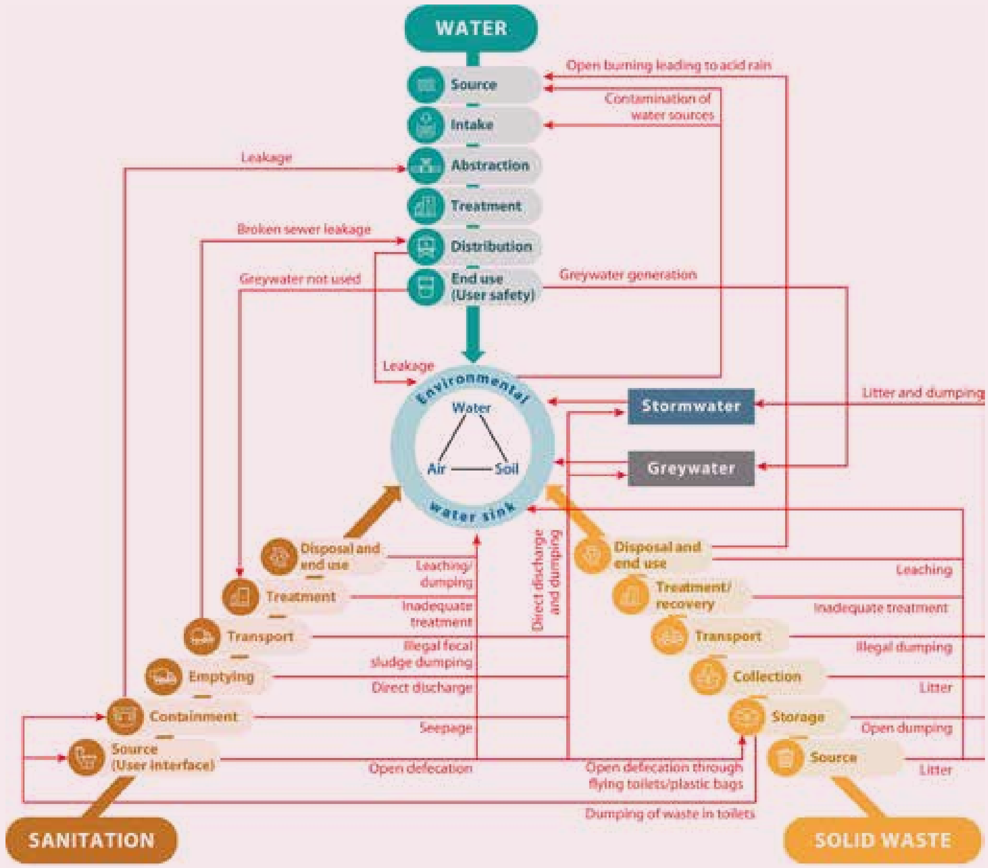
It should be noted that utilities operating in well-developed cities do not use master plans. Hamburg Wasser (Germany), for instance, uses several tools for financial planning, including water demand forecasts, as well as asset management tools to draw multi-year business plans. In France, SIIAP is guided by an overall strategy towards 2030 to determine future investments.

Alongside sanitation-specific master plans, there is growing awareness of the value of integrating sanitation with other basic services as part of integrated urban development plans. Box 16 outlines the case for integration and key lessons from experience in Africa and Asia.

Box 16: Integrating sanitation and wastewater management with wider urban development plans

There are fundamental reasons for integrating water and sanitation initiatives with wider slum improvement and wider urban development, as required for slumdwellers to achieve a decent quality of life and dignified livelihoods. In urban environments, issues such as water access, drainage, health, street design and solid waste management are all inextricably linked. Poor drainage leads to flooding, causing damage to sanitation facilities. Rubbish collected in drainage canals can exacerbate the issue and lead to stagnant water which becomes a breeding ground for disease. Pit latrines and septic tanks cannot be safely emptied if poor road access makes it impossible for emptying services to operate. And low-income urban residents may be unable to invest in improvements to their property, and mandated authorities unable to provide them with basic services, if those residents lack formal tenure (WSUP, 2021). These interconnections mean that unless water, sanitation and solid waste management services are planned together, the risk of service failure is magnified. The complex interlinkages between water, sanitation, solid waste, greywater and stormwater are presented in Figure 24.

Figure 24: Interlinkages between water, sanitation, wastewater and solid waste management.



Source: Narayan et al, 2021.

Good sanitation planning involves a holistic understanding of contextual demands and leveraging synergies with other urban development goals (McGranahan & Mitlin 2016; Narayan et al. 2021). Many cities struggle to provide safe sanitation due to the complexity of population density, urbanization, slum expansion, settlement heterogeneity, tenure security and sheer urban poverty (Chaplin 1999; Scott et al. 2015). One of the key reasons for failure in provision of sustainable sanitation, especially in complex settings such as cities in low and middle-income countries (LMICs), is the lack of adequate sanitation planning (Kennedy-Walker et al. 2015) and the adoption of sanitation technologies and policies which have failed to accommodate these contextual needs (McConville et al. 2011).

What does integration practically involve? Below we outline some key lessons from major slum upgrading initiatives in Asia and Africa.

An integrated approach to basic services requires government commitment to unblock political and bureaucratic obstacles. These commonly include lack of ownership of city sanitation plans among city governments, absence of a uniform planning framework, unreliable financial support and overlapping jurisdictions. In Asia, a notable example of this integrated approach to urban improvement is the Government of India's Slum Improvement Project (SIP), implemented across cities in India in the 1980s and 1990s (Scott et al, 2019). The project incorporated water, sanitation, solid waste, drainage and road improvements to improve the quality of the city environment. Significant improvements in basic services in the city slums resulted. Notable broader benefits included income generation, enhanced status for women and household investments in upgraded dwellings. Scott et al report how Calcutta's Metropolitan Development Authority engaged communities with councillors and contractors in the formulation, testing and monitoring of infrastructure provision and quality, which together with community-led maintenance, helped to prolong the life of assets. Further impact assessments highlighted improved infrastructure as enabling economic and social activity, primarily through increased physical access and extended use of public spaces after dark. Such impacts were perceived by residents as significant 'quality of life' factors (ibid).

Integration must be further supported by interdisciplinary and multi-sectoral collaboration and the integration of slum upgrading into city-wide strategic planning. In Nairobi in 2017, Mukuru informal settlement was declared a Special Planning Area (SPA), due to its unique environmental, health and development challenges. This resulted in the formulation of seven sector plans developed by a coalition of 46 organizations. These sector plans were harmonized and consolidated into the Mukuru Integrated Strategic Urban Development Plan-ISUD and adopted by the national and county governments for implementation. The SPA designation was significant, as it led to the suspension of conventional planning regulations, acknowledging their inadequacy for addressing local challenges, and providing space for innovation.

Mechanisms must be created for the promotion of community participation in all stages of the planning process. In Mukuru, a participatory planning process led by Muungano wa Wanavijiji, the national federation of slum dwellers in Kenya, was also central to creation of the Plan, in a process involving consultation with over 100,000 households — making the initiative one of the biggest slum upgrading projects ever attempted. Within the framework of this initiative, Nairobi City Water and Sewerage Company and Nairobi Metropolitan Services successfully piloted simplified sewer systems in Mukuru, as a cost-effective way of leveraging the settlement's existing trunk sewer infrastructure (see Chapter 5).

In Chamanculo, the poorest area of Maputo, comprehensive improvements have again been made to living standards as part of an integrated slum upgrading programme led by Maputo City Council. Under the project, Arquitectura sin Fronteras supported a process of enabling residents to gain formal land rights. Alongside this, WSUP supported the Municipality to improve sanitation facilities. The sanitation improvement work was aided by the negotiations over access and plot boundaries, and the land rights negotiations were aided by the promise of new sanitation facilities (WSUP, 2021). Having demonstrated viability, the initiative is now set to be replicated in 18 low-income communities across Maputo with support from World Bank.

An integrated approach to basic services is fully in line with international strategic commitments. These include the New Urban Agenda adopted at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III) in Quito, Ecuador, in October 2016, and subsequently endorsed by the United Nations General Assembly in December 2016. Notably, the New Urban Agenda states that "We envisage cities and human settlements that […] fulfil their territorial functions across administrative boundaries and act as hubs and drivers for balanced, sustainable and integrated urban and territorial development at all levels"; and that "We commit ourselves to long term urban and territorial planning processes and spatial development practices that incorporate integrated water resources planning and management, and considering the urban-rural continuum on the local and territorial scales and including the participation of relevant stakeholders and communities".

Donors have a key role to play in supporting this agenda through the creation of integrated funding streams. Most external funding remains highly siloed within the sanitation sector, and tied to a short project mode of delivery. Ideally, we would see funding streams for integrated slum improvement, encouraging sanitation actors to partner with actors bringing other expertise. A further key step in supporting this agenda is the continued measurement and demonstration of the increased economic and social benefits that accrue from such integrated programmes: the added value to funders as a result of enhanced direct and indirect benefits must be emphasized as new evidence becomes available.

5.2 Costing wastewater and faecal sludge management

Embedding operational costs in financial planning contributes to optimizing wastewater and faecal sludge management service delivery. While master planning provides a basis for estimating investment costs, the full costs of services also include operational expenditures. All too often the true costs of services, including operational costs of treatment services, are difficult to estimate, especially where cities have both onsite and sewer services. For instance, within the global mapping carried out for this report, four out of 11 cities and utilities do not set tariffs based on service costs. Failure to account for operational expenditures - and the subsequent absence of a cost-recovery strategy - risks systems failure due to chronic underfunding.

Some global initiatives are contributing to building capacity of city planners in identifying the full costs of services. One example is the Citywide Inclusive Sanitation Service Assessment and Planning (CWIS SAP), summarized in Box 17 and discussed further in the Nakuru case study.

Are some systems more cost-effective than others?

The cost of sanitation systems largely depends on the context of service delivery. Several studies point to the relative cost-effectiveness of onsite sanitation systems. For example, the Climate and Costs in Urban Sanitation (CACTUS)[2] looked at urban sanitation systems and services in 25 cities and ten countries across 87 systems to identify all unit costs and estimate overall lifecycle costs per capital of each system. The study found that overall, the minimum Total Annualized Cost per Household (TACH) for onsite sanitation systems can be significantly lower than TACH for septic tanks and sewerage systems (Table 2). In certain cities, TACH of onsite systems was more expensive than the TACH of sewer services. Such

2 http://cactuscosting.com/

Box 17: Building capacity to identify the full costs of services using CWIS SAP

CWIS SAP is a software tool developed in 2020 with support from the Gates Foundation to help decision makers compare the outcomes of different sanitation interventions based on criteria of equity, financial sustainability and safety of sanitation services. The tool starts with a mapping of current city-level sanitation coverage and the costs to provide services, revenues and safety levels associated with each of the sanitation systems in use. It then allows the user to model up to three scenarios that consider changes to hardware, alternative revenue and service delivery models, or any mix of those interventions. Using data provided by utilities, the tool compares the outcomes of each scenario on equity (e.g. affordability for service users), financial sustainability, measured by the cost coverage ratio and the net income of service providers and safety, defined as the per centage of waste safely managed (from containment to treatment).

As the tool was rolled out with several utilities and city governments (including in Nakuru, Lusaka and Kampala), some important lessons emerged related to data management. In particular, utilities and city planners have little visibility over:

- The extent of citywide access to basic sanitation;
- The different components of all other sanitation systems used at city level;
- Operational costs, including those related to servicing existing onsite sanitation systems and managing sewerage systems; and
- The different costs elements of sanitation systems management: capital expenditure, operating expenditure, fixed costs, variable costs and financial costs.

Although the results of CWIS SAP roll out were limited due to these data gaps challenges, conducting the exercise together with utilities has highlighted current capacity gaps for managing citywide sanitation sustainably.

Table 2: Sanitation systems cost range estimates from the CACTUS database

Sanitation system archetypes	Whole system cost (TACH, USD)		
	Median	Minimum	Maximum
Septic tanks with mechanical emptying and aerobic treatment	485	264	713
Pit latrines with manual emptying, trucking and aerobic sludge treatment	451	188	715
Combined sewers with aerobic treatment	485	269	679

Source: cactuscosting.com

findings confirm that technological choices should be grounded in the full assessments of the context, including demand for services. In contexts of high density, the full costs of sewers may turn out lower than the full costs on onsite services; conversely, contexts of low density (and low demand) may imply that onsite services would be more cost-effective.

Some studies have pointed to the potential of simplified sewer systems (also referred to as condominial or "mini-sewers") as a cost-effective technology. Delaire et al. (2021) found mini-sewers connecting several toilets to communal septic tanks to be significantly less costly per capita (USD 3-5/person/year) than sewerage systems (USD 16–24/person/year) or onsite sanitation (USD 2-14/person/year).

It is important to note that such comparative studies, while providing indications on possible cost-effective technologies, have limitations. First, conventional sewers and wastewater systems offer the additional benefit of conveying grey water, which therefore limits the comparison with dry technologies. Second, any choice of technology needs to be grounded in a detailed assessment of local conditions, including population density, which may justify investments in sewers on cost-effectiveness grounds. Other factors, such as social acceptance and enforcement capacity, also need to be factored in as well. In Kampala, in addition to WWTPs, the city has invested in a FSTP, which has proven to be an appropriate and cost-effective investment (Box 18).

Box 18: Kampala FSTP

The Lubigi FSTP Kampala was commissioned in 2014 and co-treats the faecal sludge produced by about 1 million population equivalent (PE) and the sewage from about 30,000 PE. Thanks to a simple but robust technology, it has been **running continuously for 8 years since its commissioning**. Performance is also high with pollution removal rates of 85 per cent on BOD_5 and 98 per cent on TSS.

The selection of the technology is all the more appropriate as the CAPEX and OPEX are low - only about USD 5 million and USD 20K per year, i.e. about 5 USD/PE and 0.02 USD/PE/year. Between 25 and 50 per cent of OPEX are covered by income from the resource recovery of treated sludge in agriculture.

A 2nd FSTP is currently being built in Kampala with the same capacity, but with a more complex treatment process. The CAPEX is twice as high and the OPEX 10 times higher, while the pollution removal rates on BOD_5 and TSS are only increased by 20 per cent and 2 per cent.

The upfront and large investment required for developing wastewater (and water) infrastructure have called on governments to set up specific repayable finance mechanisms.

How can treatment costs be optimized?

The selection of the treatment process has a strong impact on both CAPEX and OPEX. In a low-income context, low-tech technologies can achieve high performance while minimizing the sustainability risks of the service. Such facilities can easily be upgraded as soon as the available human and financing resources are secured for more advanced treatment options. High-tech processes involving complex electro-mechanical works are generally attractive at first glance, but often involve high CAPEX and equipment or capacities which may not be available locally, quickly placing sustainability of the service at risk. Examples of failures are numerous.

Resource recovery from the treatment process should always be fostered to finance part of the OPEX. The selection of the most appropriate recovery should be market-driven, not technology-driven. This requires a strong understanding of existing markets, and in some cases some market development. For instance, demand for nutrient recovery, especially for agriculture, is generally strong; however faecal sludge by-products must compete with other products, including non-organic fertilizers which are subsidies in many countries. The production of faecal sludge-based fertilizers must then be supported by extensive advocacy and market engagement work to support product roll-out. Some utilities, as in Germany are succeeding in operating WWTPs using self-generated energy. Energy production requires more advanced technology that bear higher sustainability risks. Finally, faecal sludge can also be used to recover protein. Demand for such by-products may increase in future as the impacts of food security and climate change continue to increase. Chapter 9 of this report explores in more detail the potential of wastewater and faecal sludge reuse.

The issue of land value

A hidden cost of wastewater and faecal sludge management is the costs of land for the construction of WWTPs and FSTPs. Decision makers can be reluctant to allocate valuable land for the construction of these facilities. When they agree, planners are pushed to construct WWTPs and FSTPs far from the city centre, on land of cheaper value. In the global mapping, at least two FSTPs have been constructed over 20 kilometres away from the city centre (Dhaka and Ouagadougou). The problem is that the distance disincentivize faecal sludge vacuum truck operators to use the facilities due to the transport costs involved. In Dhaka, the facility has stopped operating because it is disused (see the Dhaka case study in Chapter 6). Addressing the issue requires strong-buy in from policies and local governments to make available accessible land and to design smaller but multiple FSTPs across the city which require less individually.

5.3 What sources of funds to cover these costs, and what financing instruments?

The key role of governments in meeting capital investment requirements

Historically, public funds have been instrumental in the development of urban sanitation and wastewater infrastructure in Europe and the US. In the UK, for example, London sewerage network development was initiated with funding from central government – at least equivalent to USD 300 million in today's currency.

The upfront and large investment required for developing wastewater (and water) infrastructure have called on governments to set up specific repayable finance mechanisms. In France and Italy, for example, national public development banks provide repayable finance to municipal governments and/or utilities and have played an important role in funding large-scale urban regeneration, including sanitation and wastewater development (Fonseca et al. 2021).

Loans (concessional and commercial) have been used throughout a large number of countries to finance urban development, including sanitation and wastewater. In China, for example, debt financing has been very important to support urbanization drive. China has been able to invest more than 10 per cent of GDP on infrastructure – much higher than the average of 3-4 per cent in developing countries; largely owing to debt financing by Urban Development and Investment Corporations (UDIC) and Special Purpose Vehicles (SPV) (Liu, 2010). Rapid urbanization was required to absorb

Box 19: **How US local governments pay for wastewater**

The US federal government directly funds only a small portion of the nation's annual wastewater treatment capital investment. State and local governments provide the majority of needed funds. Local governments have primary responsibility for wastewater treatment: They own and operate approximately 15,000 treatment plants nationwide. Construction of these facilities has historically been financed with federal grants, state grants to supplement federal aid, and revenue from broad-based local taxes (property tax, retail sales tax, or, in some cases, local income tax).

Where grants are unavailable, local governments often seek financing by issuing bonds and then levying fees or charges on users of public services to repay the bonds in order to cover all or a portion of local capital costs. Almost all such projects are debt-financed (not financed on a pay-as-you-go basis from ongoing revenues to the utility). The principal financing tool that local governments use is issuance of tax-exempt municipal bonds. The vast majority of US water utilities rely on municipal bonds and other debt to some degree to finance capital investments.

Source: Jonathan L. Ramseur (2018): Wastewater Infrastructure: Overview, Funding, and Legislative Developments. Congressional research service

700 million rural populations in urban areas, which in turn demanded large-scale investments in urban transit, metro, power, water, sewage, etc. UDICs and SPVs have been set up to bypass restrictions on municipalities' borrowing ceiling and allow local-level borrowing to finance infrastructure.

Municipal bonds are also an important instrument to mobilize finance for sanitation and wastewater. In the US, municipal bonds are a significant part of a mix of funding and financing approaches for wastewater (Box 19). Bonds, as other borrowing instruments, require the borrower (in this case municipal governments) to have a strong credit profile. This is why the instrument is not available for many cities in developing countries that still rely on limited local revenues. The cities of Johannesburg and Cape Town in South Africa are some of the few in Africa that have issued bonds for municipal investments, including sanitation and wastewater. In Asia, In 2021 the city of Ghaziabad issued India's first green bond, with proceeds aimed at setting up a tertiary water treatment plant.

In LMICs countries, concessional loans for sanitation and wastewater from international financial institutions (IFIs) and bilateral donors for sanitation are slowly increasing. Investments in water systems are still higher, but investments in sanitation systems are steadily catching-up (Figure 25). In fact, OECD figures show that the share of investments in large sanitation systems (in principle including WWTPs and FSTPs) have sharply increased in the last few years (Figure 26).

Figure 25: The steady increase of ODA commitments towards sanitation (large systems)

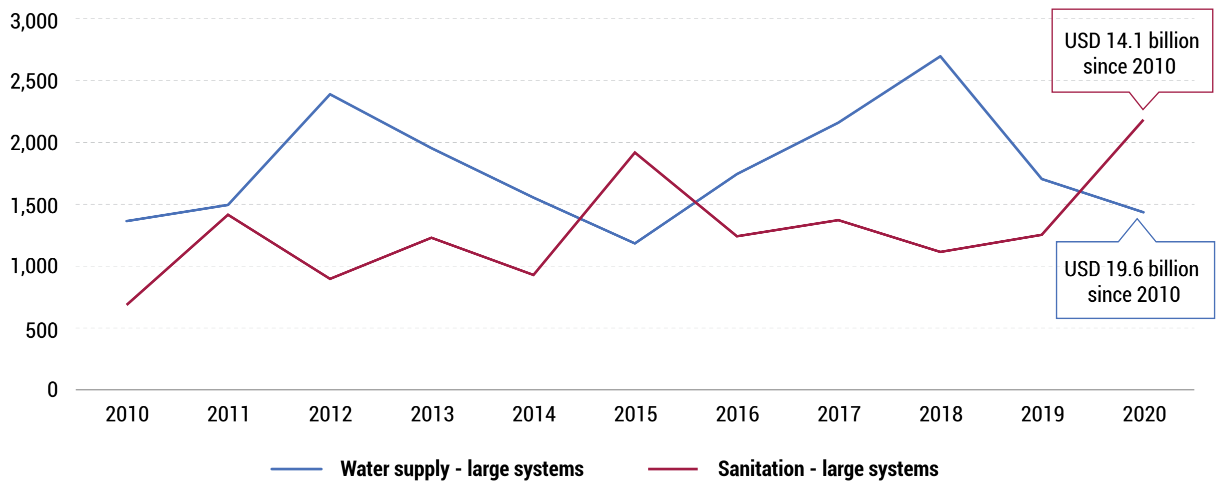
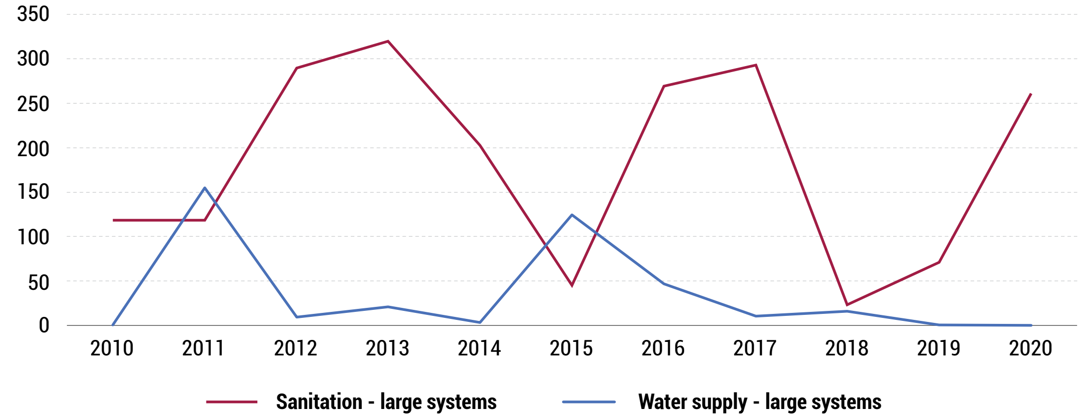


Figure 26: ODA commitments to wastewater in Vietnam compared with water



Source: OECD (Note "sanitation – large systems" refers essentially to sewers and WWTPs)

This increase is driven by strong demand for concessional finance for wastewater, as other sources of funds are secured for water investments (including from private investors). In Vietnam, for example, wastewater has become the biggest portfolio for IFIs operating in the water sector.

This increase in concessional finance for sanitation and wastewater management makes an even stronger case for cost-effective investments. As described in Chapter 4, many WWTPs constructed with ODA funding are not fully operational due to poor design and limited operating skills.

Time to go beyond traditional instruments?

The nature and size of investment needs for wastewater and faecal sludge calls for tapping into all possible source of finance.

At the same time, potential instruments such as land value capture are still under used. Some countries, as in China, have mobilized land value capture to fund large urban development projects (Paulais, 2012). There are different systems of land value capture, including:

- Recovering infrastructure investment value: this can be done in three main ways: (i) through *betterment levies*, i.e. taxes imposed on private landlords who see the value of their properties increase as a result of infrastructure works; (ii) through *developing publicly owned land*, which can then be sold at profit prices; and (iii) through *acquiring, developing and reselling* land;

- Land asset management and land sales, which involve strategic decisions as to selling or leasing publicly owned land and properties.

Box 20: How land betterment levies were mobilized in Colombia

Land betterment levies have long been a key instrument to finance infrastructure in Spain (where they are known as *contribución de valorización* or *contribución por mejoras*) and were carried out over to Latin America.

In Colombia, initially, betterment levies were calculated on a cost recovery basis. The system required that the total betterment levy recover 140 per cent of estimated infrastructure costs, whether or not land-value gains were of this magnitude. Landlords were very reluctant to pay such a levy, resulting in many difficulties for the system, and a dramatic decline in the use of *valorización*, until changes in the law in 1997.

The most important change was the introduction of the principle of levying betterment charges based on urban planning authorizations: land parcels where the municipalities have approved the conversion from rural to urban use can be subjected to a betterment levy of 30 to 50 per cent at the municipality's discretion. The betterment levy is applied to the price increment enjoyed by the landowner as a result of the planning authorization. Accordingly, the significant feature of this new form of *valorización* is that the betterment levy was due to be paid on realization of the land-value gain at the time of the land sale or redevelopment.

Between 1997 and 2007, the city of Bogota financed more than 200 municipal public works, representing over USD 1 billion in investments, through these betterment levies. It is used to finance infrastructure works all over the city, and this has helped reducing public resistance. In 2007, Bogota's mayor launched a citywide programme of improvement of streets and related infrastructure. The first phase financed and raise about USD 350 million in *valorización* revenues, levied on 1,236,346 landowners. These revenues were part of a broader financing strategy, which also includes loans and municipal bonds.

Sources: (Peterson, 2009), (Borrero, Durán, Hernández, & Montaña, 2011).

Cost-recovery: a major barrier for attracting investments in sanitation and wastewater management

Among utilities and cities included in the global mapping, only four out of 11 generate revenues from wastewater and faecal sludge that enable full cost recovery. Only two utilities (out of the 11 who provided the data) recover the full costs of wastewater services, SIIAP in France and Hamburg Wasser in Germany. Some utilities, such as DWASA in Bangladesh, are getting close to full cost recovery specifically for wastewater management (but not faecal sludge management).

Where revenues from charges and tariffs are not sufficient to cover the costs of services, some utilities are benefiting from predictable subsidies. For at least eight of these 11 utilities and cities, wastewater and faecal sludge management services are subsidized, either via the water tariff (3/8) or via direct transfers from the government (4/8) from the local government and from the central government (1/8). When subsidies are predictable, they can help attract private operators, as in the case of Hanoi (Vietnam) and Dïoïla (Mali):

- In Hanoi, a private operator has been delegated the management of several WWTPs under an "O&M" contract, in which the operator is only in charge of operations and related maintenance; as part of the contract, the operator receives an annual payment from the local government (Hanoi People Committee).
- In Dïoïla, a private operator has been delegated the management of a FSTP, under a lease-contract, in which any large repair is the responsibility of an inter-municipal structure.

Some wastewater and faecal sludge management services are not running on a cost-recovery basis and are not receiving any direct subsidy. This is the case in Trichy and Lomé, for example. Such systems carry a high risk of poor performance, if not failure.

One issue underlying poor cost-recovery is the lack of an appropriate tariff structure for wastewater and faecal sludge, reflective of the full costs of services. Globally, a range of tariff structure exists for wastewater and faecal sludge management services. Among the 18 cities studied in this report, five broad categories of tariff structure exist (Figure 27):

- Charge per m3 of water consumed: the most common form;
- Charge as a per centage of the water bill (second most common);
- Environmental protection fee as per centage of water bill (found in Hanoi, Vietnam);
- Fixed monthly fee regardless of consumption (as in Trichy, India); and
- Fee paid upon emptying an onsite facility (in Dïoïla, Mali).

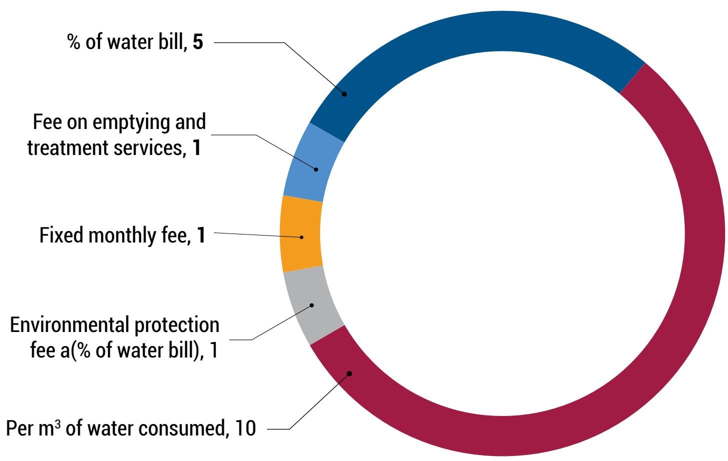
Within these categories, a broad range of prices or per centage rates are applied. For example, between 30 - 100 per cent of the water bill is applied as a sewer and treatment charge amongst the five cities. Likewise, there is a range of price per m³ of water consumed.

In some countries, specific charges apply to faecal sludge service providers for accessing FSTPs. Structures and prices of these "tipping fees" also vary widely. A major issue confronted by FSTP owners or managers is to balance revenue potential (i.e. to cover the running costs) and incentivizing faecal sludge emptiers to use the FSTP. As many FSTPs are situated in remote locations far from the city centre, in addition to tipping fees, emptying services operators need to account for transport costs (i.e. fuel), which is why some opt for illegally dumping the sludge. As a result, FSTP owners and/or operators tend to apply low fees, if they apply a fee at all. Where operating costs are not recovered through other sources (i.e. local government transfers), FSTPs inevitably fall into disrepair.

While there is no "one size fit all" model for wastewater and faecal sludge management tariff, the wide variety of models confirm that many utilities and cities are still far from setting tariffs based on a full understanding of costs involved and with the objective to recover costs. This underlines the need for stronger guidelines and regulatory tools in the area of wastewater and faecal sludge management (see Chapter 7).

Finally, many organizations in charge of wastewater and faecal sludge management still lack the appropriate corporate structure which would allow them to manage systems in full autonomy. This is particularly the case where municipalities are in charge of these services, for example via a waste management department. These departments often are not in a position to ringfence revenues from wastewater services or even control their budgets, which falls within a broader category within municipal services. Within the global mapping, Trichy in India falls in this category.

Figure 27: Tariff structures found across the 18 cities



How about the private sector investments?

When it comes to large WWTPs and FSTPs, large capital costs and limited prospects of cost-recovery do not provide the right context for private investments. Within the global mapping no cities had benefited from private sector investments in these facilities. Most contracts with private operators for the management and operations of WWTPs and FSTPs' are service or lease contracts, which do not require investments. In Vietnam, private operators actually receive annual local government transfers to meet operating costs.

Opportunities for private sector participation are more tangible for other parts of the sanitation service chain. In many cities, citizens rely on private service providers for basic sanitation services, including toilet construction as well as emptying services. In fact, such private operators are the main sanitation service providers in many cities where sewerage doesn't exist or is limited. Facilitating private sector investments in these contexts so that they deliver optimum sanitation services necessitates regulations and regulatory tools, which are generally underused for onsite sanitation as explained in Chapter 7.

One emerging enterprise-led service delivery model is container-based sanitation (CBS) (see also Chapters 6, 9). CBS is particularly well-suited to areas that are densely populated. At its core, CBS is about delivering a service as opposed to just infrastructure. Enabling the development of CBS could therefore lead to more integrated services, with one provider involved across many parts of the service chain. Although more cost-effective than other types of sanitation services, CBS would still require government and/or development partners' transfers for full cost-recovery (EY, 2021).[3]

There are also important benefits in pursuing private sector participation beyond infrastructure design and construction. Design-Build-Operate (DBO) contracts for WWTPs (and FSTPs) can be attractive for governments to ensure that design is as efficient as possible – since operators will also be in charge of operations. Such contracts also secure expertise for WWTPs operations (sometimes lacking in LMICs) and can provide the opportunity of knowledge transfer. In 2019, for example, Ho Chi Minh City awarded a USD 200 million Design Build Operate contract to a private consortium for the construction of a WWTP with a peak capacity of 34,000 m^3/hour (World bank, 2021). DBO contracts can be even more cost-efficient where remuneration is (at least partly) tied to performance during operations.

3 EY (2021). Why it's time to get behind container-based sanitation.

Recommendations

- Design context-specific sanitation systems using an incremental approach and taking into account the full costs of services across the sanitation service chain.
- Leverage opportunities to integrate sanitation and wastewater management services with wider urban development plans.
- Carefully plan wastewater and faecal sludge management, taking into account local conditions including socio-economic conditions.
- Ensure policies allow for low-cost technologies to be considered by city authorities and that appropriate (flexible) regulation is in place.
- Support service providers in setting tariffs based on costs.
- Build capacity for costing wastewater and faecal sludge management services

5.4 Case Study: Medellín and the Metropolitan Area of the Aburrá Valley, Colombia — a model of corporate governance for public utility provision of sanitation services

In the Metropolitan Area of the Aburrá Valley in Colombia, there is a shared understanding among decision makers of the necessity to ensure universal access to safely managed sanitation. This case study details how strategic and financial planning have led the water and sanitation service provider, ***Empresas Públicas de Medellín*** *(EPM), to become one of the best-performing utilities in Colombia for sanitation coverage and wastewater treatment.*

Source: All data provided by EPM.

Summary of key data for the Metropolitan Area of the Aburrá Valley

Demographics	Population in EPM's service area	2,612,958 for Medellín 3.931,447 for the Metropolitan Area
	Population density (inhabitants/ Km2)	6,941.48 for Medellín 3,717 for the Metropolitan Area
	Low-income area (LIA) population	308,194
Water and sanitation services	Water network coverage (%) connections	98.1 (dic 2022)
	Sewerage coverage (%)	96.2 (dic 2022)
	Dependent on onsite sanitation (%)	4.5
	Access to improved containment (%)	No information on the type of containmentdata
	Dependent on shared facilities (%)	N/A
	Wastewater treated (%)	90.3
	Sludge treated (%)	No data
Institutional arrangements	Policy making and regulation	▪ Water Regulatory Commission (CRA) for setting standards ▪ Superintendence of Public Utilities (SPU) for monitoring
	Planning	▪ Empresas Públicas de Medellín (EPM), a public utility
	Service provision	▪ EPM ▪ Private operators (for emptying services)

Medellin, Colombia © Ba11estas Photography

EPM: the best performing wastewater utility in Colombia

The Aburrá Valley Metropolitan Area is the most populous metropolitan area in Colombia. Two-thirds of the inhabitants of the metropolitan area reside in the largest and most populated municipality, Medellín, which serves as the commercial and urban hub of both the metropolitan area and the Antioquia Department. Medellín is also the capital of the Antioquia Department and Colombia's second-largest city after Bogotá.

In Colombia, municipalities are mandated to provide water and sanitation within their urban perimeter. They are also tasked to mobilize funding and identify a suitable service delivery model. In 1994, Law 142 allowed private businesses, public-private partnerships, and municipally controlled corporatized public utilities to provide services. Regardless of the management arrangement, utilities must meet service quality and continuity standards, continual coverage expansion, equitable service, and economic efficiency parameters set by the Water Regulation Commission (*Comisión Reguladora de Agua*, CRA).

For the Metropolitan Area, Empresas Públicas de Medellín (EPM), an industrial and commercial enterprise of the state, provides water, sewerage services, electricity and gas services. EPM is owned by the municipality of Medellín, and the Board of Directors' president is Medellín's mayor. EPM is part of the EPM Group, a business conglomerate created in 1995 due to the fusion of four different municipal entities: Energy, Water Provision, Sanitation and Phone Municipal companies.[4] The conglomerate has now expanded beyond service delivery and has incorporated new business lines on real estate management, construction, insurance and financial products.

Around 84 per cent of the wastewater produced by the Metropolitan Area receives secondary treatment and is then safely discharged to the Medellín river (*río Medellín*). The Metropolitan Area outperforms other large cities in Colombia, with the highest per centage of wastewater treated in Colombia. EPM manages two WWTPs located close to the river. Even though sanitation coverage is high and has steadily increased over the last decades, Medellín and the Metropolitan Area, still face challenges to reach universal, safely managed sanitation as unplanned and informal urban growth is occurring in the peri-urban areas.

EPM performance: a result of long-term planning, a mix of public and commercial investments and sound financial management

EPM's financial performance is the result of structured planning, supported by a ringfenced budget independent of the municipality's budget. This has allowed limiting political interference in their operation, planning and financial forecasting activities. Additionally, the close relationship with the municipalities has permitted effective coordination to reach underserved areas and to align EPM plans to the general development plans of the Metropolitan Area.

Planning for sewerage coverage is incorporated in 10-year plans mandared by CRA. The CRA requires service providers to include coverage expansion in their planning instruments and to ensure budget provisions. These financial provisions are incorporated into the ten years plans and to be financed by the service providers. However, if service providers require support, they can request funds from the local and central governments or apply for loans.

Investments in sewerage and WWTPs improvements have benefited from public funding, both from local funds and international finance institutions (IFIs). In Colombia, local governments (LGs) have two main sources of funds: the General Royalties System and the National General Budget (NGB), which are national funds for which LGs compete. To access those resources, LGs must submit project proposals to the Ministry of Housing, City and Territory, where a technical team approves or rejects the project based on compliance with technical, legal and land ordering requirements. On the other hand, the General Contributions System[5] dedicates 5.4 per cent of its resources to subsidies and investments in water and sanitation infrastructure. Additionally, LGs can generate resources through municipal taxes on private property that can be used for sanitation infrastructure.

EPM has also relied largely on users' tariffs to finance new works for sanitation. Tariffs in Colombia, as mandated by the CRA, should cover at least O&M and are expected to cover CAPEX requirements in accordance with Investments Plans. EPM's operating cost coverage ratio (total annual operational revenue/total annual operation costs)[6] for sanitation service delivery is 1.62, way above the minimum acceptable level defined by IBNET of 1.4.[7] This financial surplus has

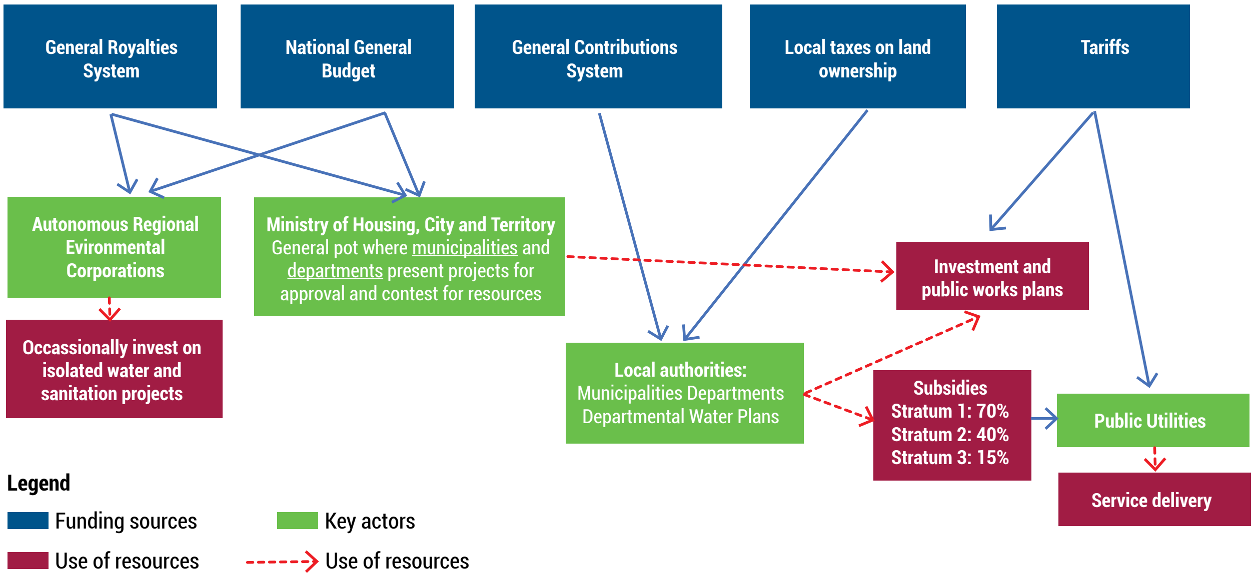
4 https://www.epm.com.co/site/english/home/about-epm/history

5 A source of funding dedicated to distributing more resources to local governments to invest in education, health and water and sanitation.

6 Operating costs include labour, energy and contracted service costs excluding depreciation and financing charges.

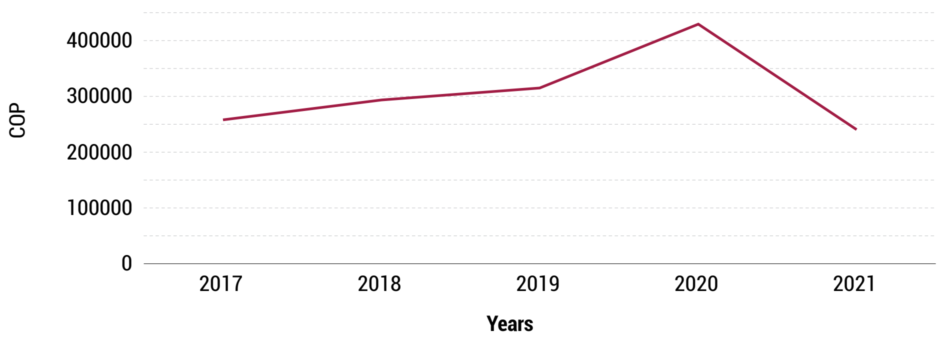
7 Van den Berg, C.; Danilenko, A. *The Ibnet Water Supply and Sanitation Performance Blue Book: The International Benchmarking Network for Water and Sanitation Utilities Databook*; World Bank Publications: Washington, DC, USA, 2010.

Figure 28: Financial flows in the sanitation sector



Source: Saker et al., 2022

Figure 29: EPM's EBIDTA (2017-2021)



allowed EPM to expand to underserved areas in informal settlements, which are more costly to reach with services, as they require investment beyond sanitation infrastructure. The last mile, in terms of sanitation coverage, represents for EPM the most difficult to reach population with challenges that go beyond the service provider's capacity in reaching informal settlements located in steep terrain, environmentally protected areas or new urban development outside existing land use planning instruments.

EPM has maintained a positive EBITDA for the past five years, as shown in Figure 6. This performance co-exists with an inclusive approach to service delivery. In Medellin, as in the whole of Colombia, utilities' water and sanitation tariffs are also cross-subsidized. Wealthier households (Stratum 6-5-4) subsidize poorer families (Stratum 1-2-3). Where there are more inhabitants from the lower stratum, municipalities can provide additional subsidies. This is the case in the metropolitan area, where municipalities provide lifeline tariffs for the most vulnerable households.

EPM is an example of successful public utility. The municipally-owned corporatized utility has managed to expand service delivery of water and sanitation internationally to Chile and Mexico and nationally to three other cities and the region of Antioquia, also covering the rural population. Its financial performance has resulted in high creditworthiness, which enabled the utility to source finance to expand, showing the profitability of service delivery.

Working with 'Popo' pump in Nakuru, Kenya © NAWASSCO

06

Responsibilities

CHAPTER IN BRIEF

Clear institutional mandates provide the foundation for a public service approach to sanitation and wastewater management. This chapter first outlines how urban sanitation mandates are currently structured and executed at the global level, before turning to how mandates and institutional structures can be re-shaped to promote equity and inclusion. The analysis shows:

- Responsibilities for sewered and onsite sanitation may be integrated within a single authority, or split between the utility and municipality. In Eastern and Southern Africa, there is a notable shift towards integration within commercial utilities.
- Countries in Asia and Latin America are also actively reviewing responsibilities for urban sanitation, addressing challenges by improving clarity.
- There is a general trend towards greater public and private delegated management of wastewater services. The private sector similarly has a key role to play in faecal waste emptying.
- At the city level, the definition of city boundaries is key to inclusive mandates. Informal settlements must be included in the service jurisdiction of mandated authorities.
- These settlements often require specific technical approaches, which need to be promoted by the mandated authority. A number of innovative models have potential for serving low-income areas as part of a citywide approach.
- Within mandated authorities, gender equity requires particular attention. Male staff outnumber female staff by a ratio of 2:1 among service authorities within our sample.

6.1 Mandate structures for urban sanitation and wastewater management

Drawing on recent research and the global mapping, this section provides an introductory overview of how mandates for urban sanitation, including wastewater management, are currently structured at the global level.

Historically, lack of clarity around responsibilities for urban sanitation, and overlapping responsibilities caused by poor coordination, have been major bottlenecks to service improvements. Institutional frameworks for urban sanitation have been characterized by competing roles and responsibilities at state and municipal levels (Schertenleib et al, 2021). In the SDG era, clarifying responsibilities has been recognized as a foundational step towards achieving citywide sanitation services. For example, Schrecongost et al (2020) argue that in order to provide universal sanitation services, there must be a responsible authority with a clear, legal mandate for inclusive urban service provision.

More broadly, significant progress can be achieved through active processes of review and reform to rationalize responsibilities for urban sanitation.

Differences can be observed across regions in the approach to structuring urban sanitation mandates and associated levels of decentralization. In Sub-Saharan Africa for example, institutional arrangements for urban sanitation have historically been more centralized compared to countries in South Asia (Schertenleib et al, 2021). However, across regions, responsibility for urban sanitation service provision, including wastewater management, generally resides with one of two institutions: the utility, which may be publicly or privately owned; or the local government (often municipal authorities).

Analysis of over 30 countries in Africa, Asia and Latin America identified five broad mandate structures for urban sanitation, looking across the full sewered and onsite sanitation service chains (ESAWAS 2021 A, see Table 7 below). An important distinction is between A) integrated responsibilities for sewered and onsite sanitation within the same authority, and B) split responsibilities between utilities and local government. In addition to utility and local government involvement, the mandate structure can be distinguished by the jurisdiction of the utility (if the utility's mandate is to provide services at the national, regional or city level).

Major urban centres in Europe, such as Paris and Hamburg, sit outside this framework, with full sewered coverage the norm. Similarly, our sample demonstrates that smaller urban centres in Africa and Asia may have no sewered services, such as Kaladougou, Mali; or negligible sewered services, such as Changunarayan Municipality, Nepal, where less than 300 households are connected to the sewer network.

Figure 30 presents responsibilities for urban sanitation service provision for 12 cities included in the Global Mapping. A key trend can be observed in Eastern and Southern Africa, where there is growing regional momentum towards integrating responsibility for service outcomes with a single authority — specifically the utility where there is one**.** Within our sample, this model can be observed in Nakuru (Kenya) and Dar es Salaam (Tanzania), and is also now being adopted in Zambia.

More broadly, significant progress can be achieved through active processes of review and reform to rationalize responsibilities for urban sanitation. Some countries are actively reviewing responsibilities for urban sanitation, addressing challenges by improving clarity. In Bangladesh, for example, the National Action Plan for the Institutional & Regulatory Framework for FSM has established a Coordinating Committee to support role clarification and to coordinate planning and investment across responsible authorities (see **Chapter 6**). The shift in Eastern and Southern Africa, where countries are actively adjusting the scope of utility mandates to include onsite sanitation, can also observed to an extent in Latin America. In Colombia, utilities are increasingly adopting additional responsibility for onsite sanitation, although this may amount to a small section of the population due to generally high levels of sewered sanitation (96 per cent in Medellin).

Consideration of an integrated approach to responsibilities for urban sanitation service provision is recommended in the African Sanitation Policy Guidelines (AMCOW,

Table 3: Existing mandate structures for urban sanitation. Subnational utilities may be city-level, or at the county/region/state level. Source: Adapted from ESAWAS, 2021A

Mandate structure	Mandate for sewered sanitation (SS)	Mandate for onsite sanitation (NSS)	Mandate for SS and NSS integrated or split	Example from Global Mapping
1	National utility	National utility	Integrated	Ouagadougou, Burkina Faso
2	Subnational utility	Subnational utility	Integrated	Dar es Salaam, Tanzania
3	National utility	Local government	Split	Kampala, Uganda
4	Subnational utility	Local government	Split	Dhaka, Bangladesh
5	Local government	Local government	Integrated	Trichy, India

In some cities, there is separation between A) responsibilities for emptying and conveyance and B) responsibilities for treatment and disposal or reuse.

2021). Arguments in favour of integration have also been set out by ESAWAS (2021a), including that split mandates can exacerbate the risk of disproportionate allocation of resources to sewered sanitation; the technical requirements of faecal sludge treatment mean that responsibilities in this area are more sensibly placed with a utility, that is likely to already hold responsibility for wastewater treatment; integration can assist the formation of effective regulatory structures; and integration can help to facilitate the introduction of cross-subsidies from sewered to onsite sanitation services, promoting equity (see Chapter 7) (ESAWAS, 2021a).

In parts of South Asia and Latin America, it is common for municipal authorities to have integrated responsibilities for both sewered and onsite sanitation. This is the prevailing model in Indian municipalities for example, including Trichy, where the City Corporation is responsible both for the 27 per cent of the population with sewered services, and for the large majority with onsite systems. Although utility involvement in sewered services is common, local governments remain the default service authority globally for onsite sanitation in cities.

An alternative model can be seen in Hatyai City, Thailand, where the Wastewater Management Authority (WMA), a state enterprise, has responsibility for sewered services provision, under the supervision of the municipality. Hatyai City Municipality and WMA signed a Memorandum of Understanding to co-manage sewered services — which cover 90 per cent of the city population — for 15 years with the agreement due for renewal in 2031.

In some cities, there is separation between A) responsibilities for emptying and conveyance and B) responsibilities for treatment and disposal or reuse. This can be observed in Kampala for example, where the local government, Kampala Capital City Authority (KCCA), has responsibility for emptying services, but NWSC is legally responsible for treatment and disposal or reuse of both wastewater and faecal sludge (KCCA also has a limited role in faecal sludge treatment, for example having invested in the piloting of biogas systems in public institutions).

6.2 Service models and delegated management structures

Within a public service approach to sanitation, the private sector can and often does have a key role to play in supporting mandated authorities to execute their responsibilities. In this section we summarize service models for sanitation and wastewater management and the central role of public-private collaboration.

Wastewater management

In Europe, there is a general trend over the past 20 years towards public and private delegated management of wastewater services. In the past, direct public management was predominant among EU member states, with the responsible public entity entirely in charge of water and wastewater services provision. Direct private management is an alternative model in place in a few European countries (England, Wales and the Czech Republic). More common are delegated public management systems, in which a management entity is appointed by the responsible public entity to execute the management tasks; and delegated private management, through which the responsible public entity appoints a private company to manage tasks, on the basis of a time-bound contract in the form of lease or concession contract (EurEau, 2018). This model can be observed in Sofia, for example, where Sofiyska Voda, part of Veolia, is responsible for water supply, sewerage and wastewater treatment services under a 25-year Concession Agreement with the Municipality of Sofia (the asset holder), which expires at the end of 2025.

Cases of delegated private management in the water sector similarly abound in Latin America, Asia and Africa. A notable example is Manila, where the concession granted to the newly formed Manila Water in 1997 by the Philippines Government was the largest in history at the time. Prior to the utility's set up in 1997, only 26 per cent of the population in the service area had 24-hour access to water supply; Manila Water expanded distribution lines and focused on reducing system losses to increase water availability to almost 100 per cent. The utility focused particularly on affordable service to customers from marginalized communities, reaching two million people in the 'Water for the Community' program.

Figure 30: Global Mapping — responsibilities for urban sanitation service provision

For sewered services, most investments in sewerage and wastewater treatment services are managed by the public sector (Nelson and Murray, 2008). This is consistent with infrastructure investment figures for the wider water sector: a PPIAF – World Bank review of infrastructure projects found the water sector accounts for 4 per cent of total investment (against 50 per cent of total investments allocated to the energy sector, and 45 per cent to transport); within the water sector, public entities account for 80 per cent of total investment (PPIAF & World Bank, 2017).

Private sector investment and public-private partnerships (PPP) for wastewater management are increasing. In China for example, over 80 per cent of wastewater treatment plants have been developed by municipalities through public-private partnerships (PPP). In Egypt, a public-private partnership was created for the New Cairo wastewater treatment plant, in which the government of Egypt worked with the International Finance Corporation and World Bank Group's Public Private Infrastructure. The PPP provided a model for future PPPs in Egypt and eventually informed the approval of a PPP law in 2010 (World Bank, 2020); wastewater service coverage in Egypt is now also most commonly supported by public-private partnership transactions (Water Aid, 2019). In Ghana, a survey by Safe Water

Citywide service provision implies the service jurisdiction of sanitation mandates must include informal settlements. Clear responsibilities for serving the poorest begin at the constitutional level, with explicit formal recognition of the human right to water and sanitation.

Network highlighted that private financial solutions such as microcredit and small-to-medium enterprise (SME) financing can be successfully applied to support household access to improved wastewater services (Appiah-Effah et al., 2019).

Faecal sludge management

Across regions, the private sector has a key role to play in the delivery of faecal waste emptying services. In countries where mandates for onsite sanitation have recently been revized, consideration is being given to the role of the private sector in supporting the responsible authority to execute. Relating to faecal waste management services specifically, the progressive formalisation of the private sector — bringing existing Vacuum Tank Operators (VTOs) and manual emptiers into the fold, and raising standards through the development and enforcement of guidelines, licensing and service provider certification — is now underway in locations across Eastern and Southern Africa, with Lusaka and Kampala notable examples (ESAWAS 2021a; see also **Chapter 6**). In low-income areas in some cities where vacuum tanker services are not feasible, formalied manual emptying has often been organised instead (Peletz et al., 2020).

In South Asia, city authorities may also provide a limited service directly, supplementing the private sector market. This can be observed in Trichy, for example, where 72 privately operated tankers provide desludging services to households; while two desludging vehicles owned by Trichy City Corporation also render desludging services, focused predominantly on desludging septic tanks in government buildings and Community & Public toilets (CT/PT) within the corporation limit.

Although on-demand desludging services are predominant in Africa and Asia, scheduled desludging provides an alternative service model. In Malaysia, where 80 per cent of the population are connected to sewered services, scheduled desludging is soon to be made mandatory again for the over 1 million residents dependent on septic tank systems, having previously been trialled from 1994 - 2008. Following a 10-year decline in service levels, the regulator SPAN has taken the decision to revert to a model of scheduled desludging, for which the national sewerage corporation, Indah Water Konsortium, has direct responsibility, though with private sector participation encouraged. IWK's concession has recently been extended, until 2030. Scheduled desludging is also under consideration in some African countries, notably Zambia and Rwanda (ESAWAS, 2021a).

6.3 Serving low-income areas and informal settlements

In the context of sanitation and wastewater management in cities, informal settlements (sometimes referred to as slums) and low-income areas more broadly require particular attention. In this section we outline key principles and some of the approaches available to mandated authorities to support inclusive service provision to these areas.

Inclusion of informal settlements within service authority mandates

Citywide service provision implies the service jurisdiction of sanitation mandates must include informal settlements. Across regions, municipal and utility services can sometimes be limited to older city administrative boundaries and formal housing areas, missing new peri-urban settlements; while informal settlements may also be excluded, in some cases as a deliberate matter of government policy. For citywide service provision to be feasible, informal settlements as well as peri-urban settlements must be explicitly included in the jurisdiction of the responsible institution (ESAWAS, 2021a).

Clear responsibilities for serving the poorest begin at the constitutional level, with explicit formal recognition of the human right to water and sanitation. In Kenya, for example, the human right to water and sanitation is explicitly recognized in the constitution. This naturally cascades into high-level legislation and development strategies, into lower-level policies, strategies, frameworks and plans, and into the attitudes and language of decision makers (WSUP Advisory, 2020).

At the city level, the definition of city boundaries is key to inclusive mandates. Responsibilities for urban sanitation service provision may include all residents within the authority's jurisdiction; but defined service areas must be connected to urban planning processes, monitored and reviewed to ensure responsibilities keep pace with urban expansion and the development of new settlements, formal or informal (ESAWAS, 2021a). Connected to this challenge, in 2022 UN-Habitat introduced a new harmonized definition, called the Degree of Urbanization, to capture the urban-rural continuum, define what constitutes urban, and facilitate international comparisons of urbanization (UN-Habitat, 2022).

Service models for informal settlements and low-income areas

Simplified sewer systems are emerging as a service delivery model suitable for slum areas with existing trunk sewer infrastructure.

Although onsite sanitation is the predominant form of service in informal settlements in Africa, low-income urban residents in Asia and Latin America are more likely to have access to sewered services. In Hatyai City for example, 10 per cent of the population live in low-income areas, where they receive sewered services. In Medellin, Colombia, low-income residents are similarly connected to the sewer network. In Trichy, over 50 per cent of the city's low-income areas are delineated with sewered sanitation, although only 28 per cent of the city population is actually connected to the sewer network. In the small town of Penjikent and neighbouring Sugdijon town, in Tajikistan, an estimated 56 per cent of total households are connected to the centralized sewerage system.

Simplified sewer systems are emerging as a service delivery model suitable for slum areas with existing trunk sewer infrastructure. Relative to conventional sewers, these systems cost less, use smaller-diameter, flexible pipes, and can be laid at shallower depths and closer to households, easing the connection process (WSUP, 2022). Already widely used in Brazil and other Latin American countries, the model is being deployed in Mburahati, a low-income, unplanned area of Dar es Salaam, under the auspices of the utility DAWASA. In Kampala, the utility National Water and Sewerage Company are trialling the approach in the low-income area of Makindye. In the informal settlement of Mukuru, Nairobi, the model has been piloted as part of a wider integrated slum development programme, with the support of Nairobi City Water & Sewerage Company and Nairobi Metropolitan Services. Evaluations of the pilot have produced positive results across key metrics including sustainability, customer satisfaction and scalability of the model (WSUP, 2022).

Any form of sewered service extension must be accompanied by robust strategies to ensure demand creation and low-income customer uptake of connections to the network. The challenges of achieving high connections uptake in sewerage investments are significant and well known. A systematic review of connections uptake in sewerage projects looked at ex-post evaluations of sewerage projects in African cities, with the great majority of evaluations reporting concerns about low connection rates (Norman and Pedley, 2011). A recent study explored strategies for connecting low-income customers in Dhaka to planned sewer network extensions under the World Bank-funded Dhaka Sanitation Improvement Project, recommending the use of income-based or area-based subsidies to overcome challenges around affordability, a key constraint that has negatively affected uptake in previous projects (Alam et al, 2020).

For onsite sanitation services, the conditionality provided by public-private partnerships can be leveraged to incentivize the private sector to target low-income customers. Studies have shown that the poorest urban residents are likely to be either unwilling or unable to pay the market price for faecal waste emptying services (Delaire et al, 2020). There are interesting examples within our global mapping of authorities taking measures to bridge the financing gap and incentivie private sector provision to these areas. In Kampala, KCCA has project funding to test benefits of offering emptying service subsidies on a quarterly basis to low-income households. In Dhaka, Bangladesh, under the SWEEP model, licensed providers are contractually required to maintain 30 per cent of their customer base from Dhaka's densely populated LICs, with services to these households cross-subsidized through higher rates to middle-income and institutional customers (WSUP, 2018).

Container-based sanitation (CBS) offers an onsite service delivery model tailored to the specific requirements of densely populated informal settlements (see **Chapter 9**). Now active in nine countries, the CBS model negates the need for upfront capital investment in containment structures, providing low-income households with the flexibility of a subscription option with little-and-often bill payments. A recent

Water utilities that tap into the female labour force have been found to be more profitable, competitive, and sustainable, and to have a more dedicated and loyal workforce.

evaluation of Clean Team, a CBS service in Ghana, found the service achieved very high levels of customer satisfaction, and closed the gender equity completely, with women and girls less satisfied than men with their previous sanitation option and very satisfied with the Clean Team service (WSUP, 2022).

6.4. Gender mainstreaming within mandated service authorities

Issues of equity and inclusion apply to the services authorities provide, but equally to human resourcing within the institution. We close this Chapter with a discussion of women's participation in the sanitation workforce.

Achieving SDG6 will require greater human resources in the sanitation sector, and specifically, alleviating the barriers to women's participation in the sanitation workforce. The Global Gender Gap Index 2020 reports that only 15 per cent of people working in engineering worldwide are women (World Economic Forum, 2020). In terms of water and sanitation provision, World Bank surveyed 64 water and sanitation utilities and found that less than 18 per cent of the workforce was female, and less than one in four managerial or engineering staff were women (World Bank, 2019).

Water utilities that tap into the female labour force have been found to be more profitable, competitive, and sustainable, and to have a more dedicated and loyal workforce (IWA, 2016). Studies have further indicated that female political leadership can lead to an increase in provision of goods and services commonly judged to be favoured by women, such as drinking water, education and health (Jha & Sarangi, 2015; Hyde & Hawkins, 2017; Syaleryd, 2009). Little attention has been paid to date to the attitudes of female decision makers to sanitation specifically in developing countries, particularly in Sub-Saharan Africa.

A recent study in Kenya identified wide-ranging barriers which may be preventing women from equal representation at leadership levels within water and sanitation utilities. Barriers were found at all stages of career development, with girls facing gender bias in school when pursuing technical degrees; young career women having to balance greater familial obligations than men; and mid-career women lacking many of the networking opportunities that men have. Bullying and sexual harassment of women were also commonly cited (WSUP, 2020). Women have also been shown to face challenges participating in faecal sludge emptying services, generally only being assigned certain 'soft tasks' (Philippe et al, 2022).

Potential measures to address these challenges include transparent channels on promotion and salary structures, enforced government mandates on gender representation, and developmental leadership and training (WSUP, 2020). Other potential measures to enhance participation include the creation of a professional network of women so they can guide, help and mentor other women professionals in the sector, offering flexi-time, and providing safe and comfortable facilities for lactation.

Among our sample, four mandated service authorities were found to have gender mainstreaming strategies in place — HSE (Hamburg), KCCA (Kampala), EPM (Medellin) and ONEA (Burkina Faso). In Nakuru, NAWASSCO are also in the process of developing a gender inclusion policy.

Male staff outnumber female staff by a ratio of 2:1 among mandated service authorities within our sample, on average. Figure 31 presents gender staff ratios for the six authorities where data relating to total staff could be accessed. Although the total number of staff by authority varies considerably across our sample — from 88 total staff in Changunarayan Municipality to 2200 staff in Hamburg Wasser — women are consistently under-represented across these six mandated authorities in Europe, Africa and Asia, with ratios ranging from 21 per cent female staff (EPM, Medellin) to 43 per cent female staff (SV, Sofia).

Women are again consistently under-represented at Director and Manager level, although there is greater variance within our sample. In Changunarayan Municipality, 8 out of 26 staff (31 per cent) at decision maker level are female. In DAWASA (Dar es Salaam) and SV (Sofia), over 40 per cent of Director and top Management post holders are female; this ratio is 35 per cent at HSE (part of Hamburg Wasser) and falls below 30 per cent at KCCA, Kampala.

Figure 31: Global Mapping — gender staff ratios in mandates service authorities

Note: Figures relate to total number of staff within the mandated authority.
Source: Reported figures from service authorities.

Recommendations

- Clarify institutional mandates for wastewater and faecal sludge management at every step of the sanitation service chain. In low-income contexts, the service jurisdiction of mandated sanitation authorities must include informal settlements and peri-urban areas.
- Ensure mandates provide clarity on who is responsible for ensuring different elements of the sanitation service chain. Where this is not the case, significant progress can be achieved through active processes of review and reform to rationalize responsibilities across the sanitation service chain.
- Ensure formal legal mandates and actual practice are aligned.
- Integrate responsibilities for sewered and onsite sanitation where possible. This is particularly recommended where there is a commercial utility with existing responsibility for sewered sanitation.
- Consider simplified sewer systems as a viable sanitation option for densely populated, low-income settlements with existing trunk sewer infrastructure.
- Ensure sewered service extension is accompanied by robust strategies to ensure demand creation and low-income customer uptake of connections to the network.
- Promote gender mainstreaming in sanitation through transparent channels on promotion and salary structures, enforced government mandates on gender representation, and developmental leadership and training.
- Gender considerations should create space for women to participate in the service delivery model beyond 'soft tasks'.
- Promote intersectoral coordination to ensure sanitation improvements are integrated into wider slum upgrading programmes.

6.5 Case Study: Ouagadougou, Burkina Faso — extending sanitation services to informal settlements

Political will to improve living conditions in the informal settlements of Ouagadougou is increasing. A national strategy for upgrading informal settlements has been developed, as part of the review of the national urban policy. The review was prompted by the Saaba informal settlement upgrading project, which led to the provision of integrated basic services such as running water, sanitation, electricity, and passable roads. This case study draws lessons from the Saaba pilot project for clarifying responsibilities and improving wastewater and faecal sludge services at citywide scale, including in informal settlements.

Table 4: Summary of key data for Ouagadougou city

Demographics	Population in Ouagadougou city*	2,453,496
	Population Density**	90.3 / KM2
	Low-income area (LIA) population	809,654 (33% of Ouagadougou's population)
Water and sanitation services	Water network coverage (%) connections	99
	Sewerage coverage (%)	0.4
	Dependent on onsite sanitation (%)	96.3
	Access to improved containment (%)	46.2
	Dependent on shared facilities (%)	6.7
	Wastewater treated (%)	18
	Sludge treated (%)	36 - 38
Institutional arrangements	Policy making and regulation	Ministry of Water and Sanitation (MEA)
	Planning	Office National de l'Eau et de l'Assainissement (ONEA) (public utility)
	Service provision	▪ ONEA (sewer services, construction of toilet facilities, WWTP and FSTP operation) ▪ Private service providers (emptying and transport, construction of toilet facilities)

Source: All data based on ONEA reports unless otherwise specified.
** Source: RGPH, 2019 (General Census of Population and Housing)*
*** Source: Ibid.*

The issue of informal settlements in Ouagadougou

According to the latest population census conducted in 2019, the city of Ouagadougou has a population of 2,453,496 inhabitants – 12 per cent of the population of Burkina Faso and 45.4 per cent of the country's urban population – distributed in both formal and informal settlements (RGPH, 2019). The city is 80 per cent formal settlements and 20 per cent informal settlements (SEKPE, 2019).

Informal settlements in the Ouagadougou context are not structured settlements (not shown in the cadastral plan), occupied outside the official rules for acquiring housing land and in the absence of official land tenure. Access to land is achieved through negotiations with customary owners, but this procedure is not formally recognized by urban authorities. The proliferation of informal settlements in Ouagadougou is the result of a housing crisis and rapid population growth.

View of an informal settlement in Saaba, Ouagadougou city © Authors

The spatial organization of these informal settlements does not follow geometrical forms. In addition, housing is not planned and there is no formal piped water network nor electricity supply, roads or sanitation. Public education or health facilities are generally lacking.

These areas are located on the city margins, on the edge of formal areas, and are marked by anarchic and unsustainable construction, and very difficult accessibility, especially during the rainy season. There are wide disparities in the living standards of informal settlement populations, with many living below the national poverty line but others more well-off.

National policies and strategies for sanitation service provision to informal settlements

Burkina Faso is committed to the SDGs on access to adequate and sustainable water and sanitation services for all people by 2030. It is, to date, the only French-speaking country in West Africa to have integrated access to water and sanitation as a national ambition into its constitution (article 18 of the constitutional law n°072-2015/CNT revising the constitution of Burkina Faso).

Burkina Faso has national policies on access to sanitation for all, confirming the political will to address the issue at national scale. A national investment programme is in place for the period 2016-2030, which includes clear plans for sanitation.

Historically, there has been no specific strategy to address sanitation in informal settlements. The Ministry of Housing, Urban Planning and the City have now initiated a project for the restructuring of informal settlements (one of its development strategies). The project was launched in 2021 and will be focused on Djikofè district in the Saaba commune for its pilot phase. This project intends to confer informal settlements the structure of an urbanized area to facilitate projects implementation, including sanitation improvements.

ONEA's mission concerns urban centres with a population of more than 10,000 inhabitants. **Its willingness to take spontaneous areas into account in the development of water and sanitation services is summed up by the use of the concept of "Urban Agglomeration" instead of "Urban area".** According to ONEA's Director of Sanitation, the urban agglomeration concept also takes into account the populations of informal or spontaneous settlements.

Initiatives for extending sanitation services to informal settlements

Several initiatives have been implemented to extend sanitation services in informal settlements. Some of the prominent ones are presented below.

The PERISAN project which is a sustainable sanitation initiative implemented from 2012 to 2016 to improve the living conditions of the populations of five informal settlements and 16 peripheral sectors of Ouagadougou. This project was developed by WaterAid (International NGO) in collaboration with Eau Vive (African NGO), ONEA and the Ouagadougou City Council, with funding from the European Union of 2.1 billion XOF. The implementation approach was to subsidize some elements of household latrines. An innovation competition led to the choice of a latrine model adapted to informal settlements and easily accessible. The "LILI latrine" consists of a metal cabin, offering households the possibility of moving the slab and cabin in case of a house move. PERISAN incited a strong demand for latrines.

Historically, a key issue affecting sanitation service provision to informal settlements in Ouagadougou has been unclear and overlapping mandates.

Following the experience with PERISAN, ONEA embarked on a plan to extend sanitation services to informal areas with its own funds, by delegating the services to private providers. The private providers' job is to encourage households to build a latrine (one of ONEA-promoted technologies). The service provider is remunerated by ONEA with 5000 XOF per latrine built. Discussions are underway as this amount was deemed insignificant by the private providers.

ONEA is working in collaboration with BASED (a design office for the promotion of sanitation in the urban environment) to extend sanitation services to new informal settlements. The aim is to target areas outside the five settlements already receiving support.

Another initiative has been underway since 2021 with support from KfW (German cooperation). Through budgetary support, KfW is assisting ONEA in the extension of water and sanitation services to all informal (peripheral) neighbourhoods throughout Burkina Faso, with a focus on the 14 other cities outside Ouagadougou and Bobo Dioulasso.

The clean manual emptying (VIMAPRO) project was an initiative led by Réseau Projection from 2015 to 2017 with the aim of formalizing manual emptying in Ouagadougou. It was implemented through capacity building of manual emptiers. The project has contributed to a better recognition of manual emptying, which is common in both informal and formal areas. It has led to an improvement in emptier' practices. Through the initiative, the association of emptiers, ABASE is recognized as a major actor in the sanitation sector: at the national level, it is involved in a large number of activities on sanitation where manual emptiers' voice is represented.

Clarifying responsibilities for serving peri-urban areas and informal settlements

Historically, a key issue affecting sanitation service provision to informal settlements in Ouagadougou has been unclear and overlapping mandates. ONEA is responsible for sanitation access in urban areas and DGA is responsible in rural areas. But until recently, there was a lack of clarity on responsibilities for peri-urban areas (and informal settlements). In this context of unclear mandates, collaboration between actors for addressing challenges in providing sanitation services in informal settlements was poor.

Uncontrolled faecal sludge deposit in Ougadougou © Authors

ONEA now has clear responsibilities for all urban areas (of 10,000 people or more), and is responsible for ensuring access to sanitation services in informal settlements that are part of the "urban agglomerations". Since ONEA has been officially recognized as responsible for coordinating sanitation services delivery in informal settlements, there has been a better organization and interest from different actors to achieve this. Several partners (support structures) such as WaterAid, the European Union, GIZ, etc. have joined ONEA to bring their contributions (financial and technical) to the extension of sanitation services in the informal settlements.

In practice, as soon as an informal settlement is identified for benefitting from water and/or sanitation services, ONEA appoints a contractor who will interface between the population and the service authority. This contractor – who lives in the area – must create a close relationship with the whole community, and find means and strategies (e.g. organizing awareness campaigns) to encourage voicing needs for sanitation services. The contractor reports the community's needs to ONEA, which discusses them with partners to provide options tailored to the community.

Model of sanitation and wastewater management services adapted to informal settlements

Due to the instability and rate of change in informal settlements, extending the sewerage network in these areas will be difficult. Onsite sanitation systems are better adapted (technically and economically) to the informal settlements of the city of Ouagadougou.

The municipality must ensure informal settlements are mapped in a continuously updated manner. This updated map will be the only way to better plan the extension of any type of service to informal settlements. ONEA will then be able to proceed with the identification of contractors in all these areas, as was the case in past initiatives with the five informal settlements of the city. Contracts should be established with these contractors to motivate them to promote sanitation services in these areas. ONEA must also broaden its partnerships in order to subsidize these populations (generally poor) to build their own sanitation facilities.

On the technical level, ONEA, in collaboration with delegated authorities must continue to promote the "LILI" latrines developed under the PERISAN project led by ONEA and WaterAid among those living in informal settlements. The particularity of these toilet models is that superstructures and slabs can be dismantled in case owner households have to move. For enhanced follow-up, it will be necessary to geolocate each toilet built and to keep the geolocation data in a database at ONEA. For the emptying and transport of these pits, ONEA can collaborate with ABASE (the association of manual emptying workers in Burkina Faso) to provide training in manual emptying and sanitation to local people in informal settlements who will provide the services. To protect against uncontrolled dumping, these emptiers also need access to FSTPs that are both within reach and adapted to the characteristics of the sludge emptied and to their means of transportation.

Manual emptiers with improved equipments
in Ouagadougou © Authors

07

Accountability

CHAPTER IN BRIEF

Regulation is core to a public service approach to urban sanitation. Key regulatory functions include setting tariffs for wastewater services, creation and enforcement of national treatment standards, and license issuing and discharge permits for wastewater and treatment plants. Without these functions, mandated authorities cannot be held acountable, for the services they provide, and citizens and ecosystems lack protection from public health and environmental risks posed by inadequate treatment. In this chapter, we first outline how responsibilities for regulating wastewater and faecal sludge management may be structured, including key regulatory models at the global level, drawing on examples from the global mapping. We then explore key tools available to regulatory agencies involved in the economic and environmental regulation of sanitation services. The analysis shows:

- There is wide variation in regulatory models across regions. In the African context, regulation by agency has been associated with a higher number of regulatory mechanisms and higher-performing regulation, and autonomous regulators have also been prominent in driving processes of sector reform. In Europe and Latin America, autonomous agencies have a key role in the economic regulation of sewered services.
- All focus countries have developed environmental regulations for discharge of wastewater effluent. There is a gap in the development of environmental regulations for faecal sludge treatment and discharge.
- Public benchmarking of service provider performance against defined key-performance indicators is a core regulatory tool in Europe and Latin America, and should be adopted more widely.
- Many regulatory authorities in LMICs, and some in HICs, lack the capacity to conduct spot checks to verify reporting on the quantity and quality of wastewater and faecal sludge treated.
- The importance of effective regulation, coupled with current capacity gaps, highlight the need for greater human and financial resource allocation in this area, including to the development of supporting data management systems.

7.1 Responsibilities for regulating urban sanitation

In several countries, water sector reforms have established regulators to professionalize the sector and reverse deteriorating performance in service provision. Regulators (whether by agency, ministry or contract) have a critical role in holding mandated service providers to account for sewered and onsite sanitation service provision, including wastewater management. In addition to supporting the definition of clear responsibilities for service authorities, regulators must ensure the clear setting of sanitation standards via national laws and municipal by-laws (Franceys and Pezon, 2010; ESAWAS, 2021B).

Regulation by agency was the predominant model for water supply and sanitation in 20 African countries, relative to 15 countries where regulation by contract predominates; and 18 countries where ministerial regulation predominates.

A distinction is commonly reflected between responsibilities for A) economic and service quality regulation; and B) environmental regulation. Figure 33 presents an illustrative mapping of responsibilities for regulating sewered and onsite sanitation, demonstrating significant variance in regulatory models; however, responsibilities are generally divided across multiple ministries and agencies.

In Sub-Saharan Africa, a major barrier to improvement has been the requirement for municipalities to act both as service provider and the enforcer of regulations (Franceys and Pezon, 2010). This has resulted in widespread ineffectiveness due to these dual roles often leading to conflict of interest (Franceys and Pezon, 2010). In other countries in the region, independent regulatory authorities have adopted responsibility for regulating the economic and service quality dimensions of wastewater management, supported by environmental authorities with responsibility for setting and enforcing standards relating to the discharge of treated effluent.

In the Eastern and Southern Africa region, Kenya, Tanzania and Zambia offer strong examples of rationalized institutionalized frameworks for regulating sewered and onsite sanitation. In these instances, there are autonomous regulatory entities — WASREB, EWURA and NWASCO respectively — with responsibility for economic and technical regulation; and national-level environmental authorities with specific roles in environmental regulation. Kenya, Tanzania and Zambia have seen recent revisions of service provision mandates for onsite sanitation, integrating responsibilities for sewered and onsite sanitation within commercial utilities (see **Chapter 5**), and this has been accompanied by the required revisions in regulatory responsibilities. In Kenya, WASREB has established a sanitation department to extend purview into OSS in response to a 2018 Executive Order. In Zambia and Tanzania, NWASCO and EWURA respectively, are providing capacity development support to utilities as they respond to their enhanced mandate.

In West Africa, potentially significant change is underway in Mali, where a new sanitation policy is being formed. Reforms under consideration include the creation of an independent regulatory agency for sanitation, alongside new agencies responsible for financing and managing treatment plants respectively. The regulator would adopt responsibility for oversight of wastewater treatment as well as faecal sludge emptying services (solid waste management may also be integrated) (WHO, forthcoming).

7.2 Models for Regulation

There are three main models by which regulation can be instituted: i) **regulation by agency**, in which a regulatory body (semi-) autonomous from the government has discretionary powers to regulate water and sanitation services); ii) **regulation by contract**, where a public entity other than a (semi-) autonomous regulatory agency and a service provider agree on contractual clauses determining how key aspects of WSS service provision are defined and controlled, such as tariffs and service standards; and iii) **ministerial regulation.**

In the African context, regulation by agency has been associated with a higher number of regulatory mechanisms and higher-performing regulation. A continent-wide mapping of the water supply and sanitation regulatory landscape across Africa, focused on water and sanitation service delivery, contrasted regulation by agency favourably with other models common across the region — namely regulation by contract, ministerial regulation and self-regulation (ESAWAS, 2022).

There remains wide variation in regulatory models across Africa, both continent-wide and within regions. Regulation by agency was the predominant model for water supply and sanitation in 20 African countries, relative to 15 countries where regulation by contract predominates; and 18 countries where ministerial regulation predominates (ESAWAS, 2022). Regulatory frameworks for onsite sanitation in particular are frequently fragmented, with different players responsible for different regulatory requirements along the sanitation service chain.

In Europe, autonomous regulatory agencies may have a key role in the economic regulation of sewered services. Examples of autonomous regulators within the European region include the Energy and Water Regulatory Commission (Bulgaria), the Water Services Regulation Authority –

Ofwat (UK), the Hungarian Energy and Public Utility Regulatory Authority, and the Water and Waste Services Regulatory Authority – ERSAR (Portugal).

Considerable variance can again be observed in the predominant regulatory model across Europe. In Paris for example, the Greater Paris Sanitation Authority (SIAAP) essentially self-regulates its role as the mandated service authority, as it drives contract regulation with private operators, though SIAAP itself acts under the control of its board (consisting of local authorities) and multiple ministries and public agencies. In Serbia, tariffs for sewered services are self-determined by service providers, with no national system in place. In Hamburg, economic regulation is performed by the Free and Hanseatic City of Hamburg-Ministry for Environment, Climate, Energy and Agriculture (BUKEA).

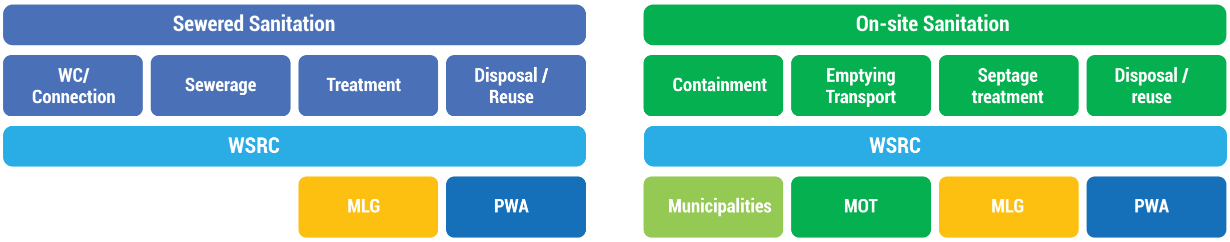
In Latin America as in Europe, sanitation regulation may be decentralized to the state level. In Argentina for example, 16 regulatory agencies operate across 24 provinces, with the largest, Water and Sanitation Regulatory Entity – ERAS, responsible for economic regulation of sewered services for Buenos Aires and 26 surrounding municipalities, covering a population of 14 million people. In Medellin, economic regulation for sewered services is performed by the national-level Water Regulatory Commission, with environmental regulation decentralized to Corantoquia, the regional environmental corporation.

In South Asia and South-East Asia, cases of autonomous regulatory agencies are less common, with economic regulation performed by local governments or through ministerial regulation. Of the six cities from these regions included within the study, no cases were identified of regulatory agencies with involvement in economic regulation (see Table 5). In Hatyai City for example, the municipality regulates tariffs for all sanitation and wastewater management services; similarly in Trichy, the City Corporation is responsible for economic regulation across

Table 5: Mapping of authorities with responsibilities for economic regulation of urban sanitation services

	Autonomous Regulatory Agency	Water Authority	Local Government	Self-regulation	Ministry
Bandung, Indonesia					X
Changunarayan, Nepal			X		
Dar es Salaam, Tanzania	X				
Dhaka, Bangladesh					X
Hamburg, Germany					X
Hanoi, Vietnam					X
Hatyai City, Thailand			X		
Lome, Togo					X
Medellin , Colombia	X				
Nakuru, Kenya	X				
Ouagadougou, Burkina Faso					X
Penjikent, Tajikistan				X	X
Sofia, Bulgaria	X				
Trichy, India			X		
Kampala, Uganda			X		
Dioïla, Kaladougou, Mali					X
Paris, France				X	
Amman, Jordan		X			

Figure 32: Responsibilities for regulating sanitation in Palestine



Five authorities have meaningful roles in regulating onsite sanitation (OSS). Municipalities have a role in enforcing containment standards for OSS; the Ministry of Transport (MOT) is responsible for issuing licenses to Vacuum Tank Operators; the Ministry of Local Government (MLG) has a role in approving treatment facilities; and the Palestinian Water Authority (PWA) has a role in enforcement of standards around discharge of treated effluent. The Water Sector Regulatory Council (WSRC) has a key monitoring role across the service chain. Source: WHO, forthcoming.

the sanitation service chain, although the State Government also has a role to play. In Bandung and Hanoi, these functions are performed at the ministry level. A notable exception outside our sample is Malaysia, where the National Water Services Commission (SPAN) acts as the national regulatory body for sewered services.

In some countries, multiple ministries may have a role to play within regulating onsite sanitation alone. An illustrative example is provided in the case of Palestine (Figure 32), where an autonomous regulatory agency, Water Sector Regulatory Council (WSRC), is supported by Ministries of Transport and Ministry of Local Government; and by the Palestinian Water Authority. In Jordan, the Water Authority has a different role, as the mandated authority responsible for tariff setting.

7.3 Complementing accountability roles for sanitation

Across regions, environmental authorities have a critical role to play in setting, monitoring and / or enforcing standards on disposal and reuse of treated wastewater effluent. In Medellin for example, Corantoquia, the regional environmental corporation, is in charge of enforcing national environmental standards, including discharge parameters, odours and biosolid standards. In Hamburg, environmental regulation is performed by the Free and Hanseatic City of Hamburg-Ministry for Environment, Climate, Energy and Agriculture (BUKEA). In Tanzania, the National Environmental Management Council has a role in enforcement and compliance monitoring of effluent discharge standards; similarly in Kenya, the Water Resources Authority (WRA) monitors compliance for effluent discharged to water bodies, supported by the National Environment Management Authority (NEMA), which both sets effluent and treated faecal sludge quality standards and enforces compliance (the regulator WASREB is involved across the sanitation service chain, with responsibility for regulating the treatment process). In Zambia, the Environmental Management Authority (ZEMA) has responsibility for monitoring compliance with standards on faecal sludge disposal and reuse, which are set by the Bureau of Standards.

In South Asia and South-East Asia, environmental regulations and standards may commonly be developed at the ministry level, with enforcement devolved to municipalities. This model applies to Changunarayan and Dhaka in South Asia; and to Hatyai City, Thailand, where the Ministry of Natural Resources and Environment (MONRE) is responsible for the development of environmental regulations and the municipality for enforcement. Similarly in Hanoi, the Vietnamese MONRO develops national standards for wastewater effluent quality, with Hanoi Department of Natural Resources and Environment (DONRO) providing guidance and overseeing implementation in collaboration with Department of Planning and Investment, Department of Agriculture and Rural Development (DARD). In Trichy, the National Green Tribunal and Tamil Nadu Pollution Control Board, at the state level, and the City Corporation all have roles in environmental regulation.

There are varied roles for Ministries of Health across regions, ranging from a

Table 6: Mapping of authorities with responsibility for environmental regulation of wastewater and faecal sludge management

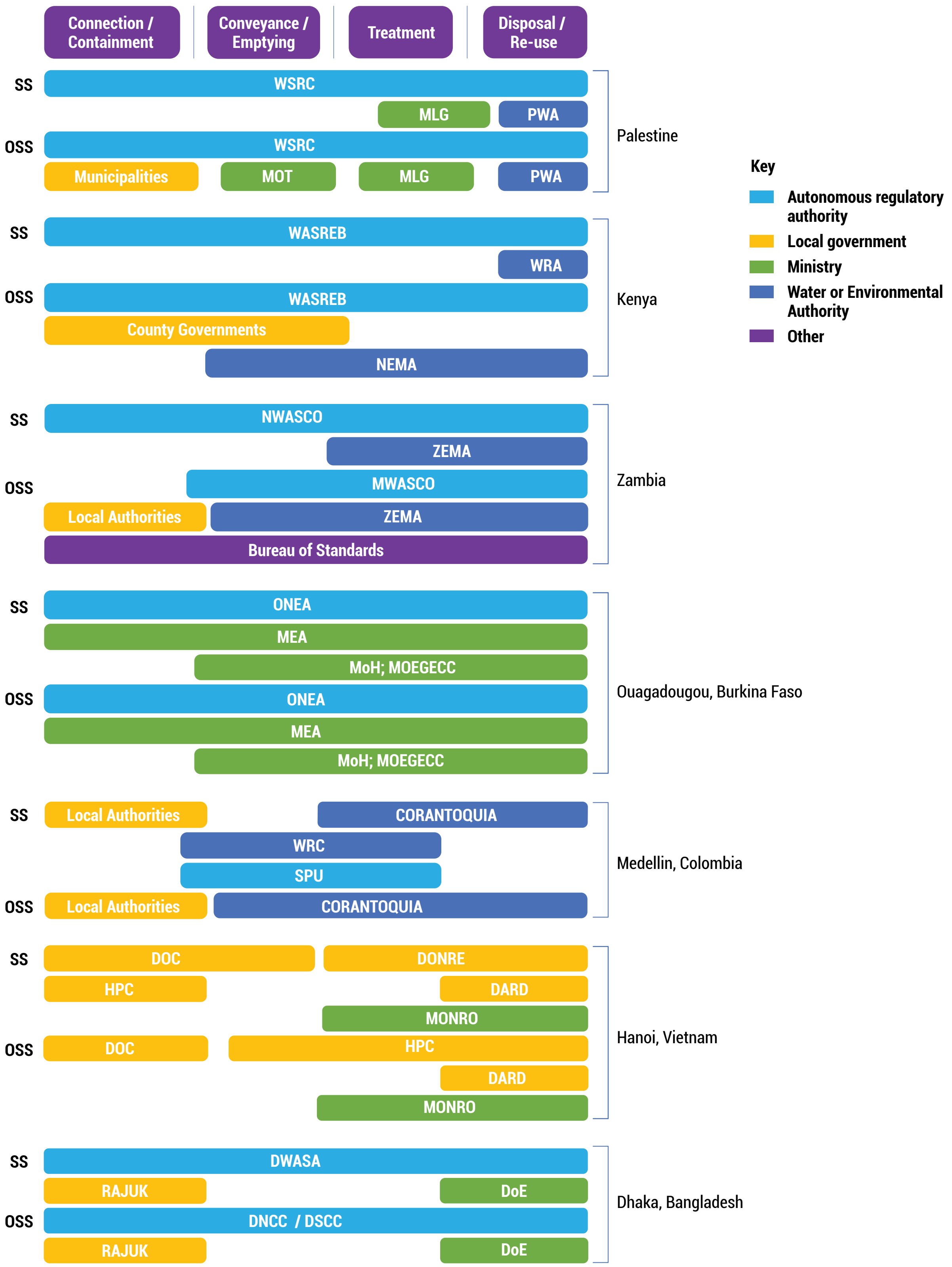
	Autonomous Regulatory Agency	Enviromental Authority	Water Authority	Local Government	Ministry / Ministries
Bandung, Indonesia					X
Changunarayan, Nepal				X	
Dar es Salaam, Tanzania		X			
Dhaka, Bangladesh				X	X
Hamburg, Germany					X
Hanoi, Vietnam				X	X
Hatyai City, Thailand				X	X
Lome, Togo					X
Medellin, Colombia		X			
Nakuru, Kenya	X	X	X		
Ouagadougou, Burkina Faso	X				X
Penjikent, Takikistan				X	
Sofia, Bulgaria					X
Trichy, India		X		X	
Kampala, Uganda		X		X	
Dioïla, Kaladougou, Mali					X
Paris, France				X	X
Amman, Jordan					X

defined role in drinking water quality protection or environmental surveillance to chief regulatory oversight of sanitation services. In Mali there is collaboration between MoH and wider ministries on water source protection from pollution caused by poor sanitation, but responsibilities of MESSD and MoH frequently overlap. While there is no formal institutional mechanism to promote collaboration, steps have been taken, including the formation of steering committees involving representatives from both ministries. Similarly in Kenya, WASREB are exploring a collaborative framework with MoH to guide how the two institutions will interact, with focus on sanitation, including regulatory aspects (WHO, forthcoming). A contrasting approach is seen in Zambia, where public health aspects of sanitation regulation are delegated to local governments, which are active in enforcing emptying of pit latrines and septic tanks, notably in Lusaka, to protect against the spread of waterborne disease.

African school girl drinking safe water from a tap

Regulatory authorities play a critical coordinating role in convening institutional stakeholders to develop consensus on regulatory responsibilities. In Zambia the regulator NWASCO has led a long-term process of OSS sector reform which offers valuable lessons for countries now tasked with developing sanitation regulation from a low base point. Subsequent to an initial legal review, a key step in Zambia was the development of a new regulatory framework for onsite sanitation and faecal sludge management. Significant progress has also been made in Mozambique, where AURA, IP have expanded their responsibilities for regulating onsite sanitation, underpinned by the development of a revised regulatory framework.

Figure 33: Illustrative mapping of regulatory responsibilities across the sewered and onsite sanitation service chains



7.4 Accountability mechanisms

Key regulatory mechanisms relating to wastewater management include the creation and enforcement of national treatment standards, licensing permits for wastewater treatment plants and discharge permits. As argued by UN-Habitat and WHO (2021), there is an urgent need to strengthen regulatory mechanisms for all sources of wastewater, and to carry out monitoring and enforcement of local service providers and industry to drive improvements for both treatment and monitoring.

Enforcement of regulations and standards for industrial wastewater treatment is a key challenge, although there are examples of strong active oversight in the European Region.

Legislation, regulations and standards

In Europe, European Union legislation provides an overarching framework for environmental regulation of wastewater, through the Urban Wastewater Treatment Directive. The 1991 directive, which is currently under revision (see **Chapter 9**), makes it compulsory that all agglomerations with more than 2,000 inhabitants in EU member countries are equipped with systems to collect and process wastewater.[8]

In Africa, significant progress has been made in developing standards for environmental protection. In a recent mapping across 54 African countries, 100 per cent were found to have developed such standards, while 85 per cent had developed guidelines for quality of service (ESAWAS, 2022). The systematic development of sanitation standards via national laws and municipal by-laws, in countries such as Zambia, has a positive impact (Franceys and Pezon, 2010).

All focus countries within our sample developed environmental regulations for discharge of wastewater effluent. Our mapping suggests a gap in the development of environmental regulations for faecal sludge treatment and discharge. Although locations within our sample uniformly had a designated authority responsible for environmental regulation of faecal sludge treatment, this is yet to translate into the development of connected regulations in Togo and Mali.

Weak enforcement of containment standards is an issue across regions. In Africa, it is common for municipal bylaws around the quality of the sanitation facility, and around the requirement to empty, to be inadequately enforced – a situation which has been linked in the literature to the impossibility of enforcing containment structures which may be unaffordable to low-income customers (ESAWAS, 2021b). In cities such as Dhaka in South Asia, a very different but widespread issue is the practice of connecting toilets and septic tanks to open drains, including by high-income residents, discharging large volumes of untreated effluent directly into the drainage (see Dhaka case study).

Enforcement of regulations and standards for industrial wastewater treatment is a key challenge, although there are examples of strong active oversight in the European Region. In Palestine, industrial wastewater treatment is not properly regulated: there are rules which state industries should follow pre-treatment, and a utilities by-law has clarified the mandate, giving clear procedures for industries to connect to the network — but enforcement is unclear. Similarly in Buenos Aires, there are high levels of compliance with the regulatory framework for wastewater treatment, but only 30 per cent compliance with standards for industrial discharge (WHO, forthcoming). Netherlands has been cited as an example of clear responsibilities for regulating industrial wastewater, with well-defined roles for UVW (Association of Water Authorities), Water Boards and Municipalities (ibid).

Key-performance indicators and public benchmarking

Strengthening transparency is viewed as fundamental for accountability, and a relatively easy win. ESAWAS argue that regardless of the institutional structure, there should be collection and transparent publication of detailed data on sanitation service levels and service quality. Collecting and publishing detailed data on sanitation service quality, with specific metrics for low-income areas, has been framed as a core requirement for accountability (ESAWAS, 2021b). This in turn requires due prioritization, and resource allocation, to the development of strong data management systems supporting ongoing monitoring (see Chapter 8).

8 Available at: https://ec.europa.eu/environment/water/water-urbanwaste/legislation/directive_en.htm. Accessed 12th December 2022.

Licensing is a robust accountability tool often deployed by regulatory authorities across the sanitation service chain.

Public benchmarking of service provider performance against defined key-performance indicators (KPIs) is a core regulatory tool in Europe and Latin America. In Buenos Aires, ERAS have implemented a benchmarking system since the late 1990s, inspired by the OFWAT (UK) system. This approach has now been diffused through ADERASA with World Bank support. ERAS are strong proponents of this approach, stating "the most effective tool is publishing the information".[9] In Medellin, there is limited benchmarking relating to volume of wastewater treatment and sewerage connections. Within Europe, in Portugal, ERSAR publishes data annually on service provider performance against 16 KPIs encompassing wastewater, water and waste management; while in Netherlands, data is publicly available on Water Board performance in areas including wastewater treatment. In Sofia, EWRC, the Energy and Water Regulatory Commission, publishes annual corporate benchmarking reports.

These reports have a "naming and shaming" function in highlighting poor performance; but no less importantly, the reports serve to generate positive incentives by highlighting good performance. In Eastern and Southern Africa, WASREB (Kenya) publishes a detailed "Impact" report annually, aiming for full public transparency around service provision by different utilities. Similarly in Zambia, NWASCO produces detailed annual sector reports with comparative performance ranking of the country's commercial utilities (CUs). In Palestine, WSRC produces published reports documenting good and bad practice, described by WSRC as "a shaming *and* appreciation list…it's about public recognition".[10] NWASCO also embrace trophies, cash prizes and corporate recognition to accompany high performance in the benchmarking process. Reputational incentives have been underutilized across Africa as a whole, with greater emphasis on sanctions and other punitive measures (ESAWAS, 2022).

Key performance-indicators should explicitly consider pro-poor services provision. Pro-poor regulatory guidelines for reaching the most vulnerable with water and sanitation services were identified as an area for improvement across Africa (ESAWAS, 2022), and hard incentives for pro-poor sanitation service provision are rare. Here a notable development is in Kenya, where WASREB requires utilities to report levels of service to low-income urban areas. The pro-poor KPI includes overall coverage of sewered and onsite services, as well as overall mapping of the sewer network (WSUP, 2018).

Across our sample, mandated service providers provide regulatory authorities with regular reporting on the quantity and quality of wastewater and faecal sludge treated. However, spot checks to verify reporting may be lacking. Such checks are performed in Amman, Hamburg and Medellin, but appear to be rarer in the African region, with Nakuru a notable exception. Checks may be performed for wastewater treatment but not for faecal sludge (as in Dhaka). Across regions, including in Europe and Latin America, environmental regulators may lack the capacity to conduct independent audits of service provider performance.

Licensing

Licensing is a robust accountability tool often deployed by regulatory authorities across the sanitation service chain. In Eastern and Southern Africa, the tool has notably been deployed to drive through expansion of service authority responsibilities. Licensing can serve as the entry point for enforcing regulations — as in Kenya, where through their jurisdiction to grant or withdraw licenses to water service providers (WSPs), WASREB has been able to push these utilities to incorporate onsite sanitation within their mandate. In Zambia, NWASCO has developed guidelines on licensing requirements for CUs, approved by the NWASCO Board but still to be fully implemented. If the utility fails to comply with regulations they are placed under special supervision, with the license then suspended and a statutory manager engaged if there is no sign of improvement. NWASCO has demonstrated their willingness to take this measure where required, having suspended a CU license twice in the past year (WHO, forthcoming). In Trichy, private desludging operators must renew their license to provide services with the City Corporation annually.

In Europe, licensing is a fundamental tool for regulating wastewater treatment. In Portugal for example, the Portuguese Environment

9 Alejo Molinari, ERAS, quoted in WHO, forthcoming.
10 Mohammad Al Hmaidi, WSRC, quoted in WHO, forthcoming.

Biologists collect sample of waste water from industry for inspection © Shutterstock

Agency issues discharge permits for wastewater treatment plants and applies penalties in cases of non-compliance. In a forthcoming study, licensing was also mentioned as a key accountability tool by respondents from Hungary and Netherlands, in the context of operators failing to meet treatment standards for effluent discharge (WHO, forthcoming).

Performance contracts

Performance contracts can be a regulatory tool for oversight of utility performance in sewered services provision. In Medellin, service-level agreements structure the engagement of EPM with sewered services, with all investments and interventions requiring approval by the municipality. In an example of ministerial regulation by contract, in Uganda, NWSC signs performance contracts with the Ministry of Water and Environment.

For onsite sanitation, contracts are also emerging as a useful tool for ensuring accountability of private sector service providers. Formal contractual arrangements are in place between mandated authorities and private providers of pit and septic tank emptying services for multiple cities in our sample, including Ouagadougou, Diolia, Bandung, Hanoi and Nakuru. In Kenya, WSPs have the exclusive mandate for service provision, but are able to engage private sector operators through performance contracts which issue the level of service offered by the private sector partner. More widely, in Senegal, the National Sanitation Office, ONAS, is looking to stimulate private sector engagement in sanitation structures through contracts; while in Zambia, Commercial Utilities can enter into service agreements with the private sector, but must first gain consent from NWASCO, with third parties answerable both to the utility and the regulator. Embedding clear tasks or even performance indicators – making the private sector remuneration partly performance-based – can help strengthen the efficiency of services (Box 21).

Box 21: Examples of contracting the private sector for FSTP and WWTP management

Clear and detailed tasks and/or KPIs should be embedded in all contracts with service providers. They can serve as performance benchmark in service or management-type contracts, or even in longer lease or concession contracts. KPIs can also be used to design a performance-based remuneration system, whereby the operator is remunerated (in parts) only if KPIs are achieved. Examples of contracts, detailed tasks and KPIs are presented below.

Detailed operational tasks in Dioila lease (affermage) contract. In Dioila (Mali) GIZ supported a inter-municipal structure gathering municipalities of several communes (situated west of Bamako) when entering a lease agreement with a private operator for the operations of an FSTP. The FSTP, of a capacity of 10m3 per day, was constructed with support from GIZ (for a total cost of USD 350,000) and in 2021 put in an operation. The contractor also operates one truck and is in charge of emptying latrines and septic tanks before transporting the sludge to the FSTP. The contract sets the price for these services (between FCFA 15,000 and 20,000 depending on the distance), paid by service users and which constitute the main source of revenues for the operator. Another source of income is the sale of crops grown using compost from the faecal sludge. The 5-year contract also clearly embeds tasks for the operator to perform when operating the FSTP. Among these, the contract includes: controlling all faecal sludge entering the facility, checking its quality to ensure it doesn't contain components that can harm the composting process and moving the dewatered sludge to drying beds, etc.

KPIs in performance-based contracts. There are examples of contracts where the private operator is remunerated, at least in part, based on the performance of treatment plants they operate. Such examples include Design-Build-Operate contracts in which one contractor is in charge throughout the project lifecycle. In such contracts private operator risks are minimized by removing all demand-side risks: the private operator is paid by the government or local government based on a pre-agreed schedule. Payment is carried out partly based on achievement of KPIs, which may include:

- Wastewater effluent to the recipient water body—compliance with discharge standards (BOD5, COD, SS, etc.)
- Wastewater treatment capacity (in m3/day, with daily and/or seasonal peak demands to be met, etc.)
- Power consumption (per m3 of treated water)/efficiency
- Chemical consumption (per m3 of treated water)/efficiency
- By-products—sludge quantity, sludge dryness contents, etc.
- Noise and smell/odor nuisance levels

In Thailand, Hatyai City provides an alternative accountability model for wastewater services, with a dedicated working group on wastewater management established within the municipality to oversee performance. The working group monitors the Wastewater Management Authority, which is obliged to provide reporting on wastewater management performance to the municipality on a quarterly basis.

Relating to wastewater and faecal sludge treatment, a phased approach to penalties is a common response to non-compliance. Financial sanctions may be deployed across regions where operators are found to be in breach of discharge permits and effluent standards are not met.

Effective accountability must be bottom-up as well as top-down. Recognizing this need, WSRC have developed an "exposure plan" to engage the public and raise awareness of duties and rights relating to sanitation and wastewater, supported by a social media, radio and television campaign. This will be further supported by the development of a new public complaints system relating to water and sanitation services (WHO, forthcoming). Within our sample, Trichy provides an example of robust mechanisms for registering and resolution of customer complaints, which must be addressed within 15 days.

Regular citywide surveys of residents' satisfaction with basic services can make a strong contribution to accountability, and can be delivered at relatively low cost. Here the Asivikelane initiative in South Africa provides a notable example: the initiative surveys residents of informal settlements across multiple cities, and publishes service level data in tandem with municipal budget data, to help advocate for improved accountability in municipal services and public finance (ESAWAS, 2021B).[11]

11 See also IBP (2020) Voices of South Africa's Informal Settlement Residents during the COVID-19 Crisis. International Budget Partnership. https://www.internationalbudget.org/ covid-monitoring/

Recommendations

- Establish the current legal basis for service regulation. A critical first step for countries looking to strengthen sanitation regulation is to conduct a detailed legal review, to clarify what agencies are responsible for regulating which aspects of sanitation services, and any gaps or overlaps in mandates.
- Ensure a strong legal framework is in place which can support independent regulation, free of political interference, focused on service standards, water and sanitation coverage and utilities performance management.
- Ensure greater focus on the monitoring and enforcement of regulations and standards for faecal sludge treatment, disposal and reuse. This in turn requires much greater allocation of human and financial resources to regulation in LMICs.
- Support the development of risk-based regulation prior to monitoring and enforcement.
- Introduce public benchmarking of service provider performance across sewered and onsite sanitation, including wastewater and faecal sludge treatment.
- Incorporate positive reputational incentives into existing benchmarking structures.
- Ensure greater focus on accountability mechanisms for pro-poor services provision — for example, integrate pro-poor KPIs into public benchmarking.
- Ensure closer attention to enforcement of containment standards. This will often require prior clarification of responsibilities for enforcement, and in some cases the development of improved standards, which should be developed taking into account evidence on costings and the relative health and environmental impacts of potential containment options.
- Consider public contracting and repercussions for non-performance of private sector operators for pit emptying and septic tank desludging services.
- Support regular surveys of public satisfaction with basic services.
- Allocate financial and human resource to strengthening data management systems (see also Chapter 8).

7.5 Case Study: Dhaka, Bangladesh — coordinating wastewater and faecal sludge management in a mega-city context

Dhaka's population has multiplied 14 times in 50 years since 1971. The megacity is now the seventh most populous in the world with over 21 million residents. This case study explores the recent evolution of Dhaka's sanitation sector, including planned investments and recent reforms to the institutional and regulatory framework, which provide a basis for strengthening accountability and tackling the entrenched practice of discharging wastewater directly to open surface drains.

Table 7: Summary of key data for Dhaka city

Demographics	Population in Dhaka city	22,478,116
	Population density	23,234/KM2
	Low-income area population	12,385,441
Water and sanitation services	Water network coverage (%)*	100
	Sewerage coverage (%)**	20
	Dependent on onsite sanitation (%)***	80
	Access to improved containment (%)****	54
	Dependent on shared facilities (%)*****	49.6
	Wastewater treated (%)******	9.6
	Sludge treated (%)*******	0
Institutional arrangements	Policy making and regulation	▪ Department of Environment (setting standards for wastewater disposal) ▪ Dhaka Water Supply and Sewerage Authority (DWASA) (self-regulation of wastewater) ▪ Dhaka North City corporation (DNCC) and Dhaka South City Corporation (DSCC) (regulation of onsite sanitation)
	Planning	▪ DWASA ▪ DNCC and DSCC through their Department of Public Health Engineering ▪ Dhaka Urban Planning Department (RAJUK)
	Service provision	▪ DWASA (sewer services, WWTP and FSTP operations) ▪ Private operators (construction of toilets, emptying and transport)

* Source: DWASA
** Source: Ibid.
*** Source: Dhaka SFD, available at https://sfd.susana.org/about/worldwide-projects/city/4-dhaka#
**** Source: Ibid.
***** Source: Ibid.
****** Source: Hossain, Afid & Mahtab, Sania & Morshed, Abrar. (2018). Performance Evaluation of the Pagla Sewage Treatment Plant. International Journal of Current Research. 10. 75049-75060. 10.24941/ijcr.32890.11.2018.
******* Source: Dhaka SFD, available at https://sfd.susana.org/about/worldwide-projects/city/4-dhaka#

The Institutional Regulatory Framework for Faecal Sludge Management: a step-change in sanitation service delivery

In Dhaka, the significant step forward in sanitation management was development of the Institutional Regulatory Framework for Faecal Sludge Management (IRF-FSM) in 2017. Prior to the IRF, no authority was responsible for the management of faecal sludge, including enforcement of containment standards for onsite systems, stopping the direct connection of containment structures to surface drains, emptying and transportation of faecal sludge, and treatment and disposal or reuse of faecal sludge. The national-level IRF-FSM clarified responsibilities for the management of wastewater and faecal sludge generated from onsite sanitation facilities in different contexts.

Importantly, a separate IRF was developed for Dhaka, recognizing its unique status in Bangladesh as a megacity with specific contextual characteristics. The IRF-FSM for Dhaka clearly places responsibility for planning and implementation of FSM services with the City Corporations, including "proper execution of the entire FSM service chain". Significantly, the IRF makes CCs responsible for the management of wastewater produced from the slums or low-income communities, which fall under onsite areas.

The clarification of responsibilities for onsite sanitation under IRF have contributed to better positioning CCs to mobilise resources, seek investments, and structure institutional arrangements for management of faecal sludge across the value chain.

Clear mandates have led to onsite sanitation services improvement…

The IRF have led to clarifying responsibilities of CCs, with evidence of gradual improvements in service delivery. IRF placed responsibility for canal maintenance and enforcement against toilet connection to open surface drains with CCs. Since the formal handover of responsibility in December 2020, CCs have begun to clear the canals filled with solid waste, serve legal notice to those illegally using the canals, and to create awareness among property owners of the need to stop direct toilet connections to canals and open surface drains.

The origins of this issue are related to Dhaka's topography and lack of environmental regulation enforcement. The city is surrounded by rivers, wetlands, and canals. A significant amount of wetland has been lost due to urbanization since the 1980s, with rivers encroached and canals increasingly polluted. These natural instruments for draining rainwater and wastewater have been partially replaced by the planned drainage and sewerage networks. Most Dhaka slums are established adjacent to rivers and canals and are not connected to planned networks. Disposal of solid and faecal waste to these waterbodies

Figure 34: Canal in low-income community of Dhaka

became commonplace, with toilets often connected directly to canals and open surface drains. A recent study of sanitation options in low-income communities in Dhaka found this practice to be highly prevalent, with 71 per cent of toilets in the study areas discharging directly to drains (Foster et al, 2021).

Though responsible for wastewater management, DWASA was unable to play any significant role in regulating this practice. Reasons include: (i) DWASA is run by executives, not elected representatives, and mobilizing residents against this practice was challenging for DWASA, (ii) surface drains were heavily connected with the canals and the drains were not DWASA's responsibility, and (iii) toilets connected with the canals were in onsite areas outside DWASA's jurisdiction.

In DNCC, the mayor has started campaigning against connecting toilets directly to surface drains and has expressed concern about containment standards and functionality of septic-tanks as onsite treatment units. DNCC has also requested full authority over wastewater management in onsite areas.

There is still a long way to go for proper planning and implementation of onsite sanitation

To date, a large part of the IRF-FSM for Dhaka is still to be executed, with the CCs slowly adapting to their enhanced roles in faecal sludge management. In particular, no significant steps have been taken to execute the CCs mandates to provide faecal sludge treatment. Currently, Dhaka has one functional WWTP and one FSTP unit, both operated by DWASA.

The Kochukhet Faecal Sludge Treatment Unit installed in 2020 is not functional as of 2023. Designed to run for 18 hours a day, with a treatment capacity of 10 m^3 sludge per hour, the facility operation is hampered by lack of financial resources. According to DWASA officials, the performance of the unit was satisfactory, but DWASA is unable to invest sufficient resources to keep the treatment system operational.

The FSTP was set up to support DNCC in implementing the Dhaka IRF-FSM, but a change in leadership within DNCC curtailed momentum. DNCC failed to provide land for the installation. The technical partner, WSUP, approached DWASA, who agreed to pilot the facility, with a vision to facilitate private faecal sludge emptying service providers working with DWASA under public-private partnership arrangements. The location of the treatment unit, far from areas of high demand for pit-emptying services, created long journey times for private sector partners looking to use the facility, further undermining viability and contributing to the shutdown of the facility.

Overall, although only 20 per cent of Dhaka's population is connected to the sewer system, the bulk of investments in sanitation services goes towards sewerage services. The Sewerage Masterplan of DWASA is prepared with a vision to serve 100 per cent of the Dhaka population with sewered systems, with an estimated required investment of USD 2.2 billion by 2035. Since approval of the Sewerage Masterplan in 2012, DWASA has mobilized almost USD 340 Million under its Dhaka Sanitation Improvement Project (DSIP), with the ambition to raise a total investment of USD 1 billion under DSIP. Investments raised under DSIP are used to upgrade the existing sewerage network.

CCs are only in the process of developing investment plans for onsite sanitation. Departments of Public Health Engineering (DPHE) have set up CWIS-FSM support to develop investment plans required for the implementation of the IRF. In practice, very little is allocated to onsite sanitation services by CCs.

Informal settlement in Thapathali, Kathmandu, Nepal

08

Data management and digitisation

CHAPTER IN BRIEF

Stronger data management systems at the city, national and global level are a first-level priority for improving wastewater and faecal sludge management. These systems are urgently required to support the key functions addressed throughout this report. In this Chapter we outline the current state of sanitation data management systems globally, highlighting strong examples identified through the city mapping. We then turn to explore digitisation as a key development in this area which can help unlock service improvements. The analysis shows:

- There remains a critical data gap at the city and national level in sanitation service coverage. This means cities are making investments without the data systems required to plan or manage the expected services and to ensure inclusion.
- The situation calls for radical strengthening of city- and country-level monitoring systems. Service authority performance should be monitored through a credible public data system incorporating all sanitation outcomes. Cities must be supported in taking ownership of data, reporting data, connecting with statistical offices, and using data to make decisions. Robust national, municipal and utility-level data collected at the lowest administrative level on a regular basis and disaggregated, wherever possible, is necessary to enable reporting, manage local service delivery, inform investments and support regulation.
- At global level, there have been improvements in data on the status of sanitation services through the SDG 6.2 monitoring framework. But the monitoring system still faces challenges, particularly with estimating, at national level, access to safely managed urban sanitation services. A specific challenge lies within country-level reporting on wastewater treatment, including industrial, which can help inform the SDG 6.3.1.
- Multiple countries across regions are on the path to embracing data systems as a key driver of sanitation service improvements and demonstrating what this involves in practice. Examples within our sample include Colombia, Kenya, Tanzania and Thailand.
- Improved monitoring at the service level can be supported by the rise of digital technologies. Underpinned by wider improvements in connectivity, these technologies also offer opportunities for improving the management of services.
- The majority of utilities in our sample have a defined vision and established governance for digital transformation, though wide-ranging barriers remain to implementation of these strategies.

8.1 City and national-level sanitation data management systems

In the Sustainable Development Goal (SDG) era, data supported decision making is key to achieving the ambitious target of universal and sustained access to sanitation services. Availability, accuracy and use of data is critical to the performance and accountability of the WASH sector and is essential to transform past trends of low service functionality and sustainability rates. Sanitation data systems are also critical for informing the provision of connected services and wider public programming affected by service levels and coverage, such as ecosystems, public health, climate adaptation and humanitarian relief.

Formalizing the sanitation sector with a public service approach requires formalizing data systems. At present, countries, cities, utilities, and finance partners are making plans and investing in hardware without the data systems required to plan or manage expected and needed sanitation services.

Understanding the current data gap

At global level, there have been significant improvements over the past 20 years in data on the status of sanitation services. The UN Water Joint Monitoring Programme (JMP) initiative, implemented by WHO and UNICEF, does provide a global picture of sanitation services based on the SDG 6.2 monitoring framework, using a combination of national surveys and statistical assumptions.

The SDG 6.2 monitoring system still faces challenges, particularly with estimating, at national level, access to safely managed urban sanitation services. This indicator is more difficult to track than in rural areas, where septic tanks (which do not systematically require associated services of emptying and treatment) are more prevalent.

Notwithstanding these improvements, there remains a critical data gap overall in sanitation service coverage. Formalizing the sanitation sector with a public service approach requires formalizing data systems. At present, countries, cities, utilities, and finance partners are making plans and investing in hardware without the data systems required to plan or manage expected and needed sanitation services. Similarly, most countries and cities lack a system of collecting and disseminating comprehensive WASH budget data (GLAAS, 2019).

A specific challenge lies within country-level reporting on wastewater treatment, including industrial, which can help inform the SDG 6.3.1. Globally, only a handful of countries have been able to share data on the quantity of wastewater produced that has received treatment via global reporting systems. As a result, as of today, there is no global picture available of the volumes of wastewater treated.

Data gaps in the availability of accurate information on global wastewater creates challenges for policy-makers responsible for pushing through improvements. Current global water quality models tend to quantify the load of wastewater using population density and national sanitation statistics as mere proxies, often resulting in vague numbers. In addition, costing accuracy is decreased further because they must be based on the fractions of population connected to sewage systems per country. Finally, data collection is further affected by the fact that local authorities with insufficient record management systems in place are responsible for critical data collection and reporting (Macedo et al., 2021). We are now seeing many practical cases where digital innovations are meeting these requirements in sanitation (IWA, 2020) and broader urban planning (GSMA, 2021) (see also Digitisation below).

Despite its importance, investments in wastewater treatment are often below required levels to generate sustained benefits (see Chapter 5). Financial investments are urgently needed to support improved monitoring of service quality of such treatment. Cities should therefore prioritize and invest in regular and reliable data collection and dissemination. Access to data by city, utility and regulatory authorities is essential to highlight the gaps in WASH service provision, inform management and budgeting of services, and ultimately to accelerate evidence-based policy, planning and resource allocation (OECD, 2011).

City and national-level sanitation data are also critical components for ensuring sustainability of services and identification of equity gaps on who is being left behind. Disaggregated data reveal the degree of disparity in access to sanitation within cities and within countries. Among our sample, sanitation service data relating to informal settlements and peri-urban areas are mainly collected by local mandated service utilities and municipalities, although in Colombia and Togo, data is centrally collected and stored at the national level.

Data platforms must be integrated within wider institutional systems, processes and feedback loops to ensure data is used effectively and responded to.

Citywide sanitation datasets are a key tool for policymakers to address inequalities through national policies, plans, and budgets, and for analyzing factors that can lead to low service sustainability, for example inadequate rates of fee collection and availability of technical support.

How can the sector respond at the country and global level?

The current situation calls for radical strengthening of monitoring systems, beginning with enhanced capacity development support and connected resource allocation at the national and city level. To strengthen accountability, improve decision making, and increase commitment and investments, service authority performance against their mandate should be monitored through a credible public data system incorporating all sanitation outcomes, both sewered and onsite. There is an urgent need for governments to invest in data systems that promote service quality and inclusivity. The need to invest in timely and credible data and information is one of the five accelerators identified under the UN-Water SDG 6 Global Acceleration Framework.

Greater capacity development support is required from sector actors to assist countries and cities in taking ownership of data, reporting data, connecting with statistical offices, and using data to make decisions. In the area of wastewater and faecal sludge treatment, and though conducted on a small scale, our study demonstrates both the latent capacities and the limitations of current monitoring systems. In some cases where aggregated national-level data on wastewater treatment is lacking, it was possible to access this data through direct engagement with service authorities. This implies data can be accessed, but conducting such studies at a larger scale evidently requires comprehensive supporting systems to be put in place.

One example of such initiatives is the UN-Water Integrated Monitoring Initiative for SDG 6 (IMI-SDG6), which supports countries in monitoring progress towards SDG 6, through a network of monitoring focal points in national line ministries involved in water and sanitation, as well as in the national statistical offices. Robust national, municipal and utility-level data collected at the lowest administrative level on a regular basis and disaggregated, wherever possible, is necessary to enable reporting, manage local service delivery, inform investments and support regulation.

Stronger country-level systems can feed into enhanced monitoring at the global level. For example, an open-access data portal specific to wastewater and faecal sludge treatment could be a useful addition in understanding global trends and facilitating cross-country knowledge exchange in this area. But this can only be of real value if countries are supported in parallel to provide the necessary data and to the quality required.

Implementing radical forms of this nature is not to be underestimated. Examples from our global mapping provide insights on what is required in practice:

Multiple countries within our sample are on the path to embracing data systems as a key driver of sanitation service improvements. The National Data Management Entity (DANE) in Medellin, the CWIS-SAP tool in Nakuru (see Case Study below), and the National Sanitation Management Information System (NSMIS) in Tanzania are key transformative examples in the study. These initiatives are working to provide accurate information for both wastewater and faecal sludge treatment processes.

Data platforms must be integrated within wider institutional systems, processes and feedback loops to ensure data is used effectively and responded to. Improved monitoring needs to be complemented by improvements in sector coordination, financing and planning, ensuring sanitation service data is collected and shared across multiple agencies, as already existent in some cities such as Medellin and Nakuru.

Strengthening monitoring systems at the national level requires financial resource allocation to hire staff skilled in data collection, analysis and communication. The majority of countries in our sample have established enabling policy frameworks for collecting, analysing and disseminating sanitation data, with notable examples from West and East Africa. In Togo, for example, data is collected and disseminated by the National Institute of Statistics and Economic and Demographic Studies (INSEED) and is guided by SDG indicators and the countries commitments.

Many sector leaders view digital transformation not as a choice, but an imperative.

In Kenya, the recently enacted National Sanitation Services Management Policy recognizes the need to develop strong compliance monitoring systems to underpin effective sanitation regulation including wastewater systems. The national regulator WASREB has progressively analysed and disseminated sanitation coverage since 2009, focused principally on sewered coverage, through the annual Impact assessment report (see also Chapter 6). The country is now piloting an inclusive national sanitation management information system for effective compliance monitoring and performance reporting, through harmonization of indicators and methods for the systematic collection of data and to generate estimates for safe management of sanitation services.

In Tanzania, the National Information Management System under the Ministry of Health and Social Welfare acts as a resource for sharing key sector updates on health and related areas, including sanitation technologies, enacted policies and laws, health strategic plans and linkages with other health departments. Key data tracked and updated includes toilet coverage, villages declared ODF, and households with toilets and handwashing facilities.

In Thailand, the Office of Natural Resources and Environmental Policy and Planning collects data for each wastewater management facility, including Hatyai City, and publishes on the national website. Through these efforts, there is detailed data on wastewater treatment in Thailand (such as the estimated total of 99, 419 m^3 of treated wastewater produced per day across all locations).

8.2 Digitisation

This chapter outlines where emerging and established digital technologies offer opportunities for improving the management of services. It begins by outlining conceptualizations of digitalization and where these are applicable in wastewater processes, before turning to discussing specific use cases in more detail.

A key prerequisite for practically all digital technology is connectivity. It is hard to understate the phenomenal rise in the use of digital technologies by populations in the last two decades. Mobile subscriber rates in Africa and Asia are rising rapidly, together with the use of digital payments and mobile money (see Figure 35), creating new payment options and the potential for enhanced financial inclusion in sanitation service provision. This acceleration is a great proxy for levels of digital development and highlights the opportunities opening in new markets.

Mobile applications are increasingly being deployed to support real-time data collection and analysis, which can ultimately be used to strengthen city and national-level data systems. In Togo for example, the "TogoInfo MICS" application, available and accessible on smartphones, is used regularly by the Ministries in charge of health and sanitation and water to ensure data is up-to-date.

Many sector leaders view digital transformation not as a choice, but an imperative (Sarni et al, 2019). According to a Global Water Intelligence survey of utility leaders, the return on investment (ROI) in digital infrastructure is between three per

Figure 35: Unique mobile subscribers and mobile money transactions

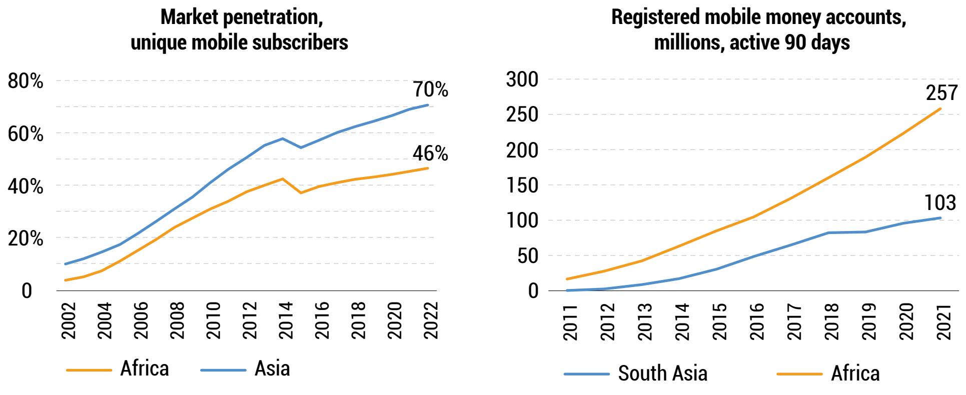
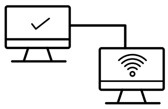
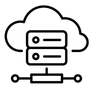
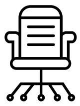
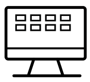


Figure 36: Key technology domains

	Customer relationships: tools that modify customer-utility relationships (e.g. billing and payments, customer complaints and social media engagement on services).
	Data acquisition and integration: the infrastructure needed for digital data collection (e.g. sensor networks, smart pipes, smart meters and data collected using mobile devices and other tools).
	Connectivity and network infrastructure: the availability of suitable network infrastructure for communication and the communication infrastructure used (e.g. radio transmitters, wireless fidelity (Wi-Fi), internet, voice, SMS, USSD and data services).
	Data processing and storage: the systems and processes used to manage data from different sources (e.g. ERP systems, cloud computing).
	Management and control: technologies that use two-way control to allow for remote operation (e.g. supervisory control and data acquisition (SCADA) and IoT solutions that allow for process automation and optimisation tools).
	Modelling and analytics: the combination of data sets to produce specific analytics (e.g. GIS data on assets and customers) and tools used to present data for decision making (e.g. web-based communication and information systems tools, and dashboards with key company information).

cent and 34 per cent, depending on the technology (Leading Utilities of the World, 2019). Within wastewater, the investment case rests not only on the financial side; remote sensing and monitoring technologies are critical tools in ensuring regulatory compliance and safety.

There are many ways to conceptualize utility digitalisation, but it begins with an examination of the technologies and how they are applied. Figure 36 outlines several key 'domains' for considering where digital solutions enter wastewater services. These domains also act as a rough 'reference architecture' for considering the key elements needed in data management systems.

While it is an essential first step to identify specific technology elements, more significant is considering how clusters of technologies come together to solve specific service challenges. It is important to view specific digital initiatives in the broader context of the organization and service model in which they are being delivered. Often making progress across multiple domains is critical to reaping full benefits. For example, the benefits of more efficient data collection will only be fully

Figure 37: Key digital solutions and applicability in wastewater

Digital payments and remote asset tracking	The combination of digital payments and assets that can be tracked remotely has opened the door to a new wave of service models. While the model has primarily gained traction in the energy sector, some urban sanitation models, particularly CBS, can benefit from flexible payment models linked to service delivery.
IoT and remote sensing data	Smart monitoring of system performance can increase operational efficiency and ensure that WWTPs are operating within safe parameters. Additionally, sensors at discharge points can enhance visibility around harmful discharges. Drones and other robots are increasingly used in sewer inspection.
Big data, AI, and machine learning	Use of large data set to manage decision making and implement algorithmic automation for optimisation of utility operations, and a better understanding of the impacts of a certain decision.
Augmented Reality and Virtual Reality tools	Obtain critical asset information for repairs and inspection, as well as the mapping of geographic information system (GIS), combined with remote sensing removes the need to physically travel to identify and resolve issues, and can be used in predictive maintenance and the creation of digital twins.

realized if these data are accessible through applications that enable them to be used in decision making.

The Covid-19 Pandemic was a catalyst for digital innovation in many sectors, including sanitation and wastewater, and particularly regarding revenue collection. Utility bill payments for utility services proved a critical policy tool for economic relief, as many countries suspended these during the most intense phases of the pandemic (SIWI, 2020; Akrofia & Antwi, 2020). At the same time, providers were required to find innovative ways to collect payments remotely where they could. These two trends applied opposite pressures on utility providers' finances during the pandemic, in the medium- to long-term it is likely this phase has laid the foundation for many providers going cashless. A 2020 UN review of P2G payments in 193 countries (UN, 2018) found that digital utility payments are offered in 75 per cent of countries. The annual GSMA review of mobile money use found that bill payments processed via mobile money leapt in 2021, growing by 37 per cent to exceed USD 5 billion in value per month (GSMA, 2022a).

Utilities worldwide are at various stages of maturity when it comes to adopting these types of digital solutions and approaches, and very little is currently known surrounding the level of digital adoption in wastewater. A recent systematic review of digital innovation in water services low and middle-income countries (LMICs) found that evidence is only just emerging, and quality evidence on the impacts of digital innovations is particularly scarce (Amankwa et al, 2021). The evidence base in sanitation and wastewater is even more scarce.

The majority of utilities in our sample have a defined vision and established governance for digital transformation. Key barriers to digitalization process remain. Barriers cited by respondents included lack of financial resources, lack of clarity on return on investment, complexity of the technologies, fear of change, and disintegrated systems due to lack of formalisation of the relationship between public authorities, central government and local government. Fear of change and too many risks were also reported, though not universal in the study.

The IWA's Digital Water Steering Committee's work has become one of the central repositories for learning on digitalization in water and sanitation, and their recently published book, *A Strategic Digital Transformation for the Water Industry,* is one of the most complete repositories of learning in the sector (IWA, 2022). There is also an increasing number of organizations supporting digital innovation, these are highlighted in Figure 38.

Numerous studies, based on interviews with digital technology adopters, demonstrate digital solutions can assist utilities and other sanitation providers in overcoming a variety of obstacles, but presents its own set of challenges. Among the most pressing issues mentioned were cybersecurity, utility resistance to change, IT failures, a lack of funding, a limited return on investment, political opposition, and community opposition. A joint GSMA and WSUP study of the digitalisation of water utilities (GSMA & WSUP, 2022) highlights these through in-depth case studies, alongside key lessons and opportunities. Figure 39 highlights some examples of innovators leading in digital innovation.

Figure 38: Organizations enabling digital innovation in wastewater and sanitation

GSMA Digital Utilities programme	Enable digital solutions and partnerships between innovators, mobile operators, government providers of utility services through: de-risking and catalytic funding, research and insights, partnership facilitation; and technical advice.
Imagine H2O	Provide catalytic funding for some of the most experimental innovations in the sector, and though many focus more on water there is a huge crossover in the technology to wastewater and building capacity within utilities for digital adoption.
Toilet Board Coalition	Run an accelerator programme for social enterprises working in sanitation, many of which use digital technology.
Transform	A joint initiative between Unilever, the UK's Foreign, Commonwealth & Development Office (FCDO) and EY, that have supported many CBS providers leveraging digital technologies.

Figure 39: Digital innovations in sanitation and wastewater

Kampala Capital City Authority	In 2017, KCCA upgraded their GIS tracking system, and developed and deployed an app to work as a platform to connect customers to pit latrine emptying services, and then track service delivery to ensure safe disposal.
Fluid Robotics	In the wake of the COVID-19 pandemic Fluid Robotics re-purposed their sewer-scouring robot to collect samples to check for COVID and other diseases and have combined sewer mapping with IoT to improve wastewater surveillance.
Lintasarta	In Indondesia, Lintasarta provides a GSM-based wastewater quality measurement solution that is available on a monthly subscription without upfront costs.
FLYABILITY	Their Elios 2 drone has been used by multiple utilities to map the sewer network. Using Lidar and camera footage, pipes can be mapped quickly and effectively.
Xylem	Numerous digital products, including turnkey solutions for Digital Twins of wastewater treatment plants.
Arup	Leader in applying machine learning at a catchment level to optimise wastewater networks.
SatSense	A company in the process of developing the technology to apply AI and use satellite data to monitor water quality from space
Garv Toilets	In India GARV Toilets, are providing safe sanitation services in 12 states. Their prefabricated public toilet units, manufactured in India, integrate IoT devices such as PIC micro-controllers, proximity sensors and motion sensors.
Loowatt	Loowatt provide waterless CBS solutions globally. Loowatt customers can use mobile money to pay for collection services and SMS to schedule collections and maintenance, and Loowatt personnel use a mobile app and web platform to manage operations and track waste from households to the treatment facility.

Partnerships between these private sector innovators and centralized utilities and municipalities have emerged as an innovative and impactful way to address critical gaps in sanitation and waste water management - particularly when it comes to improving operational efficiencies and enabling new business models with the capacity of reaching low-income urban populations in informal settlements. These partnerships have the potential to combine the technology, innovative financing, and agility of start-up ventures with the public sector's scale, service mandate, and resources. Forming partnerships between stakeholders with different organizational cultures, time horizons, and strategic priorities can pose challenges. Other challenges include understanding evolving public sector incentive structures, regulation, and political economy dynamics, finding sustainable financing solutions for collaboration in the context of higher risk perceptions, moving from pilots to scale, and evaluating the impact of these partnerships over time (GSMA, 2022b).

Recommendations

- Establish and fund robust public data management systems to inform regulation and service improvements. Monitoring systems must be strengthened at the city and national-level, requiring financial resource allocation, including to hire and train staff skilled in data collection, analysis and communication

- Invest in nationwide mobile network coverage and access to the cloud for digital solutions

- Invest in digital wastewater and water quality monitoring, including river and groundwater

- Explore enhanced use of cloud-based solutions and promote easy-to-use customer apps linked to sensors

- The global sanitation sector needs to appreciate the potential of data and ICT to leverage the opportunity and use it more effectively to monitor and manage services and increase their sustainability

- Harmonize indicators to include wastewater and FSM data on the whole sanitation chain for comparability of data across cities and countries

- Provide guidance on how to invest in the soft infrastructure of national and local authority data systems or assessing, planning, and improving services. This a fundamental requirement for translating finance and assets into sustained services

- More accurate and reliable data on global wastewater and faecal sludge figures are required to help determine the gap. An open-access data portal specific to wastewater and faecal sludge treatment could be a useful tool in understanding global trends and facilitating cross-country knowledge exchange in this area. But this is dependent on much greater support to countries in providing the necessary data to the quality required.

8.3 Case Study: Nakuru, Kenya — Bridging the sanitation data gap

In the city of Nakuru, Kenya, there is a shared understanding among decision makers of the urgent requirement to bridge the sanitation data gap. This case study details how Nakuru Water and Sanitation Services Company (NAWASSCO), *the sanitation service provider in Nakuru, is collaborating with the national regulator to WASREB to develop a new tool to provide the basis for enhanced sanitation data management and informed sanitation investment planning.*

Table 8: Summary of key data for Nakuru city

Demographics	Population in NAWASSCO service area*	512,100
	Population density**	1,976 / KM2
	Low-income area (LIA) population***	308,194
Water and sanitation services	Water network coverage (%)	91
	Sewerage coverage (%)	28
	Dependent on onsite sanitation (%)	72
	Access to improved containment (%)	64
	Dependent on shared facilities (%)	41
	Wastewater treated (%)	28
	Sludge treated (%)	35
Institutional arrangements	Policy making and regulation	▪ Ministry of Water ▪ Ministry of Health ▪ Water Services Regulatory Board (WASREB) ▪ National Environmental Management Authority (NEMA)
	Planning	▪ Nakuru County Department of Water and Department of Health ▪ Nakuru Countywide Sanitation Technical Steering Committee (NACOSTEC) ▪ Nakuru Water and Sanitation Services Company (NAWASSCO)
	Service delivery	▪ Nakuru Water and Sanitation Services Company (NAWASSCO), a public utility ▪ Private operators

** Source: WASREB (2022) IMPACT 14.*
*** Source: Nakuru County Integrated Development Plan 2018-2022.*
**** Source: Ibid.*

Significant initiatives are underway in Nakuru to strengthen sanitation data management in Nakuru. At the national level, it is also important to note newly-enacted **National Sanitation Services Management Policy** recognizes the need to develop strong compliance monitoring systems to underpin effective sanitation regulation. Compliance monitoring is currently weakened by factors including inadequate funding for regulatory agencies; inadequate human resources and institutional capacity; political interference; and the lack of an inclusive national sanitation management information system for effective compliance monitoring and performance reporting.

Use of ‘Popo’ pump, Nakuru, Kenya © NAWASSCO

Data management: a key issue to overcome for fulfilling mandates for both sewered and onsite sanitation

Since 2012, the local government-owned public utility NAWASSCO is explicitly in charge of sanitation across the country. This also means the utility is responsible for planning and delivering both sewered and onsite sanitation services.

Lack of data is clear limitation for NAWASSCO to fulfil this mandate. Whereas the utility has up-to-date information on key metrics for sewerage services (including the number of domestic and industrial connections), with data readily accessible through an automated system, data related to onsite services is lacking. Data critical for guiding investment and service planning — for example, the proportion of households with access to pit latrines and septic tanks respectively within a given service area — has not been collected. In addition, where it exists, data is domiciled within other institutions (for example the Department of Health). In the view of Zaituni Rehema, Manager for the low-income customer services department of NAWASSCO, in order to make better informed decisions on investments for wastewater and faecal sludge management, the utility must “ensure we put together all the data on sanitation — this has been the gap”.[12] As outlined by Richard Cheruiyot, Director of Monitoring and Enforcement at WASREB: “as we think about investments in sanitation, we need to have a basis for planning different interventions… we need to understand how we can optimize our investments in sanitation to achieve the desired outcomes”.[13]

Understanding the data gaps via the CWIS SAP tool roll-out

NAWASSCO participated in a pilot of the Citywide Inclusive Sanitation Services and Planning (CWIS-SAP) tool. The tool was designed by Athena Infonomics and Aguaconsult, with technical inputs from WASREB and the Eastern and Southern Africa Water and Sanitation (ESAWAS) Regulators Association and financial support from the Gates Foundation.

The tool is designed to assist planners and service providers in mapping city-level service coverage as well as costs and revenue models involved. This mapping is used to set a “baseline” or status quo scenario, which utilities can then use to develop additional scenarios and consider costs and revenues implications.[14] Some key data entry requirements of the tool are presented in Table 3. In Nakuru, NAWASSCO modelled three scenarios in addition to the status quo:

i. **Onsite heavy investment**: for example, investment in 4 transfer trucks, 6 mobile desludging units and 1 WWTP

ii. **Mixed investment**: for example, 25KM sewer network extensions, 1 WWTP, 1 Vacuum Truck)

iii. **Sewer-heavy investment**: for example, 57KM sewer network extension, 1 WWTP

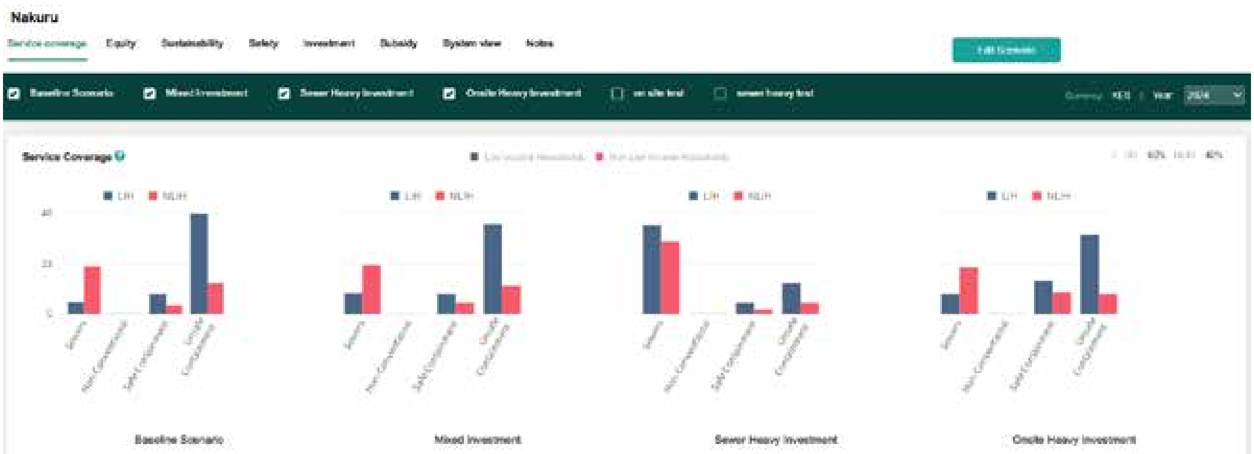
The pilot has proved formative in underlining

12 KII: Zaituni Rehema. 28th June 2022.
13 KII: Richard Cheruiyot, 22nd June 2022.
14 CWIS SAP Learning Brief – Regulatory Use Cases

Table 9: CWIS SAP Indicators. See Figure 40 below for example dashboard for "Service Coverage"

Key Metric	Indicators
Service Coverage	Service coverage for low-income and non low-income households, disaggregated by sanitation categories: ▪ Sewers ▪ Non-conventional ▪ Safe containment ▪ Unsafe containment
Equity	*[All indicators sub-divided by low-income / non low-income households; sanitation categories]* Public Expenditure Targeting Public Expenditure Capex Public Expenditure Opex Public Expenditure per Capita Average Annual HH Expenditure
Sustainability	*[All indicators sub-divided by low-income / non low-income households; sanitation categories]* Total Government Cost (Grants & Government Transfers) Cost Coverage (Revenue/Cost Ratio; Net profit / loss) Water requirement
Safety	Safely managed Faecal Waste (per centage of waste safely managed at each level of the sanitation chain for each sanitation category)
Investment	Utility Net Income Private Operator Net Income Available Finance Vs Required Investment
Subsidy	Subsidy requirement Household components (by containment option)

Figure 40: User interface for the draft CWIS-SAP tool



Source: www.equiserve.io: Accessed 16th May 2023

the level of data required to support effective long-term sanitation investment planning. The process of populating the tool was instructive in identifying data required for decision making by NAWASSCO not currently collected: "it has opened up understanding from utilities of the data they have to collect. It has pushed utilities to develop systems ensuring data is available".[15] It also exposed data storage is currently fractured, with information domiciled in different departments within NAWASSCO — to complete the tool, the utility "had to call different people from different departments".[16] To support more efficient decision making and informed investment planning, this information needs to be centralized. As an immediate next step, NAWASSCO is considering creating a new post with responsibility for Monitoring and Evaluation across utility departments and functions.

15 KII: Richard Cheruiyot, 22nd June 2022.

16 KII: Zaituni Rehema. 28th June 2022.

Engineers assesing waste water treatment plant with industrial drone © Shutterstock

09

Emerging innovations

CHAPTER IN BRIEF

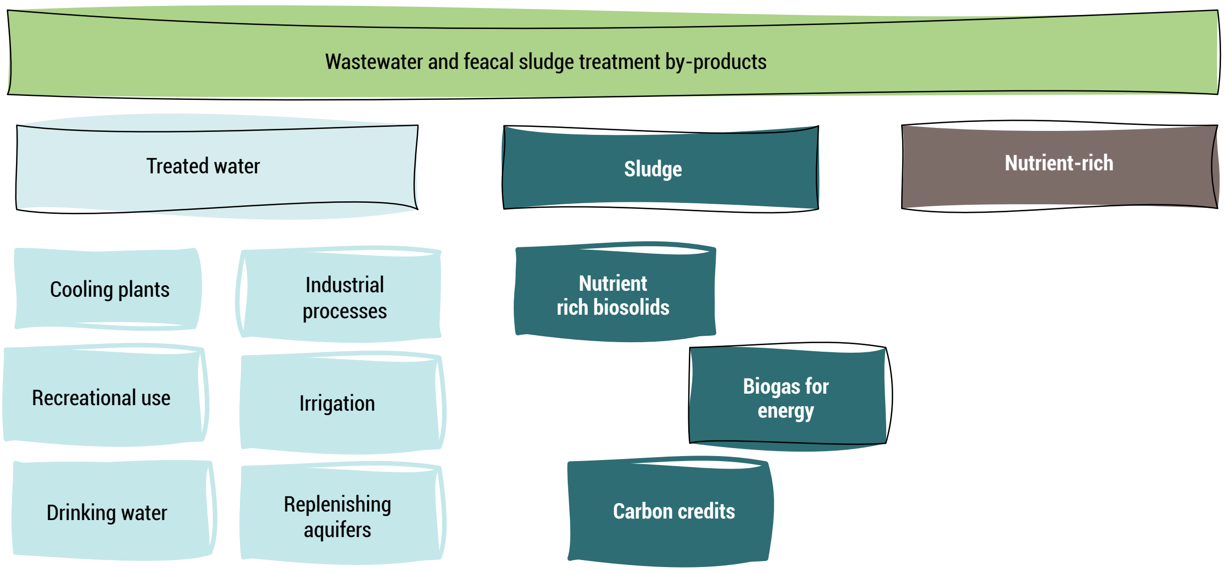
This is an exciting time for wastewater management. A number of innovations are gaining traction, including wastewater reuse, and wastewater-based epidemiology, which played an important role in national responses to the Covid-19 Pandemic. Alongside these shifts, there is urgent need for planners and service authorities to adapt their approach to wastewater and faecal sludge management in response to the urgent threat posed by climate change. In this chapter, we provide an overview of recent innovations in wastewater and faecal sludge management and their potential significance. The analysis shows:

- There is a paradigm shift to viewing wastewater as a resource not a waste stream. Most notably, wastewater has a role to play in responding to the global water crisis through conversion into potable and non-potable water, as already practiced in some countries. This practice also carries inherent risks, and must be supported by further development and enforcement of regulations and standards.
- Wastewater reuse has been accompanied by development of a circular economy for faecal sludge based on renewable resource flows, with container-based sanitation (CBS) providers at the forefront.
- City planners and utilities around the world are already adopting a wider range of measures in response to current and future climate change risks.These include the development of flood-resistant urban drainage systems, as in Hanoi and Shanghai.
- In part because requirements for wastewater testing are often significantly lower than those for clinical testing, wastewater-based epidemiology has an important role to play in public health monitoring in specific contexts.
- At the systems level, decentralized feacal sludge treatment plants are a potentially vital innovation to address the deficit in effective faecal sludge treatment in LMICs.

9.1 Wastewater and faecal sludge recycling, energy and nutrient recovery

Paradigm shifts are occurring as the sector is realizing that wastewater and faecal sludge can be turned into an economic opportunity. After many decades of technological advancement and urban population growth that led to an ever-increasing demand for natural resources, there is now a widespread understanding that available resources are finite. Concerns about how to find new resources capable of assisting in reaching the balance between demand and supply arise as pressures on water resources increase. In response, a circular economy is being established globally in an effort to reduce the human impact on the environment. The circular economy generally tries to minimize the continuous extraction of natural resources that results in waste creation and disposal by encouraging the full commercialization of any remaining resources. As summarized in Figure 4, many economic sectors are set

Figure 41: Wastewater and faecal sludge by-products resource recovery



to benefit from this shift, from industrial production to energy generation, agriculture and the leisure industry. In faecal sludge management, there is movement towards a circular economy for faecal sludge based on renewable resource flows, with container-based sanitation (CBS) providers at the forefront.

Today, wastewater treatment promotes a shift in focus from pollutant removal to resource recovery, with wastewater increasingly seen as a resource not a waste stream. For example, cities are phosphorus "hotspots," with urine as a main source. Phosphorous can be recovered from wastewater treatment: sludge incineration ash offers an efficiency of about 90 per cent for phosphorus recovery (Cornel & Schaum, 2009). Hamburg Wasser is utilizing an innovative process (the TetraPhos process[17]) to recover phosphorus from sludge ash produced by its wastewater treatment plants. Similarly, 30 per cent of global nitrogen fertilizer demand could be met through wastewater recovery practices (Mulder, 2003). In addition to fertilizers, wastewater may be used to recover cellulose, volatile fatty acids (VFAs), extracellular polymeric substances (EPS), and single-cell protein (SCP). More products can be recovered from wastewater in theory, but evidence on such pathways is currently sparse, creating uncertainty.

Wastewater and faecal sludge are also a potential source of energy recovery. Municipal wastewater includes organic carbon, which provides chemical energy that may be recovered as biogas. The city of Hamburg has implemented an innovative project that involves upgrading biogas produced at the wastewater treatment plant and feeding it into the public gas grid. The project utilizes a state-of-the-art technology known as "biomethane upgrading," which purifies the biogas to a quality suitable for injection into the natural gas grid. The purified biomethane can be used as a renewable energy source for heating and transportation. This project helps to reduce greenhouse gas emissions and promote the use of renewable energy sources, while also generating additional revenue for the wastewater treatment plant through the sale of biomethane.

Domestic wastewater may be used as a thermal energy source. Warm water conservation and heat recovery have the potential to save and recover large quantities of energy from the water cycle. Because hot water is still thrown into the sewage system, domestic wastewater acts as a heat transporter. As one innovative example of the potential in this area, Veolia's Energido

17 The TetraPhos process involves treating the sludge ash with sulfuric acid, which dissolves the phosphorus and separates it from the other contaminants. The resulting solution is then treated with magnesium oxide, which precipitates the phosphorus as magnesium ammonium phosphate (MAP). The MAP can then be separated from the solution and used as a fertilizer.

technology recovers the energy contained in wastewater to totally supply the heating and cooling needs of 300 dwellings in the AZUR CAP eco-district in the south of France (Veolia, 2022).

Treated wastewater can be used for non-potable purposes such as agriculture, land, irrigation, groundwater recharge, golf course irrigation, vehicle washing, toilet flushing, firefighting, and building construction activities.

Wastewater reuse: a contribution to solving the global water crisis

Treated wastewater can alleviate the water crisis. In many countries, water stress has been addressed through conventional measures such as expanding resources made available by dams or man-constructed canals. These options are often expensive and environmentally unsustainable. Treated wastewater has the potential to help ensure the population's access to and regular supply of water. The treated effluent can be classified as potable or non-potable water depending on its final quality and the treatments used. Non-potable treated wastewater could be used for agricultural irrigation, industrial activities such as cooling, and urban uses including recreational use. Potable water often requires an environmental buffer before consumption, which can be achieved through aquifer recharge, reservoirs or river discharge.

When treated, wastewater potential use abounds. Treated wastewater can be used for non-potable purposes such as agriculture, land, irrigation, groundwater recharge, golf course irrigation, vehicle washing, toilet flushing, firefighting, and building construction activities. In Israel, where about 90 per cent of its treated wastewater is used in irrigation, the water authority's master plan aims to reuse 100 per cent of the treated wastewater, the water policies are encouraging smart water management, and water sector research is focusing on water leak detection and drip irrigation (Smart Magazine 2020). According to the Ministry of Environmental Protection, the advanced wastewater reuse system in Israel is due to a combination of economic tools (e.g. tariffs and close market principle along with economic orientation of the water and sewerage corporations), and strict environmental regulations.

There are also advances in using wastewater as a source of potable water. Advanced treatment technologies allow the production of highly treated wastewater quality for reuse at increasingly reasonable costs and reduced energy inputs. Planned indirect potable reuse and direct potable reuse are water recycling approaches increasingly being adopted by water utilities. In planned indirect potable reuse, highly treated wastewater is discharged directly into groundwater or surface water sources which will again be treated as drinking water. Direct potable reuse, on the other hand, involves the direct reintroduction of highly-treated wastewater into the potable water supply. Highly-treated wastewater requires advanced treatment such as reverse osmosis and ozone-biological active filtration.

View of Hamburg waste water treatment plant © Hamburg Wasser

Table 10: Examples of existing DRP schemes (modified from USEPA 2017)

Location	Year implemented	Treatment Processes	Effluent end use
Windhoek, Namibia	1969	PAC → Pre-ozonation → Coagulation/Flocculation → DAF → Rapid Sand Filtration → Ozonation → BAC Filtration → GAC Filtration → UF → Chlorination	Blended with raw water prior to drinking water treatment
Beaufort West, South Africa	2011	Sand Filtration → UF → RO → UV/AOP → Chlorination	Blended with raw water prior to drinking water treatment
Big Spring, Texas, USA	2013	MF → RO → UV/AOP → Conventional Treatment	Blended with raw water prior to drinking water treatment
Village of Cloudcroft, New Mexico, USA	2016	MBR → RO → UV/AOP → Storage → UF → UV → GAC → Chlorination	Blended with raw water prior to drinking water treatment

BAC: biological activated carbon; MF: micro-filtration; DAF: dissolved air flotation; GAC: granular activated carbon; PAC: powdered activated carbon; RO: reverse osmosis; UF: ultra-filtration; UV: ultraviolet irradiation; AOP: advanced oxidation process

While planned indirect potable reuse has been implemented in countries such as the United States, United Kingdom, Australia, Belgium, Singapore, and South Africa, it has yet to be adopted globally. One of the barriers to implement planned potable reuse in low and middle-income countries is lack of financial resources.

It must be emphasized that fully leveraging the potential of treated wastewater requires safeguards and the development and enforcement of standards. The use of untreated wastewater is currently widespread (see Hanoi case study), with negative health impacts for farmers, communities and consumers of irrigated crops (see Chapter 3). Realizing the potential of wastewater will require legal instruments that set standards for valorization, supported by capital investment in technologies capable of producing the required treatment products.

Faecal sludge: towards a circular sanitation economy

Innovators have also brought several developments to faecal sludge management in order to achieve a circular sanitation economy based on renewable resource flows. The circular sanitation economy employs off-grid solutions combining some components of the established approach to create a sanitation chain of interconnected flows of material, energy, and information without the heavy infrastructure required by the sewer systems (Toilet Board Coalition 2017). With this in mind, sanitation entrepreneurs have developed toilets suitable for both poor and rich nations, FS treatment technologies to recover nutrients, energy and water, and business models to generate revenue.

Members of the Container-based Sanitation Alliance (CBSA) are sanitation enterprises promoting this circular economy approach to sanitation. According to the CBSA, during 2021-22, their members served over 190,588 people, sold 4,431 CBS toilets, serviced over 10,874 CBS toilets, removed over 18,207 tons of sludge, and provided over 531 jobs, operating over nine countries and 26 municipalities. The innovative aspects of CBS include that it can be installed where space is constrained and in areas with water scarcity, high water table and prone to flooding; and that households have to pay only a periodic (daily, weekly, or monthly) fee, not requiring upfront investments. Further demonstration is required to evidence the long-term financial viability of CBS and the capability of CBS enterprises to operate at greater scale. Nonetheless, CBS has emerged as an inclusive, resilient, affordable approach with strong potential as part of a mix of services at the city level. Most CBS providers also work towards optimizing resource recovery from sludge management, mainly in the form of compost and fuel briquettes.

Table 11: Examples of CBS service providers and their characteristics

CBS provider	Containment	Treatment process	Reuse products	Service costs to user per year
SOIL	Portable seated	Aerobic composting: static pile then windrow turning, with sugarcane bagasse co-waste at start of process	Compost branded as Konpos Lakay, sold at USD 280/t.	USD 36
Sanergy	Fixed squat	Aerobic composting with a variety of agricultural/ organic co-waste materials.	Evergrow compost sold at USD 400/	USD 63*
		BSFL digestion of faeces.	Pure Protein animal feed, under development.	
Clean Team	Portable seated	Municipal treatment plant	None	USD 106
Sanivation	Portable or fixed seated	Pasteurisation	Solid fuel briquettes	NA
Loowatt	Portable seated	Anaerobic digestion	Electricity, fertilizer	NA

Note: BSFL = black soldier fly larvae
** Estimated based on a family of two adults and three children, each making one paid visit per day*
Source: adapted from World Bank, 2019; Mackinnon 2019

9.2 Climate resilient systems

The provision of sanitation services is already affected by climate change impacts. Droughts, floodings, severe weather events, and sea level rising are causing damage to infrastructure and health impacts on those affected (Campos and Darch 2015a). To maintain functionality in the face of climate-related shocks and stresses, a resilient system must be reflective, robust, redundant, flexible, resourceful, inclusive, and integrated.

Box 22: Features of resilient cities

Arup's city resilience framework provides a strong conceptual overview of system features in this area. The framework outlines:

- **Resilient systems** require mechanisms to continuously evolve, and will modify standards or norms based on emerging evidence, rather than seeking permanent solutions based on the status quo.
- **Robust systems** withstand the impacts of hazard events without significant damage or loss of function.
- **Redundant systems** can accommodate disruption, extreme pressures or surges in demand.
- **Flexible systems** can change, evolve and adapt in response to changing circumstances.
- **Resourceful systems** imply that people and institutions are able to rapidly find different ways to achieve their goals or meet their needs during a shock or when under stress.
- **Inclusive systems** emphasise the need for broad consultation and engagement of communities, including the most vulnerable groups.
- **Integrated systems** promote consistency in decision making and ensure that all investments are mutually supportive to a common outcome.

Source: Arup, 2015.

Climate adaptation is about much more than infrastructure. Such measures need to be supported by non-structural interventions - Non-structural adaptation measures may include improved planning, institutional and regulatory arrangements, capacity building, monitoring, public awareness or behavioural responses.

In order to face different climate variables, including flooding, wind, drought and rising temperature, infrastructure is key. Infrastructural adaption measures to create resilience of sanitation systems may include constructing elevated sanitation facilities (e.g. pit latrines), using special coatings, or with smaller or shallower size of pits to improve ability to withstand flood events and reduce contamination in the case of collapse (Morshed and Sobhan, 2010); separating stormwater from wastewater to reduce risks related to overflows or damage to collection and treatment infrastructure (WHO, 2018); and using water saving and reuse-oriented sanitation systems (e.g. container-based sanitation) in water scarce areas (Luh et al. 2017).

The development of climate-resilient urban drainage systems will be a key part of the response in many cities. Hanoi (Vietnam) is highlighted as a case study of a city proactively changing its approach to services in new urban areas through the introduction of climate-resilient and sustainable urban drainage systems. The experience of Shanghai (China) is also notable. As outlined by Arup, the massive scale of urban development in Shanghai has increased the impermeable area for the catchment while reducing green space leading to increased stormwater runoff across the city. This has caused serious urban flooding and river pollution in recent years. In 2018 the city authority launched a design competition to look for advanced yet implementable strategies for the highly populated city centre. Arup's resulting strategy involves a 'blue, green and grey' infrastructure approach involving water sensitive urban design, integrated flood control planning and decentralized infrastructure as key components.[18] The Rainwater Management Program for Climate Adaptation (RISA) in Hamburg is also a good example of a comprehensive initiative aimed at managing rainwater in an environmentally-friendly and sustainable manner. The program includes a range of measures, such as the installation of green roofs, rain gardens, and permeable pavements, which help to reduce the amount of rainwater runoff and increase groundwater recharge.

18 https://www.arup.com/projects/shanghai-drainage-masterplan

Climate adaptation is about much more than infrastructure. Such measures need to be supported by non-structural interventions. Non-structural adaptation measures may include improved planning, institutional and regulatory arrangements, capacity building, monitoring, public awareness or behavioural responses (Mills et al. 2019). Specific examples include:

- **Strengthening capacity of sanitation system managers** to address climate change risks to overcome knowledge gaps that may limit adaptation (Kirchhoff and Watson, 2019);
- **Revising the national, regional, and municipal Water and Sanitation Master Plans** to include climate risks and adaptation measures (Godfrey and Tunhuma, 2020);
- **Holding community training sessions** to discuss climate change remediation measures for existing hydro-agricultural and drinking water systems (Godfrey and Tunhuma, 2020);
- **Developing effective information systems** to ensure that sanitation workers and users can access updated and reliable data, which are needed to make informed decisions to ensure services are maintained (WHO, 2019).

Utilities around the world are already adopting a wide range of measures in response to current and future climate change risks. A notable example is eThekwini Water & Sanitation Company in South Africa. Here key innovations include the creation of a resource recovery demonstration facility at the wastewater treatment plant, which produces 30 per cent less sludge, uses 30 per cent less energy and has a 50 per cent to 75 per cent smaller physical footprint than convention treatment works; the Durban Water Recycling Project, applying innovative approaches to wastewater treatment technology; and Struvite crop trials, involving the development of a magnesium ammonium phosphate formed by combining source-separated human urine with a magnesium salt to produce an odourless safe fertilizer.

Table 12 below presents further wide-ranging measures adopted by African countries Malawi, Sierra Leone and Tanzania.

Table 12: Adaptation options prioritized in the country risk assessment (modified from ODI 2014)

Categories	Priority	Malawi (rural)	Sierra Leone (urban)	Tanzania (rural)
Understanding climate impacts	1	Study of groundwater levels, surface water flows, and climate variability	Flood risk mapping in programme areas	Public education around flood risk
Capacity and enabling environment	2	Recurrent hydro-meteorological data collection and publication	Guidance on appropriate latrine technologies in high water table areas	Training for local government authorities on encouraging groundwater recharge
Design and implementation	3	Catchment protection	Simple rainwater harvesting to supplement other sources during dry season	Catchment protection
		Lined and raised pit latrine	Latrine with small vault instead of pit, above ground for regular emptying	Proper supervision and drilling boreholes to the bottom of the aquifer

Box 23: Climate adaptation strategies being adopted by wastewater utilities in the UK

In the UK, wastewater utilities have developed comprehensive adaptation strategies to address current and potential climate change risks, presented below (adapted from Campos and Darch, 2015b).

Climate change impact	Sanitation infrastructure issues	Adaptation strategy
Flooding	Wastewater treatment	• Separate storm flow and create foul only system
	Power outages and service failures	• Backup generators • Dual electricity supply from a separate sub-station • Consideration of power outage in design to avoid overflows will lead to customer flooding
	Saline intrusion	• Continuous monitoring of effluent quality • Review of data at part of periodic review process, identify areas of saline infiltration and target sewer rehababilitation work on vulnerable asset
	Asset deterioration	• Periodic review of structural condition of assets • Change asset design standard to accommodate changing use • Increase in flood defence around treatment works
	Inundation of WWTPs and pumping stations from river flooding	• Increase in flood defence around treatment works • Raising critical equipment to higher level • Surface Water Management Strategy
Droughts	Sewer blockages	• Maintain self-cleansing systems • Sewer maintenance (jetting) • Bag it & Bin it campaign to raise public awareness of dumping • inappropriate items down toilets • Improve sewer monitoring

	Increased septicity	• Review stormwater tank size and mode of operation due increased retention time • Odour strategy to deal with customer complaints
	Lower average and peak flows at pumping stations	• Backup pumps as increased failures would have a very high impact • Use of materials which resist corrosion • Design pump stations to resist wear • Chemical dosing to reduce H2S levels • Self-cleansing pump systems
	Reduced water quality of receiving waters	• Extend monitoring • Develop and agree more appropriate consents • Improve discharge quality where necessary
Temperature rise	Treatment performance	• Review operational target parameters • Continuous monitoring of wastewater effluent • Monitoring and process control
	Increase odour	• Review chemical needs of treatment process • Review operational target parameters • Increased/additional aeration • Review bio-solids strategy

Despite the sanitation sector being exposed to climate risks, it is not a major component of Nationally Determined Contributions (NDCs). NDCs provide an indication of each country's priorities for reducing national emissions and adapt to impact of climate change. An analysis of the SDG–NDC connections tool data on SDG6, showed that globally only 2 per cent of the NDCs deal with sanitation access and 3 per cent with wastewater management, while 95 per cent include other activities such as water management, water access and supply and improved irrigation (Dickin et al. 2020). This analysis also observed that Middle East and North Africa (MENA) region and Sub-Saharan Africa had the largest sanitation and wastewater activities in the NDCs, potentially due to great experience of water reuse and treatment in the MENA region, and the water scarcity challenges facing both regions.

In addition, not much is known on what wastewater managers are doing to reduce vulnerabilities, build resilience, and adapt to climate change. A mixed method study (Kirchhoff et al. 2019) found that over 60 per cent of wastewater managers in the US are adapting by implementing structural changes in the sewer networks and treatment plants and changing practices and procedures to cope with storms. The findings also indicate that 80 per cent of wastewater managers made the adaptations due to past extreme climate events, while only 20 per cent mentioned the adaptations were motivated by future climate change impacts. The study suggested that wastewater managers are aware of climate change but generally see climate change as a distant threat in time or space.

Sanitation services have so far received only a small share of climate financing. In 2017, projects targeting mitigation and adaptation related to basic sanitation and large sanitation systems received only 3 per cent of climate-related finance for the water supply and sanitation sector (Dickin et al. 2020). Innovative adaption measures on sanitation services can be accelerated with the support of the climate financing scheme. The current lack of understanding by the part of water and sanitation stakeholders on how climate financing schemes work seems to be delaying the adaptation of sanitation services to climate change impacts (SWA, 2019).

9.3 Wastewater-based epidemiology

The analysis of wastewater contents can provide insights on population exposure and health status and can be used as a real-time monitoring tool during disease outbreaks. Historically, many chemical contaminants have been detected in municipal wastewater, including pharmaceuticals, personal care products (PPCPs), and illicit narcotics. The existence of these substances reflects human behaviour and lifestyle, providing data on chemical exposure as well as health conditions. The advanced analysis of wastewater to evaluate a population's exposure and health status is known as wastewater-based epidemiology.

Wastewater-based epidemiology has a wide application from estimating drug and pharmaceutical consumption to testing presence of antimicrobials and resistant microbes, chemical exposure, and estimation of infectious diseases such as polio, measles, and hepatitis A at the population level (O'Keeffe, 2021). Growth has occurred in this area in part because resource requirements for wastewater testing are often significantly lower than those for clinical testing. Such programmes are influenced by sanitation and socio-economic context. Areas with high proportion of population connected to sewers have relatively simple technical environmental surveillance programmes compared with a high proportion of individual with onsite sanitation system.

Wastewater epidemiology was adopted during the initial spread of the SARS-CoV-2 virus in early 2020 after the detection of the virus in human faeces. Globally, 2300 sites in 55 countries adopted wastewater-based epidemiology for the first time as a complementary public health surveillance tool, particularly for monitoring trends in SARS-CoV-2 prevalence in large cities (O'Keeffe, 2021).The results from SARS-COV-2 for routine COVID-19 surveillance provide early indication of a change in COVID-19 at a population level, warning of trends, emergence of variants which can help in planning for healthcare services and identifying peak demand (WHO, 2022). In addition, purposes of wastewater-based surveillance for SARS-COV-2 include efficiencies in risk communication, targeting of public health surveillance and response (WHO, 2022).

Challenges have been identified in the use of wastewater-based technologies in areas with onsite sanitation systems and a lack of clinical laboratories accredited to international standards. It is essential to develop innovative and cost-effective methods that can monitor, taking in consideration their sanitation system diversity and context.

BOX 24: Decentralized wastewater and faecal sludge treatment systems

A key innovation in urban sanitation is the emergence of decentralised approaches for wastewater and faecal sludge treatment. These might take the form of decentralised faecal sludge treatment plants, enabling faecal sludge to be emptied, treated and used or disposed at or near the point of generation (Semiya et al, 2015). Such decentralised systems can be an effective option in low-income and slum settings, supporting the affordability and financial viability of formal pit emptying services by reducing transport times and associated operational costs for pit emptiers, who might otherwise be required to travel a long distance to a centralised treatment plant. A notable example of this approach is Lusaka, where community-based organizations known as Water Trusts were contracted by the utility, Lusaka Water & Sanitation Company, to provide formalised emptying, transport and decentralised pre-treatment in the peri-urban areas of Kanyama and Chazanga (WSUP, 2015).

In South Asia, small-scale sewage treatment plants are widely deployed, notably in Indian cities, which have over 25,000 such facilities. These units are mostly implemented and operated at building level by the private sector, largely as a result of various pollution abatement and water saving policies. By removing pollutants from sewage and greywater, they reclaim valuable water for toilet flushing, irrigation of urban gardens and other purposes, although in their current form these systems often fail to achieve the desired performance (Klinger, M, Ulrich, L, 2020). A 2020 study of decentralized wastewater and faecal sludge management in urban India, led by Asia Development Bank, examined four cases of decentralised sewage and faecal sludge treatment, concluding these systems are more effective and affordable for treating wastewater and reusing it productively, compared with large centralised sewerage systems (Rath et al, 2020).

9.4 Emerging treatment technologies

Emerging technologies such as membrane technology, microbial fuel cells, microalgae, and ultraviolet (UV) radiation are becoming increasingly popular solutions for mitigating the effects of wastewater on human health and the environment.

Increased urbanization and economic activities are producing large volumes of wastewater with new emerging pollutants. Emerging pollutants such as pesticides, pharmaceuticals and personal care products have been exacerbating problems of wastewater management. As a result, emerging technologies such as membrane technology, microbial fuel cells, microalgae, and ultraviolet (UV) radiation are becoming increasingly popular solutions for mitigating the effects of wastewater on human health and the environment.

With evolving health concerns and the development of new, lower-cost membranes, the use of membrane technologies in wastewater treatment has grown dramatically over the last decade. Membrane filtration technology is a thin layer barrier for size differential separation and is usually integrated with other chemical and biological treatments or standalone secondary treatment technologies (Armah et al., 2020). The advantages of this technology include the production of high-quality products and flexibility in system design. The low lifetime of the membranes and high energy consumption increases the operation and maintenance cost of this technology. Several examples of membrane bioreactors are available in the UK, Germany and Italy (Armah et al., 2020).

Microalgae-based technologies have high potential to sequester nitrates and phosphorous. These technologies also remove heavy metals as well as organic carbon from wastewater (Armah et al., 2020). Microalgae use inorganic nitrogen and phosphorus for their growth and can be used as a natural phenomenon to remove phosphorous in wastewater treatment ponds (ibid). The advantage of microalgae-based technologies includes energy saving, mitigation of CO_2 gas emissions, reduction of pollutants and pathogens, and recovery of nutrients as biomass. Despite all advantages, land requirement, algae biomass separation from water, and low efficiency in cold climates limit discourages full-scale use of this technology (Armah et al., 2020).

Microbial fuel cells (MFC) can address both water and energy challenges (Armah et al., 2020). This biological wastewater treatment process generates electric power by oxidizing the organic matter (and sometimes inorganic material) in wastewater (ibid). The power-generated by MFC can offset (partially or totally) waste treatment costs and be used to power an energy intensive conventional treatment process (Capodaglio et al., 2016). When compared to activated sludge treatment methods, MFC yield 50-90 per cent less solids for disposal. The advantages of the application of MFC include long-term sustainability, use of renewable resources, degradation of organic and inorganic waste and the removal of compounds like nitrates (Armah et al., 2020). This technology requires high capital cost which makes it challenging to scale up. As a result, it is still only used on an experimental basis, with modelling studies focusing on analyzing its success.

Chlorination is the most commonly used disinfectant worldwide and is effective against many pathogenic bacteria and viruses. The trend is shifting towards the usage of ultraviolet irradiation (UV) as it does not produce known disinfection byproducts. Despite challenges such as high capital and operation costs (Collivignarelli et al., 2020), continuous low and medium-pressure ultraviolet (UV) systems can be successfully used in conventional WWTPs as a method of pathogen disinfection, especially chlorine-resistant strains such as Cryptosporidium (Zewde et al., 2019). For example, this is why over 20 per cent of wastewater treatment plants in North America now use this environmentally friendly technology (Zewde et al., 2019). Despite the fact that UV disinfection is widely used for water and wastewater treatment in many parts of Asia and Europe, it is still considered difficult to implement in low-income countries (Hazell, et al 2019).

Finally, as outlined in Chapter 3, microplastics are an emerging contaminant of concern, the direct sources of which include discharge from sewage treatment plants, weathering and degradation of plastic waste in water bodies, and terrestrial input from soil erosion or surface runoff (Li, Busquets and Campos, 2020). Further research is required to identify treatment technologies that can maximize removal of these substances in the treatment process.

Recommendations

- Develop institutional frameworks for wastewater and faecal sludge reuse, including treatment requirements and associated costs.
- Clarify reuse standards for agriculture purpose and engage with farmers on adequate practice.
- Monitor quality of treated wastewater used in agriculture.
- Promote wider understanding of the potential of planned indirect potable reuse and direct potable reuse of treated wastewater, treatment requirements and associated costs.
- Invest in climate resilient infrastructure especially when considering onsite sanitation solutions. Water scarcity is a key challenge for scale-up of flush toilets and there will be a need to explore further low-water/waterless solutions (e.g. container-based sanitation).
- Promote the use of wastewater and faecal sludge by-products.
- Invest in market assessment and building for these products, as well as advocacy.
- Make the case for stronger links between climate change and wastewater/ faecal sludge management to mobilise climate finance and strengthen sector sustainability.
- Promote wider understanding of the applications of wastewater-based epidemiological surveillance, the situations in which it has been shown to add value to public health decision making, and what is needed to plan and coordinate an effective wastewater surveillance programme, drawing on WHO interim guidance in this area.
- Ecentralized faecal sludge treatment plants, as a context-specific solution the long-term financial viability of pit emptying services, reducee transport times and emore efficient service delivery. These facilities must be supported by sustainable operations and maintenance arrangements.

Hamburg waste water treatment plant © Hamburg Wasser

9.5 Case Study: Hanoi, Vietnam — Flood prevention via sustainable urban drainage systems and wastewater reuse

Hanoi, the capital city of Vietnam, faces many challenges in wastewater and faecal sludge management intensified by water pollution and urban flooding. In line with the national strategy, Hanoi wants to be water pollution and flood free by 2030. As a result, much attention has been drawn to wastewater and faecal sludge management. This case study details how sustainable urban drainage systems (SUDS) are contributing to urban flood mitigation. In addition, recognizing the potential and potential dangers of wastewater reuse for agriculture, authorities in Hanoi are developing institutional arrangements and policies to protect consumers, while enabling farmers to use nutrient-rich wastewater. Wastewater reuse, and its implication at policy level is another focus of this case study.

Table 13: Key data for Hanoi City

Demographics	Population*	8,246,500
	Population density**	2,454 / km^2
	Low-income area (LIA) population	N/A
Water and sanitation services	Water network coverage (%) connections***	100 in urban area 42 in suburban area (in 2010)
	Sewerage coverage (%)****	>60
	Number of sewer connections	N/A
	Dependent on onsite sanitation (%)*****	>90
	Access to improved containment (%)******	>90
	Dependent on shared facilities (%)	< 2
	Wastewater treated (%)*******	28.8
	Sludge treated (%)********	2-8
Institutional arrangements	Policy making and regulation	▪ Ministry of Construction ▪ Ministry of Natural Resources and Environment (MONRE)
	Planning	▪ Hanoi People's Committee (HPC), local government
	Service delivery	▪ Hanoi Sewerage and Drainage One-member State Company Limited (HSDC) for sewerage services and one WWTP management ▪ Phu Dien Construction Investment and Trading Joint Stock Company (Phu Dien Co.) for one WWTP management ▪ Hanoi Urban Environment Company (URENCO) for emptying services of institutional septic tanks and management of one FSTP ▪ Private operators for emptying services to households

Hanoi Statistical Yearbook, 2021
** *Hanoi Statistical Yearbook, 2021*
****HAWACO cited in Lucía et al, 2017*
**** *Technical Infrastructure Department, Ministry of Construction*
***** *Harada et al, 2008*
*******Harada et al, 2008*
******* *Hanoi Department of Construction, 2021*
******** *SFD Report Hanoi, Vietnam, 2016*

Urban flooding mitigation in Hanoi

The risks of urban flooding

Rapid expansion of Hanoi has led to the inadequate and poor management of the city's wastewater and drainage system, causing damaging and costly floods. Around 16 key locations across Hanoi suffer from chronic and severe flooding (lasting up to 18 hrs), especially in Long Bien and Gia Lam districts. In these districts, the drainage and wastewater systems rely on gravity and have not been developed as full networks. The existing systems are mainly conventional drainage infrastructures and canals are not properly channelized. A project focused on the modelling of Long Bien and Gia Lam flooding indicates that a combination of natural and man-made changes will significantly increase the risk of flooding. Without appropriate measures, by 2030, the total area suffering from heavy flood will increase to at least 65 per cent and almost of one fifth of the districts will be vulnerable to flooding since the current drainage systems can only handle rainfall with a return period of 1.54 years.[19]

A multi-stakeholder approach required for flood management

Although responsibility for the wastewater drainage management lies within Hanoi Sewerage and Drainage Company (HSDC), other stakeholders are involved in retention water basin (urban lake). These include Department of Natural Resource and Environment, local authority, private owners, etc. HSDC has digitalized of the network and updated it to a GIS-based system. HSDC has also built a monitoring centre to track rainfall-related flooding events.

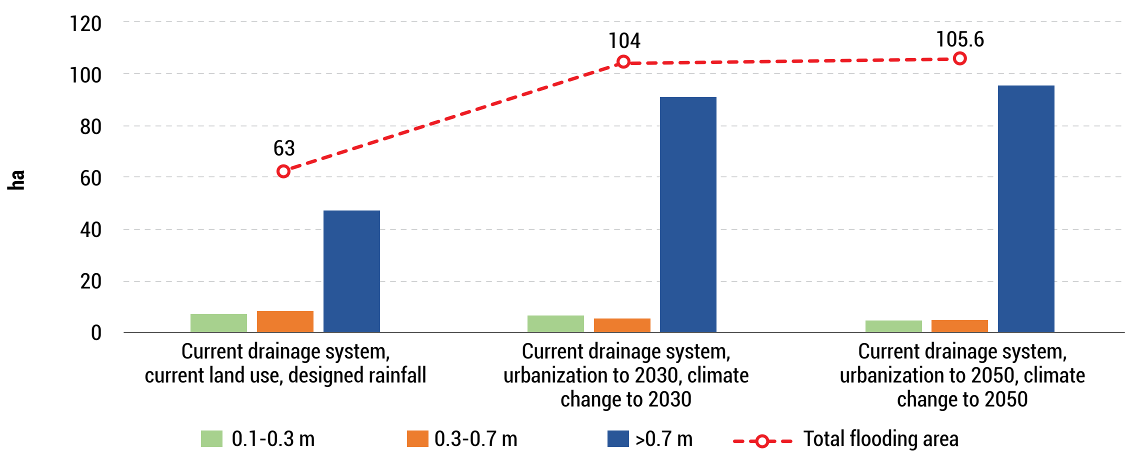
Hanoi has also developed a management structure for extreme flood scenarios. In this structure, the Hanoi Steering Committee for Natural Disaster Prevention and Control, Search and Rescue takes the central role in providing the guidance, plan development, and coordination of disaster prevention and control[10]. Under the guidance of this Steering Committee, districts develop their strategy for disaster prevention and control, search and rescue, which needs to be revised annually. HPC CP also approves on a yearly basis Hanoi City dyke protection plans for critical dyke sections, relief plans to ensure the lives of Hanoi people, and plans for responding to natural disaster and to emergency situations of the city's reservoirs. These plans complement the districts' strategies to form a solid protocol for extreme event management and relief measures in the city.

Sustainable urban drainage system for flood mitigation

Sustainable urban drainage systems (SUDS) are drainage solutions designed to reduce flooding risks. They provide an alternative to the direct channelling of surface water through networks of pipes and sewers to nearby watercourses, aiming at reduction of flooding, improvement of water quality, and enhancement of the amenity and biodiversity

19 World bank 2020 "Policy note: Hanoi – Toward a water pollution and flood free city"

Figure 42: Cost of no action on flood management in Long Bien and Gia Lam districts[10]



value of the environment. SUDS achieve this by lowering flow rates, increasing water storage capacity and reducing the transport of pollution to the water environment.

In the case of Hanoi city, SUDS can be considered as a Source-Pathway-Receptor approach to manage flooding and pollution risks. To mitigate urban flooding risks, Hanoi has been implementing specific interventions at the source, the drainage system, and the receiving water basins (rivers). Much of current drainage system for Hanoi City are combined wastewater and rainwater systems that increase the charge on the drains. Extracting lessons learned, Hanoi is focusing on the separation of sewerage and drainage systems for new urban areas to better manage stormwater for flood mitigation.

Source control solution

Rainwater is harvested from the micro-scale to the medium scale. A demonstration project on drainage system improvement has been implemented for flood mitigation for Nguyen Khuyen Street and Temple-Of-Literature (Van Mieu – Quoc Tu Giam) areas which are often being flooded with the rainfall event of 30 – 70 mm/hr. An underground rainwater tank with a volume of 2000 m^3 is constructed and placed at the yard of Ly Thuong Kiet secondary school. During heavy rains, runoff is collected via a 22-m collection pipe and then stored at the underground rainwater tank. There are three submerged pumps placed in the tank (two working pumps and one standby pump) to pump rainwater into drainage system. This rainwater harvesting system reduced the floods in Nguyen Khuyen street. For example, with a rainfall event of 138 mm/2 hrs, the rainwater system reduced the flooding duration from 18 hours to 1-2 hours.

At micro-scale, roof-harvested rainwater is a technique that can be used for flood mitigation. Roof-harvested rainwater systems have been implemented at the community-based level, for example at Hanoi University of Civil Engineering (Figure 6). Two roof-harvested rainwater systems installed at the university contributed to delaying the time of concentration and the peak flow of the runoff, resulting in flood mitigation at the university. Harvested rainwater was then treated to supply drinking water to students and lecturers[20].

20 Nguyen Viet Anh et al., 2020 “Policies study on rain-water harvesting for drinking in Vietnam” – final report for WASAT

Figure 43: Rainwater storage tank for flood mitigation in Nguyen Khuyen Street

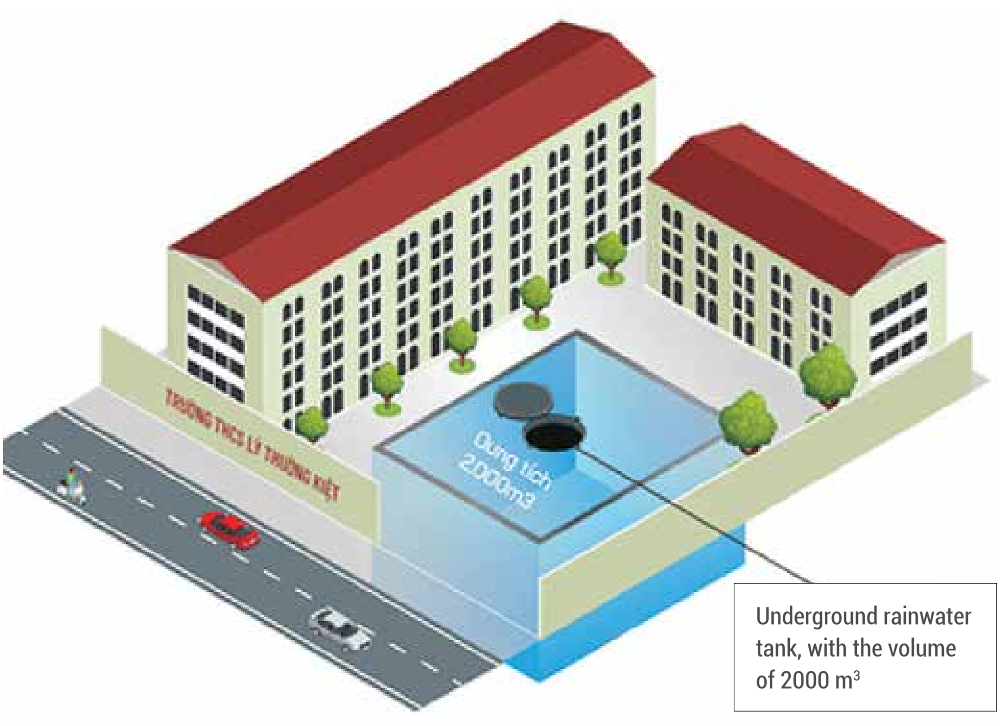


Figure 44: Rainwater storage tank at Hanoi University of Civil Engineering for flood mitigation and drinking water supply

Drainage system improvement (Pathway-Receptor control).
Source: Nguyen Viet Anh et al. 2020 "Policies study on rainwater harvesting for drinking in Vietnam" – final report for WASAT

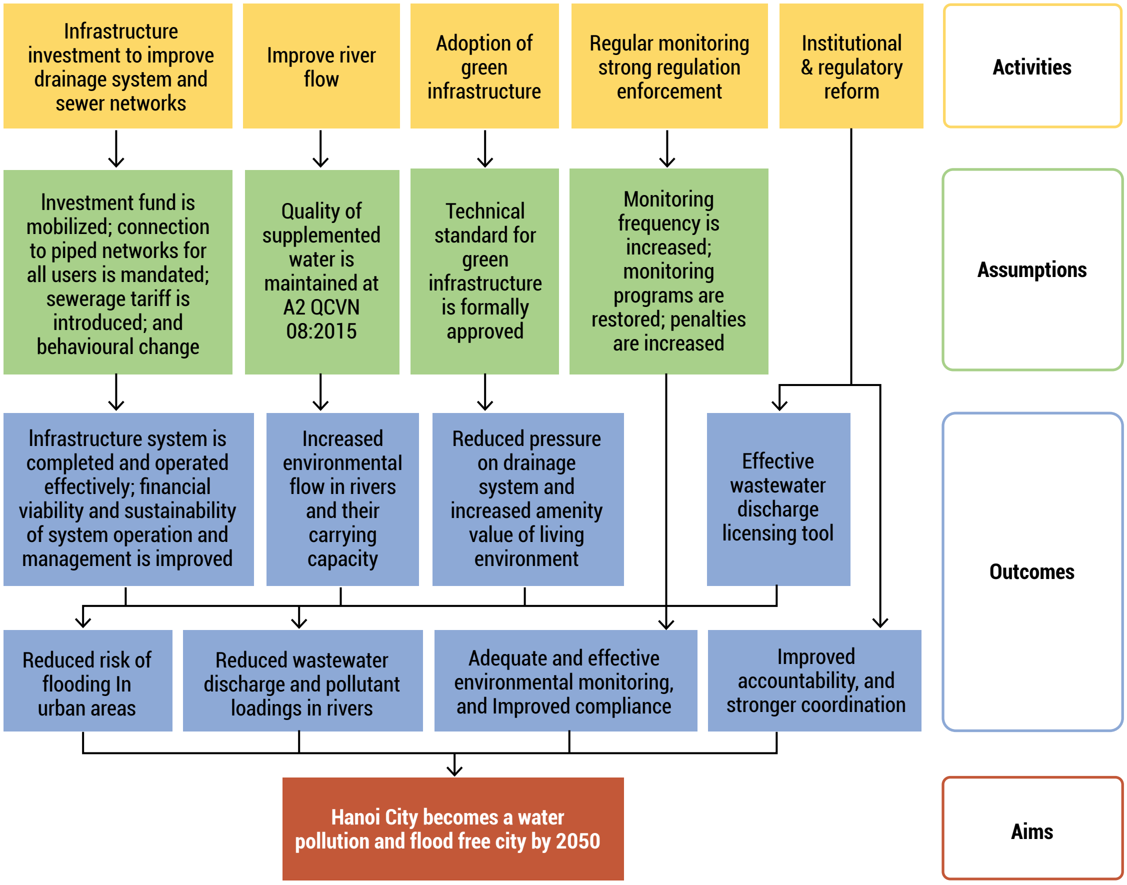
After historic floods in 2008 (which killed 18 people), Hanoi spent trillions of VND to build a drainage system and pumping stations. To prevent floods in the western part of the capital city, VND 7.4 trillion was spent to build Yen Nghia pumping station in Ha Dong district. With a capacity of 120 cubic meters per second, the station can pump water from Nhue River's valley to Day River, easing floods in the districts of Ha Dong, Thanh Xuan and Nam Tu Liem. In recent years, Hanoi has spent more than VND 15 trillion on anti-flood solutions and the improvement of reservoirs in inner city districts and the western part. Streets still turn into 'rivers' whenever it rains heavily.

In 2019, a study was launched with support from the World Bank to tackle water pollution in the city's key rivers. The study aims to develop an effective and comprehensive management and investment programme to address water pollution in To Lich, Nhue, Day and Tich rivers, by improving drainage and wastewater management in prioritized locations – Long Bien and Gia Lam districts. Technical challenges identified in the study include: rapid population growth and urbanization, dwindling water resources in rivers, infrastructure deficit (i.e. shortage of wastewater collection and treatment capacity, lack of tertiary sewers and household connections to wastewater collection network, absence of stormwater pumping stations in two districts), and slow implementation progress of Hanoi Drainage Master Plan. Building on the baseline assessment, the study proposed engineering interventions, both grey and green, to alleviate the problems, adopting the Source-Pathway-Receptor approach. Hydraulic and water quality modelling were conducted to assess the effectiveness of these interventions in short, medium and long term. Recommendations from the study are presented below. They provide an example of a comprehensive approach, involving both infastructure development and institutional reform, in order to mitigate floods, while protecting rivers fron wastewater pollution.

Figure 45. Yen Nghia pumping station

Source: https://vinadicme.com

Figure 46: Recommendation of investment theory of changes for SUDS in Hanoi[11]



Source: World bank (2020): "Policy not: Hanoi – Toward a water pollution and flood free city"

Wastewater reuse in peri-urban Hanoi

Policy to support the reuse of wastewater

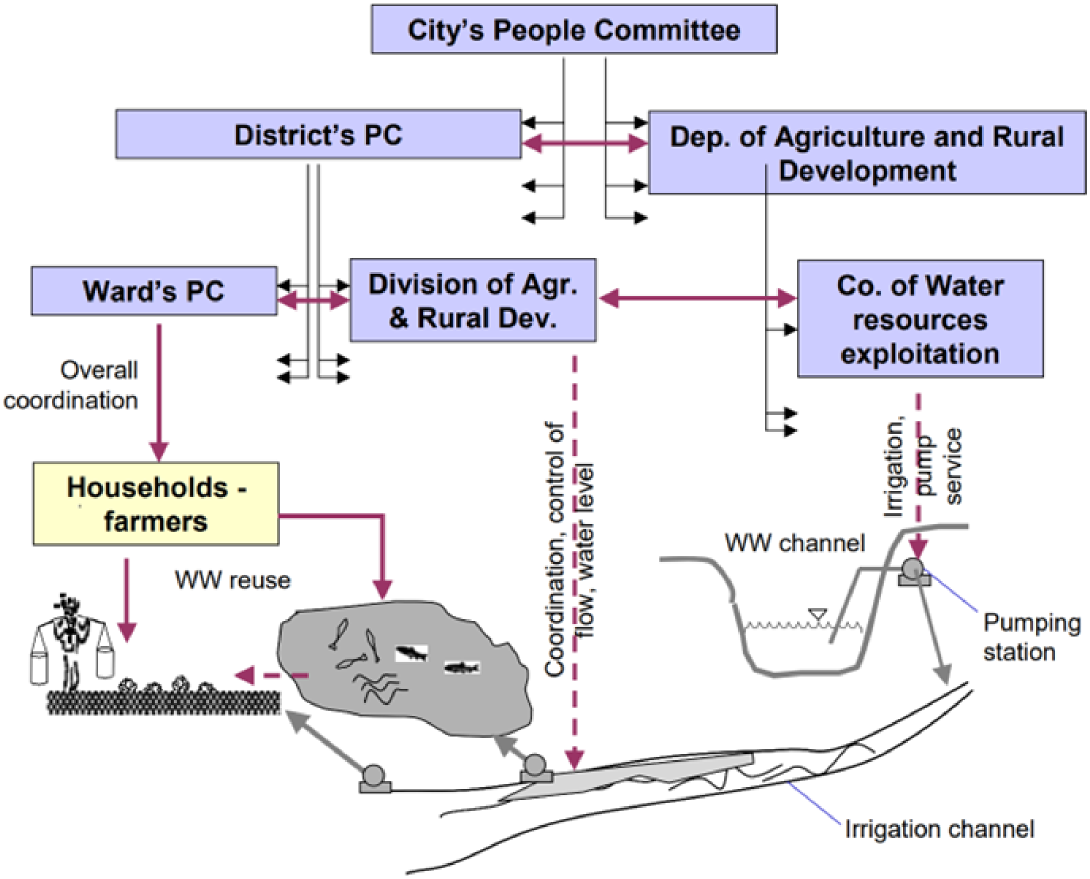
Hanoi authorities recognize the importance of wastewater-fed fish culture and have included it in the Master Plan of Hanoi City Development and in the Master Plan for Fisheries. National level policies have been provided to support the reuse of wastewater in the city. For example: the Decision No 1930/QD-TTg dated November 20, 2009 describes the development of urban drainage and wastewater up to 2025 and a vision to 2050, stating that about 20 – 30 per cent of treated wastewater should be reused for plant watering, road cleaning, and other purpose in the city. Article 72 of the Law on Environmental Protection 2020 provides for the reuse wastewater that satisfies environmental protection requirements.

Several other pieces of Vietnamese legislation, spanning water exploitation and supply, sanitation and pollution control also endorse resource recovery and reuse (RRR) including wastewater treatment and use. The key laws of relevance is the Law on Water Resources (LOWR, 2012), as well as multiple decrees and decisions that accompany it. Reuse of wastewater is a part of integrated water resources management which has become an overarching viewpoint of Vietnam and has been shown throughout the National Strategy on Water Resources.

Institutional arrangements for wastewater reuse management

In peri-urban areas, where HSDC do not operate, responsibility for wastewater management rests within the Department of Rural and Agricultural Development (DARD) of Hanoi City. This is the case of, for instance, Thanh Tri (south of the Hanoi).

Figure 47: Management arrangements for wastewater management in peri-urban areas of Hanoi[19]



The management of wastewater reuse also involves a local people committee (Figure 12). Wastewater is extracted from drainage channels and reused for irrigation or rice paddy fields and vegetable production which are later sold in local markets in and around Hanoi. For wastewater reuse, there is internal agreement in relation to the pumping of wastewater to the paddy fields, or to individual fishponds. The fishpond owner pays pumping expenses. Pumping service is provided by a company for exploitation of water resources, under the district's Division of Planning and Rural Development.

Practice of wastewater reuse

Over the last decades, famers in suburban areas of Hanoi have practiced reuse of wastewater in aquaculture and agriculture. Evidence shows about 658,000 farmers use wastewater to irrigate 43,778 ha of land in Hanoi in 2008[21], mostly in Thanh Tri district and Hoang Mai district (Box 25). Most of this reuse is considered unplanned and informal[15]. It is estimated that reuse of wastewater in fishery brings a significant financial benefit with an increase of 2 to 2.5 times in comparison with non-wastewater-fed-fishponds[22]. In the case of vegetable cultivation, famers can get 10 – 15 per cent greater yields and 10 – 20 per cent higher financial benefit when reusing wastewater for irrigation[16]. A study on the reuse of wastewater in urban and peri-urban area of Hanoi shows about 700,000 farmers are estimated to reuse wastewater in agriculture and aquaculture [23]. Most users were located along Hanoi's main wastewater conveyance and treatment system as shown in Figure 48.

21 Evan et al., 2014 "Policy support for wastewater use in Hanoi"

22 Nguyen Ngoc Thu, 2015 "Urbanization and Wastewater Reuse in Peri-Urban Areas: A Case Study in Thanh Tri District, Hanoi City"

23 Fuhrimann, S., Nauta, M. and Winkler, M. (2019). Disease burden due to gastroenteritis infections among people living along wastewater reuse system in Hanoi, Vietnam. In: J.B. Rose and B. Jiménez-Cisneros, (eds) Water and Sanitation for the 21st Century: Health and Microbiological Aspects of Excreta and Wastewater Management (Global Water Pathogen Project). (S. Petterson and G. Medema (eds) Part 5 Case Studies), Michigan State University, E. Lansing, MI, UNESCO. https://doi.org/10.14321/waterpathogens.68

Box 25: Wastewater reuse in Hoang Mai District, Hanoi city[ii]

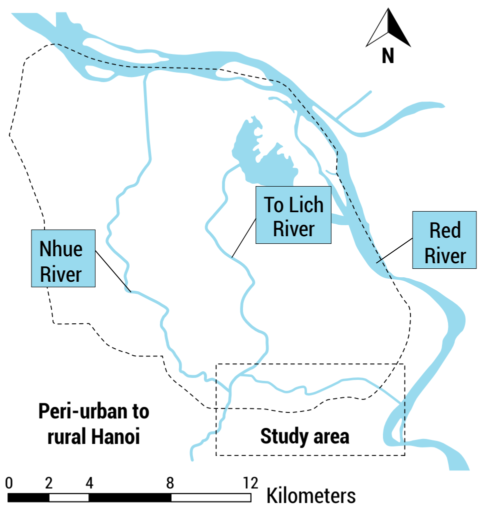
Hoang Mai is a peri-urban district in the south of Hanoi undergoing intensive urbanization. A large part of the city's wastewater flows through the district prior to discharge into the Nhue and Red rivers. Wastewater that flows from the city is widely-used by farmers living on the edge of the city. The sewerage and drainage system in Hoang Mai was built to receive a mix of domestic wastewater and runoff and the flow is directed to the irrigation network on the fields. With increased urbanization, several canals, formerly used for irrigation, have become sewerage and drainage canals. As urban-based activities intensify the demands on existing water resources increase and, at the same time, local watercourses become increasingly polluted, wastewater has become increasingly used for aquaculture and irrigation – either directly or indirectly. In some wards of Hoang Mai district (such as Yen So, Hoang Liet, Thinh Liet, Tran Phu, Linh Nam), untreated wastewater is extracted from drainage channels and reused for irrigation or rice paddy fields and vegetable production, which is a traditional livelihoods activity and a major income source in Yen So Ward, Hoang Mai district. There are 20 ponds with a total area of 185 hectares using wastewater for feeding

ii Nguyen Viet Anh et al., 2005 "Decentralized wastewater management in Vietnam – a Hanoi case study"

There is limited regulation of wastewater reuse in Hanoi. Although there are minimum standards, enforcement and monitoring have been difficult due to limited financial resources. City authorities have called on farmers to observe safe and hygienic production practices, but the enforcement of regulations is still limited.

In recent years, increasing amounts of contaminants in untreated wastewater, mostly from industrial and service activities, has led to the decline of wastewater reuse in aquaculture. For instance, wastewater-fed ponds only use 10-30 per cent wastewater in ponds, which is a considerable reduction from 10 years ago. Untreated wastewater for aquaculture and irrigation has become a great concern for users and farmers. Toxins in the wastewater have killed fish and some cases of poisoning due to consumption of unsafe vegetable have been reported. Nevertheless, there is still demand for wastewater. A 2010 study focuses on the quality of domestic wastewater in Hanoi City in terms of nutritive value and potential risk for agriculture found that Hanoi wastewater contains high concentration of organic matters - nutrients such as N, P were found at a rich concentration, which is a good for agricultural irrigation. However, it also contained potentially toxic elements such as 1.09-2.14 µg Cd/L, 0.16-0.33 mg Cu/L, 2.75-4.02 µg Pb/L, 0.20-0.34 mg Zn/L and 0.22-0.44 mg Mn/L. These quantities of heavy metals were higher than in natural river water, and posed risks to soil biota and human health.

Figure 48. Study area where 700,000 farmers reuse wastewater for agriculture and aquaculture[17]



Legislation and practice gap on wastewater reuse

Reuse is receiving attention in the city and district development plans. Techniques and skills developed are far from being sustainable and optimal in achieving the dual objectives of aquaculture production and treatment of the wastewater. Further studies are required to improve the effectiveness of wastewater-fed fishpond systems in terms of wastewater treatment and reuse through aquaculture, rice and vegetable culture and their potential health risks.

Although legislation documents support wastewater reuse in agriculture and aquaculture, there is limited guidelines to facilitate implementation. Key laws (Law on Environmental Protection 2020 and the Law on Water Resources 2012) endorse the reuse of wastewater but the technical guidance is still lacking, especially to mitigate potential health and environmental impacts.

Worker working in ditch for sewage system in the city in Asia © Shutterstock

10

The way forward — bringing sanitation and wastewater management to the heart of urban development

Drawing on existing literature and primary data collection across 18 cities, this study has underlined the scale of the challenge in strengthening sanitation and wastewater management at the global level, while also demonstrating that many inspiring examples exist for cities and countries to follow. In this chapter we synthesize key conclusions and recommendations.

The report has highlighted the pace of urbanization worldwide, a huge driver of economic growth but also a potential vector of environmental and human health degradation. While firmly established in high-income countries, urbanization is a fast-revolving reality in less wealthy areas like Africa and South Asia for example, with fewer resources and capacity to absorb the influx of people. As a result, the huge potential of urbanization for countries' development is turning into a threat to the environment as well as human health. Reaping the benefits of urbanization requires much greater attention to basic services such as health, education, transport, safe water supply, and solid waste. In wastewater and faecal sludge management, it requires governments to adopt a public service approach, delivering against a clear public mandate to ensure services for all.

The report lays bare that wastewater and faecal sludge management remain on the fringe of urban development. The urban development sector seldom appreciates the critical role of sanitation and wastewater in improving public health and eradicating poverty and inequality in cities and human settlements. While cities have made significant progress in extending water services, globally, the management of wastewater and faecal sludge is not gathering the same level of attention. Whether because sanitation is traditionally seen as dealing with "disgusting" things or private matters, or because financial and technical skills are simply lacking, cities are sprouting and rapidly developing without due attention being paid to how to deal with wastewater and faecal sludge management.

In many countries, systemic under-prioritization of wastewater and faecal sludge management has led to sanitation systems which are not fit-for-purpose, from the point of excreta and wastewater collection up to treatment services. This is reflected in 1.9 billion people (around 25 per cent) globally using inadequate toilets, 3.6 billion people (nearly 50 per cent) not using safely managed sanitation and an estimated 56 per cent of wastewater treated globally. While these figures may represent slow but steady progress over the past 20 years, anticipated extreme weather brought by climate change are likely to setback these achievements in the absence of a strong public policy response.

The inspiring examples included in this report show that where systems are broken, they can and must be fixed. This report has showcased examples where political will has turned the tide: who would have thought one could safely swim in the Seine river, on the banks of Paris, one of the most densely populated city in the world? Of course, globally, most cities could not afford this type and level of treatment, nor would this be appropriate considering water consumption levels and service users payment capacity. But incremental approaches, involving low-cost technologies, can be implemented

Around the world, cities are beginning to develop the economic, institutional and regulatory measures required to ensure the agriculture sector and wider society can benefit from treated wastewater. Valorization of wastewater and faecal sludge into energy is moving beyond the pilot stage in many developing countries.

in the short to medium-term, as cities further develop and increase their financial capacities.

The invaluable resource treated wastewater and faecal sludge can provide to support the growth of cities will become apparent. Around the world, cities are beginning to develop the economic, institutional and regulatory measures required to ensure the agriculture sector and wider society can benefit from treated wastewater. Valorization of wastewater and faecal sludge into energy is moving beyond the pilot stage in many developing countries. Fixing sanitation systems should lead to wider use of these natural resources.

How can governments, city planners and their development partners move forward in practice? Drawing from a holistic analysis of the challenges involved in sanitation and wastewater management, the report identifies six priority sets of actions for achieving improved services and positive impacts on human health, the environment and cities' socio-economic development. Each set of actions is consistent with a public service approach to sanitation. These are presented in Box 26 below. In addition, research and peer-to-peer learning are highlighted as enabling factors that can help to accelerate progress and unlock barriers to change.

Each of the recommendations is further developed below.

1. Invest more, and more smartly

The extent of the global wastewater and faecal sludge management challenge calls for greater investments in the sector. Governments and city authorities, and their development partners, will not meet their commitments to SDG6 and related sanitation and wastewater targets without stepping up financial allocations.

Considering huge investment requirements, investing in wastewater and faecal sludge management needs to be done smartly, so that investments are both efficient (costs are minimized) and effective (impacts are maximized). Experience has demonstrated unless properly targeted, infrastructure investments in water and sanitation do not necessarily lead to better services for the urban poor. Smarter investment will involve:

- **Strong data systems as a basis for informed planning:** For many cities this implies lifting the blindspot represented by onsite sanitation services, so that city planners can embed all areas and conditions in their planning. There is an increasing body of knowledge globally on the types of data required to plan for onsite sanitation improvements. Investing in digital systems and leveraging new and emerging data sources is fundamental to achieving these aims. Additionally, digitizing payments and sounds financial accounting can act to de-risk investments for financiers, and open the door to innovative revenue share financing models.

- **Detailed context-specific planning to avoid basing investment decisions on external trends**: This means understanding local conditions, including physical conditions such as wastewater and faecal sludge characteristics, topography, climate change hazard and risks, and socio-economic conditions, as well as the intended use of treated wastewater and faecal sludge by-products (whether valorization or discard). Context-specific planning will mitigate the risks of implementing technologies and infrastructure management not suitable for the context. For instance, combined sewerage and stormwater systems are not suitable where rainfall can occur frequently with high intensity; similarly, where most households already have septic tanks, it will be difficult to connect them to a sewerage system without strong incentives.

- **Adopting an incremental approach that prioritizes access to containment for all and cost-effective containment options**: In many cities the problems with wastewater and faecal sludge begin at the containment stage, with households using inadequate toilet facilities or even practicing open defecation. Addressing the issue of poor containment should be an integral part of governments and city planners' response to wastewater and faecal sludge management.

- **Considering emptying and transport in the planning of faecal sludge treatment**: This study has underlined that FSTPs are often constructed but then under-used, and

Box 26: Recommendations and enabling factors

Priority Actions:

1. Cities need to invest more, across the sanitation service chain, and invest more smartly, with specific attention to the environmental context as well socio-economic conditions and climate change risks.

2. Wastewater and faecal sludge management services must be integrated with national and local urban policies, strategies and plans, including slum upgrading processes.

3. Roles and responsibilities with regards to sanitation, from policymaking to service delivery across the sanitation service chain, have to be clarified so that actors have clear mandates to deliver on.

3. Financial and human resources must be allocated to regulation design and enforcement, without which service providers will not have incentives to invest as they should.

4. National monitoring systems for sanitation, wastewater and faecal sludge management services must improve radically, with countries supported in developing credible public data systems incorporating all sanitation outcomes.

5. Cities need to adopt measures for safe wastewater and faecal sludge valorization, even ahead of the full development of sanitation services, to mitigate health and environmental risks associated with this resource.

Enabling Factors:

1. Funding for research into wastewater and faecal sludge management needs to continue and increase, to support the development of technologies and service models adapted to different contexts and resilient to climate change.

2. Peer-to-peer learning and south-south cooperation must be supported to share knowledge and inspire replication of best-fit approaches.

sometimes disused. A clear problem for treatment facilities is their location, often far from city centres (due to land scarcity and costs). As a result, private operators have few incentives to use FSTPs. City planners must find ways to make FSTPs more accessible; for example, by adopting decentralized small-scale plants located in different parts of the city.

- **Adopting appropriate service level standards, including for treatment:** In the same way as technologies cannot be simply replicated regardless of the context, service level standards cannot be imported. The progress in wastewater treatment and population lifestyle in developing countries have led to the adoption of stringent treatment standards, designed to treat pollutants found in high-income contexts. Where such pollutants and pathogens are not a major issue, standards should allow for lower treatment standards, yet high enough to meet local needs.

- **Investing in community engagement:** the radical changes required to bring about wastewater and faecal sludge improvements call for community buy-in, whether for investing in toilets or a sewer connection, regularly emptying household, shared and communal facilities or accepting the need to construct treatment facilities. Such community engagement requires training and investments in communication materials and fora.

- **Making use of all possible funding sources, while nurturing financial self-sufficiency and operational efficiencies:** No matter what technology is prioritized, considering the starting point of many cities, investment requirements will be large. Although many municipalities or utilities have been assigned or delegated the management of wastewater and faecal sludge, meeting these needs will require extensive support from central governments, including for accessing loans from IFIs. The sector needs to look beyond traditional instruments, including tapping into locally generated funds such as land value capture. In the meantime, promoting operational efficiencies, ring-fenced budgets and improved revenues, via regulation, can help reduce financial constraints. Digitization also holds potential for operational efficiencies and costs reduction.

2. Integrate wastewater and faecal sludge management services with wider urban development and slum upgrading processes

There are fundamental reasons for integrating sanitation initiatives with national and local urban policies, strategies and plans. In urban environments, issues such as water access, wastewater and faecal sludge management, drainage, health, street design and solid waste management are all inextricably linked. Poor drainage leads to flooding, causing damage to sanitation facilities. Rubbish collected in drainage canals can exacerbate the issue and lead to stagnant water, which becomes a breeding ground for disease. Pit latrines and septic tanks cannot be safely emptied if poor road access makes it impossible for emptying services to operate. And low-income urban residents may be unable to access services, and unwilling to invest in a better toilet, if they lack formal tenure. These interconnections mean that unless water, sanitation and solid waste management services are planned together, the risk of service failure is magnified.

A lady visits a toilet built by NAWASSSCO in Githima, Nakuru, Kenya © Brian Otieno

An integrated approach to basic services is fully in line with international strategic commitments. These include the New Urban Agenda adopted at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III) in Quito, Ecuador, in October 2016, and subsequently endorsed by the United Nations General Assembly in December 2016.

There is now an increasing body of case studies where sanitation improvements have been successfully integrated with wider urban development initiatives. These include Asian countries such as India and Indonesia, and Kenya and Mozambique within the African context. However, there is still a lack of practical guidance on how national governments and city authorities can navigate the complexities of intersectoral collaboration. Correspondingly, there is a need for further research and proactive dissemination of success stories in this area (see Enablers).

What then does integration practically involve? Below we outline five recommendations derived from experience in Africa and Asia:

- **Advocate for high-level government commitment to unblocking political and bureaucratic hurdles.** In Asia, a notable example of this commitment is the Government of India's Slum Improvement Project (SIP), implemented across cities in India in the 1980s and 1990s. The project incorporated water, sanitation, solid waste, drainage and road improvements to improve the quality of the city environment, delivering diverse economic and quality of life improvements.

- **Create structures for interdisciplinary and multi-sectoral collaboration, supported by the integration of slum upgrading into citywide strategic planning.** In Nairobi in 2017, the informal settlement of Mukuru was declared a Special Planning Area (SPA), due to its unique environmental, health and development challenges, resulting in the formulation of seven sector plans developed by a coalition of 46 organizations. Within the framework of this initiative, Nairobi City Water

Box 27: Selecting context-appropriate options for wastewater and faecal sludge containment, conveyance and treatment

This study has outlined that to deliver effective wastewater and faecal sludge management, the basic foundations must be in place, including large-scale and smart investment, clear mandates, and strong regulation. Beyond these foundations, there are a wide range of technical options available to planners and service authorities as part of the mix of services required to achieve citywide scale. The study has highlighted a number of options having strong potential, in climate change context:

Separate sewers can be an effective option when rainfall occurs frequently with high intensity. Combined sewer systems remain in widespread use globally, as demonstrated by the mapping conducted for this study, in which eight cities deploy such systems. While many combined systems are able to ensure wastewater and stormwater are safely transported and treated most of the time, these systems are vulnerable to overflowing when an excessive amount of rainwater is added to the flow of raw sewage. In turn, these overflows damage freshwater and aquatic ecosystems and present a major public health risk. This pattern of overflows can be seen across regions, notably in Europe and South-East Asia, including cities with relatively high levels of rainfall (such as Bandung, Changunarayan and Hanoi). Existing combined sewer systems may lack the capacity to handle the increasing amounts of stormwater runoff caused by continued urban growth and by climate change. To address these challenges, city authorities and urban planners can consider measures such as separating stormwater and sewage into separate pipes, increasing the capacity of the sewer system, and implementing green infrastructure such as rain gardens and permeable pavements. Within our sample, Hanoi provides an inspiring example, where separate sewerage and drainage systems are now being developed for new urban areas to promote flood mitigation (see Hanoi case study).

Simplified sewer systems offer a promising, low-cost approach for serving densely populated low-income urban settlements with existing trunk sewer infrastructure. These systems are already deployed in Brazil and have recently been trialled in Kenya and Tanzania. As for sewered service extension more generally, SSS must be accompanied by robust strategies to ensure demand creation and low-income customer uptake of connections to the network.

Nature-based solutions such as wetlands, waste stabilization lagoons, biological filters and anaerobic digestion have proven potential. Where land is available, wastewater stabilization ponds, as deployed in cities such as Dar es Salaam, can provide a low-cost, low-maintenance, high-performance wastewater treatment process suitable for use in low- and middle-income countries.

Container-based sanitation has potential as part of a mix of services in climate-vulnerable contexts, including as a waterless option in areas with water scarcity. Additionally, CBS is well suited to densely populated low-income settlements, because of the lack of capital infrastructure requirements at the containment level.

Decentralized faecal sludge treatment plants have an important role to play in supporting the long-term financial viability of pit emptying services, reducing transport times and promoting more efficient service delivery. These facilities must be supported by sustainable operations and maintenance arrangements.

and Sewerage Company and Nairobi Metropolitan Services successfully piloted simplified sewer systems in Mukuru, as a cost-effective way of leveraging the settlement's existing trunk sewer infrastructure. More broadly, Citywide Inclusive Sanitation should be incorporated in city development plans for onsite areas.

- **Place urban development departments at the centre of urban sanitation service planning**, to support the pro-poor targeting and expansion of sanitation services at the city level. Connected to this, governments must establish clear mandates, not only for urban sanitation (see Recommendation 3 below), but also for urban development, local government, and housing, among other functions.

- **Ensure institutional mechanisms for the promotion of community participation in all stages of the planning process**. In Mukuru, a participatory planning process led by Muungano wa Wanavijiji, the national federation of slum dwellers in Kenya, was also central to creation of the Integrated Strategic Urban Development Plan (ISUD), in a process involving consultation with over 100,000 households — making the initiative one of the biggest slum upgrading projects ever attempted.

Lack of clear mandates contributes to the paralysis of institutions when it comes to wastewater and faecal sludge.

- **Provide financial incentives through the creation of integrated funding streams**. Most external funding remains highly siloed within the sanitation sector, and tied to a short-project mode of delivery. Funding streams need to evolve to address integrated slum improvement, encouraging sanitation actors to partner with actors bringing other expertise. A further key step in supporting this agenda is the continued measurement and demonstration of the increased economic and social benefits that accrue from such integrated programmes: the added value to funders as a result of enhanced direct and indirect benefits must be emphasized as new evidence becomes available.

3. Clarify mandates across the sewered and onsite sanitation service chains

To date, many cities still lack clear mandates for wastewater and faecal sludge management. Municipalities and service providers are not fully aware of the extent of their responsibilities with regards to sanitation, possibly because national policies and strategies have not made them explicit. In particular, responsibilities for delivering services in unplanned settlements are not always well-known; and *what* services need to be provided can be unclear. Lack of clear mandates contributes to the paralysis of institutions when it comes to wastewater and faecal sludge. A critical first step to clarify mandates for sanitation is to conduct a legal review: such a review would clarify which agencies are responsible for which aspects of sanitation services, and any gaps or overlaps in mandates.

There are strong arguments for integrating responsibilities for sewered and onsite sanitation within a single service authority.

***Who* is in charge of sanitation services matters less than the clarity over *what* services they should provide**. The global mapping demonstrates a wide range of mandate structures deployed globally for urban wastewater and faecal sludge management. Responsibilities for sewered and onsite sanitation may be:

- **Integrated within a single utility**, as is commonly observed in Latin America (for example Medellin), and increasingly in Eastern and Southern Africa (for example, Nakuru and Dar es Salaam);
- **Split between the water and sewerage utility and municipality:** in Dhaka, municipalities are clearly in charge of onsite sanitation, while the public utility is strictly in charge of sewerage services;
- **Within the municipality only,** as in Trichy (still the default arrangement globally);
- **Delegated to the private sector:** Across contexts, the private sector is playing a key role in supporting the mandated authority to execute their responsibilities, whether through private delegated management of wastewater services, as increasingly seen in Europe, or through performance contracts for septic tank emptying.

Alternative models can also be observed, as in Hatyai City in Thailand, where sewered sanitation is the responsibility of a dedicated Wastewater Management Authority.

There are strong arguments for integrating responsibilities for sewered and onsite sanitation within a single service authority (see Chapter 6). This connects to sanitation planning, which must be on a long-term basis. Having one authority with lead responsibility can facilitate gradual, consistent and effective implementation of plans and strategies. Where institutions are adopting new responsibilities for onsite sanitation, sustained and structured capacity development of staff is essential to help manage this transition.

It is equally important that policymakers ensure mandates are inclusive. Rapid rural-to-urban migration is leading to increasing numbers of low-income urban residents living in slums and informal settlements on the periphery of towns and cities. A number of tangible measures can be taken to help ensure these residents receive access to sanitation services. At the policy level, these measures include enshrining the human right to sanitation in the constitution, as in Kenya and Burkina Faso; and promoting intersectoral coordination to integrate sanitation improvements into wider slum upgrading programmes.

Currently, few national and local governments have a clearly defined urban development policy, let alone a policy for water and sanitation in slums and informal settlements. This must be rectified to ensure policies promote inclusive service provision; and are responsive to the rights and needs of women, children and youth, older persons and persons with disabilities, migrants, indigenous peoples, and others that are in vulnerable situations, in line with the New Urban Agenda.

Within sanitation authorities, the global mapping affirmed the gender equity gap is profound. There is widespread under-representation of women at director and manager levels, despite evidence indicating that utilities, which tap into the female labour force are more profitable, competitive, and sustainable than others. There are still important barriers preventing women from playing a key decision making role, starting with girls facing gender bias in school when pursuing technical degrees; young career-women having to balance greater familial obligations than men; and mid-career women lacking networking opportunities. These barriers exist in many contexts, as demonstrated by only four service authorities within our sample reporting the existence of gender mainstreaming strategies. Potential measures to address gender mainstreaming in sanitation include transparent channels on promotion and salary structures, enforced government mandates on gender representation, and developmental leadership and training.

Without effective regulation, mandated authorities cannot be held accountable, in a meaningful but fair way, for the services they provide.

Finally, local governments and service providers must be supported in their critical role in the provision of sanitation and wastewater management services. The global mapping affirms that local and regional governments are at the forefront of the water and sanitation management challenge. Achieving citywide access will require strengthening the institutional capacity of these essential service providers, particularly in LMICs.

4. Allocate human and financial resources to regulation for greater accountability

Regulation is core to a public service approach to urban sanitation. Without effective regulation, mandated authorities cannot be held accountable, in a meaningful but fair way, for the services they provide, and citizens and ecosystems lack protection from the public health and environmental risks posed by inadequate treatment. The importance of effective regulation, coupled with current capacity gaps, highlights the need for greater human and financial resource allocation in this area.

The specific regulatory model is secondary to whether regulatory functions have been identified and are implemented. A wide range of regulatory models have been observed in the global mapping. In the African context, regulation by agency is developing fast, sometimes out-performing regulation by Ministry or by Contract. In this regard, Kenya, Tanzania and Zambia, where there is clear delineation between autonomous agencies with responsibility for economic and technical regulation of sewered and onsite sanitation, and national-level environmental authorities with specific roles in environmental regulation of these services, may provide examples to follow.

Environmental regulation is an important lever that drives investments in service delivery and must be strengthened. In many cities, standards for treatment and disposal of wastewater effluent and faecal sludge do exist and are commonly set at the national level. The enforcement of these standards is a widespread challenge, with environmental regulators lacking the capacity to conduct independent audits of service provider performance, and to spot check reporting from service authorities on the quantity and quality of wastewater treated. Some cities are also leading the way, as in Hamburg and Medellin, where the enforcement of environmental standards is a top priority.

Economic regulation of wastewater and faecal sludge services is nascent in many cities and deserves more attention. Many utilities and municipalities do not use strict methods for setting tariffs (often set as a per centage of the water bill), with limited consideration for the actual costs of service delivery. Promoting sustainable investments in wastewater and faecal sludge management calls for understanding the full costs of services and linking tariffs to those costs. This approach does not exclude that wastewater and faecal sludge services may be subsidized (with capital and operational costs benefiting from local government transfers); on the contrary, setting tariffs based on costs can help service provides to clearly formulate their funding gaps.

Other regulatory tools should be deployed to boost service providers' performance. First among these is public benchmarking, incorporating positive reputational incentives. Our mapping shows this tool to be commonly but not universally deployed across regions, in countries as diverse as Bulgaria, Colombia and Kenya. Stronger bottom-up accountability is also urgently required to raise public awareness of duties and rights relating to wastewater and faecal sludge management. Here regulators such as in Palestine are setting an example through large-scale campaigns and the development of accessible customer complaint mechanisms. Wider development actors also have a role to play in this area, for example by supporting regular surveys of public satisfaction with basic services.

5. Radically improve country-level monitoring of wastewater and faecal sludge management

Multiple countries across regions are on the path to embracing data systems as a key driver of sanitation service improvements, demonstrating what such a shift involves in practice.

National and city-level data on wastewater and faecal sludge management remains scarce in many countries, hindering service planning. Data is particularly lacking regarding onsite sanitation services, but sewerage services are not exempt. Many utilities that manage water and wastewater do not regularly publish wastewater services performance data. And where data is collected, they are scattered across multiple institutions with responsibility for sanitation, limiting capacities to use the data for informed decision making. Ultimately, many cities are making investments without the data systems required to plan or manage expected services and to ensure inclusion.

There is an urgent need for governments to invest in credible public data systems incorporating all sanitation outcomes (sewered and onsite) and promoting service quality and inclusivity. The need to invest in timely and credible data and information is one of the five accelerators identified under the UN-Water SDG 6 Global Acceleration Framework**.** This in turn involves radical strengthening of city- and country-level monitoring systems, beginning with enhanced capacity development support and connected resource allocations. Greater capacity development support, financial and human resources are required to assist countries in taking ownership of data, reporting data, connecting with statistical offices, and using data to make decisions. For example, the UN-Water Integrated Monitoring Initiative for SDG 6 (IMI-SDG6) supports countries in monitoring progress towards SDG 6, through a network of monitoring focal points in national line ministries involved in water and sanitation, as well as in national statistical offices. Robust national, municipal and utility-level data collected at the lowest administrative level on a regular basis and disaggregated, wherever possible, is necessary to enable reporting, manage local service delivery, inform investments and support regulation.

Multiple countries across regions are on the path to embracing data systems as a key driver of sanitation service improvements, demonstrating what such a shift involves in practice. The National Data Management Entity in Medellin, the CWIS-SAP tool in Nakuru (see **Nakuru case study**), and the National Sanitation Management Information System in Tanzania are examples of initiatives aimed at providing accurate information for both wastewater and faecal sludge treatment processes. In Kenya, the recently enacted National Sanitation Services Management Policy recognizes the need to develop strong compliance monitoring systems to underpin effective regulation including wastewater systems. In Asia, Thailand provides a strong example of rigorous national-level data management for wastewater treatment.

At the global level there have been notable improvements in data on the status of sanitation services. The UN Water Joint Monitoring Programme (JMP) initiative, implemented by WHO and UNICEF, does provide a global picture of sanitation services based on the SDG 6.2 monitoring framework, using combination of national surveys and statistical assumptions. The monitoring system still faces challenges, particularly with estimating, at national level, access to safely managed urban sanitation services.

A specific challenge lies within country-level reporting on wastewater treatment, including industrial, which can help inform the SDG 6.3.1. Globally, only a handful of countries have been able to share data on the quantity of wastewater produced

Leveraging the potential of treated wastewater requires safeguards and the development and enforcement of standards.

that has received treatment via global reporting systems. As a result, there is no global picture available of the volumes of wastewater treated. Though conducted on a small scale, our study demonstrates both the latent potential and the limitations of current monitoring capabilities in this area. In some cases where aggregated national-level data on wastewater treatment is lacking, it was possible to access this data through direct engagement with service authorities. This implies data can be accessed, but conducting such studies at a larger scale evidently requires comprehensive supporting systems to be put in place.

There is an important role for actors at the global level, including multilateral agencies, donors and international finance institutions, in supporting improvements to sanitation data management. International agencies can support the training of city authorities and service providers on how to monitor sanitation services, including the definition of global indicators and how they relate to national and city-level indicators. Strengthening country systems and promoting complementarity with global metrics will only help strengthen global monitoring.

As cities look to improve sanitation data systems, digital technologies offer opportunities. Investment in digital systems is often central to effective monitoring. Mobile applications are increasingly deployed to support real-time data collection and analysis, which can ultimately be used to strengthen city and national-level data systems. Digital assets - including smart meters, sensors, and other IoT devices – provide new and reliable data sources. When combined with geospatial, remote sensing, and other innovative data sources these open the door to new service models and improved planning. International agencies can also contribute directly to enhanced data collection and storage systems. For example digital approaches to wastewater quality monitoring have huge potential, but require initial investments, which some cities may not be able to afford.

Due to the multi-sectoral nature of urban sanitation, harmonization of indicators and data acquisition methodologies and tools is critical. National governments should prioritize the establishment of intersectoral platforms and conventions to coordinate investments in sanitation, as well as regularly reviewing data and data systems, to operationalize strategies and target those who lack access.

6. Implement measures for safe wastewater and faecal sludge valorization

A potentially significant shift is taking place, with wastewater increasingly viewed as a resource rather than a waste stream. Planned valorization of wastewater for agricultural purposes is taking place in countries such as United States, United Kingdom, Australia, Belgium, Singapore, and South Africa. Countries such as Israel have aspirations to reuse 100 per cent of treated wastewater in guiding master plans. Leveraging the potential of treated wastewater requires safeguards and the development and enforcement of standards. But in light of increased water scarcity and the water crisis already affecting many regions of the world, exacerbated by climate change, the global sanitation community must act now to ensure the potential of wastewater and faecal sludge reuse is fully realized.

This potential is far from being fully realized globally – and in fact the use of untreated wastewater is widespread (see Hanoi case study). Realizing the potential of wastewater and faecal sludge requires:

- **Opting for relevant technologies**, which allow valorization, and providing capital support to developing these technologies;
- **Legal and regulatory instruments** that set standards for valorization and licensing for the production and sale of by-products such as compost and biogas;
- **Institutional arrangements** to ensure the fair allocation of resources, especially for farming purposes; and
- **Incentives** that contribute to market building for by-products; for example, the provision of subsidies for faecal based (organic) compost; or support with community/end-user engagements to promote by-products.
- **Strong environmental monitoring and controls** to mitigate risk.

Enabler: Invest in further research and innovation on wastewater and faecal sludge management

There are numerous areas of research that can help the sector in delivering more innovative and effective wastewater and faecal sludge management services. Below we outline some of the key research priorities emerging from this study:

- Developing a stronger understanding of faecal sludge characteristics and how to anticipate them for more efficient sanitation systems designs, including in situ and off-site treatment;
- Guidance for designing contracts and service level agreements providing incentives for management of full chain of onsite sanitation services to treatment stage, in an integrated manner, just as is traditionally done for sewerage services;
- Development of guidance and tools to support the integration of wastewater and faecal sludge management with wider slum upgrading processes, building on the growing body of case studies in this area;
- Development of reliable, empirical, field-based methods for characterizing and estimating faecal sludge at scale. Because of the high variation and variability of faecal sludge generated, quantification and characterization studies will be required at the local level and based on the requirements specific to each location;
- Identification and development of cost-effective treatment processes for emerging pollutants and microplastics, to create a stronger foundation for the futureproofing of wastewater systems against chemical contamination;
- Further research into optimal climate resilient sanitation systems, including what is optimal from a cost perspective
- Further research into the feasibility and applications of wastewater-based epidemiological surveillance in low and middle-income contexts, including the contexts in which it can add value to public health decision making, and what is needed to plan and coordinate an effective wastewater surveillance programme, drawing on WHO interim guidance in this area.
- Investigating the potential of digital solutions and approaches in wastewater specifically, for which the evidence base remains thin at present;
- Finally, development of practical guidance on how to invest in the soft infrastructure of national and local authority data systems for assessing, planning, and improving services.

Peer-to-peer learning is a proven approach for addressing urban service delivery challenges.

Enabler: Support peer-to-peer learning and south-south collaboration

Peer-to-peer learning is a proven approach for addressing urban service delivery challenges. Sector support in this area can help to catalyze change in wastewater and faecal sludge management. Governments and local governments stand to gain immensely from the experiences of their peers and other organizations throughout the globe dealing with shared challenges. These are some examples of initiatives:

- **Water operators' partnerships (WOP) can help utilities in low- and middle-income countries leverage the knowledge and experience of other organizations to improve their operations**. WOP allows recipients to increase their planning and technical abilities and improve sanitation service delivery by implementing new strategies while being exposed to new technology and networking opportunities. Mentors improve skills and abilities by using knowledge to problem solve under a variety of settings; developing strategic ties for future alliances; and networking with peers to resolve shared challenges.
- Through the use of **South-South cooperation**, two or more developing countries may be able to work together to define objectives for the development of national capacity-building, engage in collective (inter-)regional activities, and exchange resources and knowledge.
- **Regional-level associations** such as ESAWAS, ADERASA, African Ministers' Council on Water (AMCOW) and African Water Association (AfWA) have a key role to play in developing guidance and facilitating knowledge exchange between countries, in key technical areas spanning policy development, regulation and service provision.

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Appendix

Appendix A: Glossary of Terms

Blackwater: Mixture of yellow water, faeces, and flushing water along with anal cleansing water. It may contain urine.

Biogas: Biogas is produced after organic materials, including those derived from plants and animals, are decomposed by bacteria in an oxygen-free environment, a process called anaerobic digestion.

Biosolids: Nutrient rich, semisolid wastewater byproducts. During wastewater treatment, the liquids are separated from the solids. These solids are biologically or chemically stabilized to form biosolids.

Centralized wastewater systems (technologies and hardware): Large-scale processes that gather wastewater from many users for treatment at one or a number of sites.

Combined sewers: Sewer systems designed to collect and transport both municipal wastewater and urban runoff.

Decentralized wastewater systems (technologies and hardware): Processes that deal with wastewater from institutions and small clusters of users at the neighbourhood or small community level.

Domestic wastewater: wastewater flows from residential settlements and services households.

Emerging pollutants: Any chemicals, whether man-made or naturally occurring, or any microorganism that is not often seen in the environment but has the potential to penetrate it and have known or suspected negative impacts on the ecosystem and/or human health. The prominent classes are pharmaceuticals, pesticides, disinfection by-products, wood preservation and industrial chemicals.

Eutrophication: The progressive accumulation of phosphorus, nitrogen, and other plant nutrients in aquatic systems, which causes harmful algal blooms, dead zones, and fish kills.

Excreta: Mixture of urine and faeces only (not mixed with any flushing water)

Greywater: Bathroom, laundry and kitchen water, sometimes mixed or treated along with blackwater

Improved water source: are those that, due to the nature of their design and construction, have the potential to deliver safe water.

Improved sanitation facilities: facilities designed to keep excreta away from human contact

Industrial wastewater: Water that has been discharged after being used in or produced by industrial processes and has no further immediate value to these processes.

Nonpoint source pollution: Sources of pollution resulting from land runoff, precipitation, atmospheric deposition, or land drainage.

Offsite sanitation A sanitation system in which excreta and wastewater are collected and conveyed away from the plot where they are generated, this relies on a sewer technology for conveyance.

Onsite sanitation A sanitation system in which excreta and wastewater are collected and stored or treated where they are generated.

Open defecation The disposal of human faeces in fields, forests, bushes, open bodies of water, beaches, or other open spaces, or with solid waste.

Persistent organic pollutants (POPs): Toxic substances impacting human health and the environment, such as Printed Circuit Board (PCBs), Dichlorodiphenyltrichloroethane commonly known as DDT, and dioxins. POPs may be found in the environment for very long periods of time and may bioaccumulate in the fatty tissues of living organisms.

Point source pollution: Pollution loads discharged at a specific location from conveyance methods

Safely managed and treated sanitation Facilities that are not shared with other households and where excreta are safely disposed of in situ or transported and treated offsite.

Sanitation Basic sanitation is defined as having equitable access to effective waste disposal or sewerage facilities that safely separate human waste from human contact.

Sludge: Faecal sludge: Undigested or partially digested slurry, resultant solid from the storage or treatment of blackwater or excreta

Wastewater sludge: originated from sewer-based wastewater collection and (Semi-) Centralized Treatment processes

Urban runoff: Surface runoff of rainfall and other forms of precipitation (e.g, snowmelt) in urban settings, where most of the land surface is covered by pavement and buildings that prevent water from infiltrating into the soil.

Wastewater: wastewater is produced by domestic, industrial, commercial, and institutional sources. Urban and agricultural runoff, which can be extremely contaminated, are also essential elements of the wastewater management cycle.

Yellow water: Urine which does not contain greywater and blackwater, rich in nitrogen and phosphorus

Appendix B: Introduction to wastewater and faecal sludge technologies

This section provides a technical introduction to treatment technologies and processes available to safely treat wastewater and faecal sludge. Primary data from the global mapping is integrated to explore the prevalence of different technologies and approaches in the focus cities.

Box 28: What you need to know on wastewater treatment technologies and processes

Physical, chemical, and biological treatment methods are typically used in wastewater treatment plants to remove constituents of concern found in wastewater (figure 49).

Physical unit operations are treatment methods relying heavily on the application of physical forces. Screening, mixing, sedimentation, filtration, and absorption are examples of physical unit operations. **Chemical** unit processes are treatment methods in which constituents are removed through the addition of chemicals or chemical reactions. Disinfection, oxidation, and precipitation are examples of chemical processes. **Biological** unit processes are treatment methods in which constituents are removed through biological activity. Activated sludge and trickling filter processes are examples of biological treatment processes. In treatment flow diagrams, unit operations and processes appear in a variety of combinations.

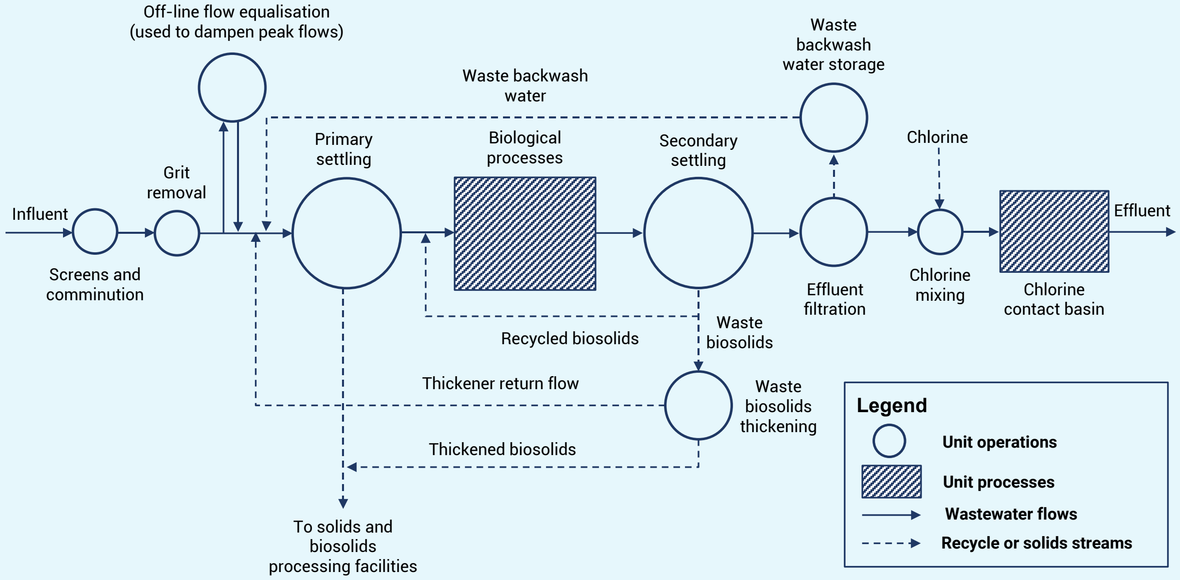
Physical unit operations are a major part of most wastewater treatment systems.

Units operations most commonly used include: (1) screening which is the first unit encountered in a plant and which is used to retain large solids found in the influent, (2) Flow equalisation used to overcome any operational problem caused by flow rate variations, (3) Mixing can be found in many phases of treatment and used for homogenizing, (4) Flocculation which promote the aggregation of small particles into large ones, (4) sedimentation and flotation promoting the removal of settleable and suspended solids accordingly, and (5) Filtration which depending on the filter size could remove a variety of constituents.

Chemical unit processes are usually used in conjunction with the physical unit operations and the biological units.

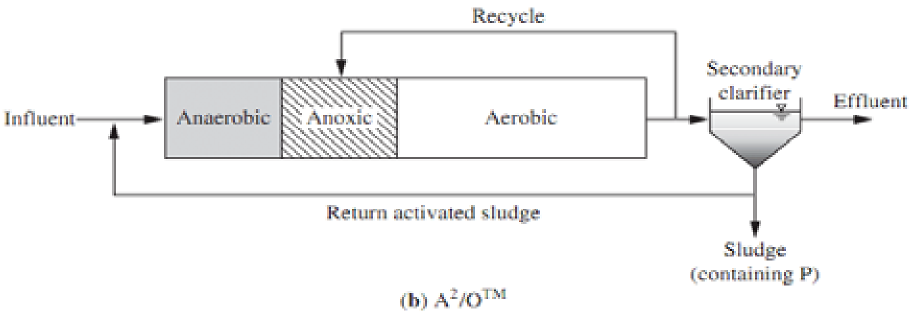
The main chemical processes used in a wastewater treatment plant include: (1) coagulation (2) precipitation (disinfection) (3) oxidation and (4) ion exchange. Chemical processes have been developed for the removal of many constituents of concern in wastewater influents. To date, the most important applications of chemical processes are for coagulation of particulate matter, precipitation of phosphorus and disinfection.

Figure 49: Conventional wastewater treatment plant



Source: Metcalf and Eddy

Figure 50: schematic diagram of the Anaerobic-Anoxic-Oxic process.



Source: Metcalf and Eddy

In high-income countries, the activated sludge process is the most widely used biological wastewater treatment process. This involves the use of microorganisms to break down organic matter in wastewater. The microorganisms are "activated" by adding oxygen to wastewater, which stimulates their growth and activity. This process breaks down the organic matter into simpler, less harmful substances. The activated sludge process can treat large volumes and is appropriate in every climate. The main operating cost in activated sludge is for aeration and mixing, but the process has high energy input demand and produces excess sludge that requires further treatment.

From the global mapping carried out for this report, Medellin, Sofia, Amman and Hanoi have reported using an activated sludge process for wastewater treatment. With the exception of Paris, these are the cities with the highest treatment capacities and higher country GDP compared with other cities. In some treatment plants, such as Sofia, the activated sludge process was coupled with chemical nitrogen and phosphorous removal, while in others, such as Hanoi, the aeration tank of the activated sludge process was coupled with an anaerobic and anoxic phase (Figure 50). This is a biological method for removing nitrogen and phosphorus, which contributes to sustainability through the generation of biogas, which can be used as a source of energy. The performance of this process can decrease during wet weather due to cold and low-strength wastewater that does not readily become anaerobic.

WWTPs in Paris, on the other hand, are based on biofiltration. This process involves the use of a bed of porous media, such as gravel or sand, through which the wastewater is passed. The porous media provides a habitat for a community of microorganisms, which break down the organic matter in the wastewater. One of the main advantages of biofiltration is that it is a natural, biological process that does not rely on chemicals or other artificial means to remove pollutants. This makes it a sustainable and environmentally friendly option for wastewater treatment. Biofiltration is also relatively simple and inexpensive to operate, making it a cost-effective option for many wastewater treatment facilities. In addition, biofiltration can effectively remove a wide range of pollutants from wastewater, including organic matter, nitrogen, and phosphorus. This makes it an effective treatment option for many different types of wastewater. Despite these advantages, there are also some limitations to the use of biofiltration. For example, the porous media used in biofiltration can become clogged over time, reducing its effectiveness. In addition, biofiltration is not effective at removing certain types of pollutants, such as heavy metals and some organic chemicals.

Table 14: Mechanical treatment plants within the study sample of the global mapping.

Country	City	Treatment facility	Treatment technology WW	Treatment technology FS
Colombia	Medellin	Aguas Claras WWTP	Activated sludge	gravity thickening tank, centrifugal thickening, anaerobic digestion, centrifuge dewatering
		San Fernando WWTP	Activated sludge	treated off-site
Bulgaria	Sofia	Sofia WWTP	Activated sludge and chemical phosphorus removal	Gravity and mechanical thickening, anaerobic digestion, mechanical dewatering and drying beds
		Voynegovtzi WWTP	Activated sludge and UV Disinfection	treated off-site

Country	City	Treatment facility	Treatment technology WW	Treatment technology FS
Jordan	Amman	As Samra WWTP	Activated sludge	anaerobic sludge digesters
		South-Amman WWTP	Activated sludge and chlorination	sludge thickening and dewatering
France	Paris	Seine centre WWTP	Physical-chemical decantation followed by Biofiltration	sludge thickening and incineration
		Seine aval WWTP	80% clariflocculation, biofiltration, and 20% pretreated and biological ultrafiltration	anaerobic digestion, thermal conditioning
		Seine Gresillons WWTP	Physical-chemical decantation followed by Biofiltration	anaerobic digestion, thermal conditioning
Vietnam	Hanoi	Kim Lien WWTP	Grit chamber and primary settling tank Anaerobic-Anoxic-Oxic, final settling and disinfection	sludge thickening and dewatering
		Truc Bach WWTP	Grit chamber and primary settling tank Anaerobic-Anoxic-Oxic, final settling and disinfection	sludge thickening and dewatering
		North Thang Long WWTP	Grit chamber and primary settling tank Anaerobic-Anoxic-Oxic, final settling and disinfection	sludge thickening and dewatering

Wastewater treatment produces solid or semisolid by-product material that needs to be treated. Apart from sludge thickening and dewatering, anaerobic digestion is a commonly used wastewater sludge treatment method.. It consists of a series of biological processes in which microorganisms break down organic matter in the absence of oxygen. Anaerobic digestion is a sustainable and environmentally friendly way to manage wastewater and organic waste. Anaerobic digestion technology holds great potential for achieving multiple socio-economic outcomes, including to promote renewable energy production, climate change mitigation, circular economy, improving food security and urban air quality.

Upflow anaerobic sludge blanket (**UASB**) **is a type of anaerobic reactor that has an important advantage for urban areas.** The UASB reactor is designed so that wastewater flows upward through a bed of granular sludge, which is made up of anaerobic microorganisms. As wastewater flows through sludge, the microorganisms break down organic matter, producing biogas. It is a compact technology that requires a small footprint and has low operating costs. This technology is suitable when the wastewater has a high organic matter. For better efficiency, UASB is often integrated with other processes such as filtration or stabilization ponds.

Sludge incineration involves burning the sludge at high temperatures, typically in a specially designed incinerator. This process destroys organic matter in sludge, reducing its volume and mass. One of the main advantages of sludge incineration is that it is a highly effective way to reduce the volume of sludge. This makes it easier and less costly to transport and dispose of the sludge. In addition, the heat generated by the incineration process can be used to generate electricity, making sludge incineration a potentially energy-efficient option. Another advantage of sludge incineration is that it destroys pathogens and other harmful microorganisms in sludge, making it safer to handle and dispose of. Despite these advantages, there are also some limitations to the use of sludge incineration. For example, the incineration process produces emissions, including air pollutants and ash, which must be carefully controlled to prevent environmental damage. In addition, the high temperatures of the incineration process can destroy some of the valuable nutrients in the sludge, reducing its potential value as a fertilizer.

In some countries, especially lower-income countries, nature-based solutions for wastewater treatment are becoming increasingly popular. These solutions aim to provide effective and economical wastewater treatment services that take advantage of functioning ecosystems with minimal dependence on mechanical elements. These processes use plants, soil, porous media, bacteria, and other natural elements to treat wastewater. Soil acts as a natural filter; nitrate is biologically taken up by plants and microorganisms; pathogens are diluted and killed in the saline environment by mechanisms such as predation by protozoa.

Waste stabilization ponds are the most common nature-based solutions. They are a low-cost, low-maintenance, high-performance wastewater treatment process especially suitable for use in low- and middle-income countries. But land availability and high market value of land restrict their use, especially in urban industrialized areas. In a waste stabilization pond system, wastewater is first passed through a primary treatment process, where coarse solids are removed from wastewater. Wastewater is then directed into a series of ponds, each with a different function in the treatment process. The first pond is an anaerobic pond, the second waste a facultative pond and finally, the third pond is the anaerobic pond.

From the global mapping carried out for this report, Dar es Salaam, Hatyai City, Bandung and Ouagadougou have reported using a stabilization pond for wastewater treatment (table 3). In Thailand and Burkina Faso, it was also combined with aquaculture systems (shallow ponds or wetlands). This is also very frequently done in Indonesia and China where fish, duckweed or aquatic vegetables are produced (Cisneros, 2011).

Constructed wetlands (CW) are another common and accepted natural treatment process used to remove organic matter, pathogens, and nutrients from wastewater through biodegradation, absorption, or filtration. Most of the CW input requires pre-treatment via a septic tank or other methods such as Imhoff tanks or sedimentation tanks. CW are highly efficient nature-based solution for wastewater treatment. Even after 20 plus years of operation, CW typically can remove up to 80 per cent of TSS, 92 per cent BOD, 83 per cent of COD, 46-90 per cent of total phosphorous and 16 – 84 per cent of total nitrogen (Oral et al., 2020). They are also capable of removing pesticides, heavy metals, pharmaceuticals, and other various contaminants of emerging concern. CW are widely used in China and Bangladesh to treat wastewater and produce fish and ducks (Cisneros, 2011). In addition, interest in CW on small and medium scales in Mexico has recently been expanding (Garca-Garca et al., 2015). Additionally, CW are now commonly used in European countries, particularly for small-scale projects (Bixio et al., 2006). The Netherlands and Belgium have carried out medium to large-scale initiatives, typically used for habitat construction, restoration, and provision of further treatment before release of the wastewater (Bixio et al., 2006).

Nature-based solutions can contribute towards a number of environmental, economic and health benefits. These solutions can promote circular cities with regenerative and accessible urban systems, provide aesthetic appeal and can support the physical and mental health of citizens. Economic benefits include reduced cost of treatment facilities, reduced economic loss due to flooding, water reuse and increased tourism and recreational opportunities. It requires large land area and significantly control over treatment performance to ensure the safety for humans and the environment.

Besides treating wastewater, nature-based solutions can be an essential feature for urban resilience in managing stormwater, carbon storage and sequestration, flood risk reduction, increase biodiversity, contributing to urban cooling through evapotranspiration, alleviating urban heat island and supporting urban green with local water resources (Oral et al., 2020). For instance, the HYDROUSA project in Greece (rainwater harvesting in water-scarce areas), the Gorla Maggiore water park project in northern Italy (urban wetland to protect the city from flooding and provide ecosystem services), and the KURAS project in Berlin (rainwater harvesting and water sewer overflow management) are all examples of such initiatives (Oral et al., 2020).

Table 15: Treatment technologies deployed at treatment plants from within the study sample of the global mapping.

Country	City	Treatment facility	Treatment technology WW
Indonesia	Bandung	Bojongsoang WWTP	Stabilization ponds consisting of anaerobic, facultative and maturation pond
Tanzania	Dar es Salaam	Mikocheni WWTP	Stabilization pond
		Mabibo WWTP	Stabilization pond
		Lugalo WWTP	Stabilization pond
		Buguruni WWTP	Stabilization pond
		Vinguguti WWTP	Stabilization pond
		Kurasini WWTP	Stabilization pond
		Airwing WWTP (NOT FULLY OPERATIONAL)	Stabilization pond
Bangladesh	Dhaka	Pagla WWTP	Primary sedimentation tank, facultative lagoons, chlorination
Thailand	Hatyai	Hatyai WWTP	Primary, facultative, maturation Pond and Constructed Wetland
Burkina Faso	Ougadougou	Kossodo plant	Microphyte lagoon system, anaerobic basins in parallel, facultative basins maturation basins

4.3.3 Faecal sludge treatment technologies and processes

Numerous treatment options are available to treat faecal sludge following desludging. In a typical process, faecal sludge is first dewatered. Dewatering can be done mechanically or via drying beds. Depending on the final objective, further treatment requirements may include the stabilization of organic materials and/or pathogen reduction. These treatment processes can include among others aerobic digestion, anaerobic digestion, and composting. Each of these methods has its own unique set of advantages and disadvantages, and the appropriate method will depend on a variety of factors, including the type of waste being treated, the availability of resources and equipment, and local regulations.

Within the cities in our study sample, Dar es Salaam and Ouagadougou's treatment plants both included unplanted drying beds. The treatment process of drying beds is based on filtration and evaporation. Sludge percolates through sand and gravel filter layers before being collected at the bottom by a drainage pipe for further processing. Dewatering usually takes several hours to days, whereas drying takes usually longer (several weeks to months). The drying time is affected by the properties of the sludge as well as the local climate. Drying beds are designed for solid-liquid separation, and not sludge stabilization. They have relatively low maintenance requirements, but the sand filter layer needs to be replaced regularly for reliable operation.

Pathogen reduction and stabilization can be achieved with co-composting. The global mapping indicates that a treatment facility in Hanoi is co-composting faecal sludge and the organic fraction of municipal solid waste. Due to the low carbon-to-nitrogen ratio, faecal sludge cannot be composted without the addition of carbon-rich organic matter. The C to N ratio for composting should be between 25 to 1 and 35 to 1. Composting technologies are low-cost, but they require space, optimum temperature and humidity, and faecal sludge must be dewatered before composting. The end-product is a compost that can be used in the same way as any other compost.

Treatment of faecal sludge in conventional WWTPs can lead to poor performance and eventual failure. There are opportunities for co-treating faecal sludge and wastewater, but the risk of failure is high. As previously stated, faecal sludge is different from wastewater and cannot be treated in a similar way. An essential recommendation for cotreatment is dewatering faecal sludge and sending the liquid fraction to be treated with wastewater and the solid fraction to be treated with sewage sludge. Typically, faecal sludge should never be added directly to secondary wastewater treatment but be treated by an appropriate sludge treatment process. However, in practice, many WWTPs in low and middle-income countries receive faecal sludge without mitigation measures.

The process of anaerobic digestion of faecal sludge is identical to that of sewage sludge. However, large centralized anaerobic digestors for faecal sludge are uncommon. In addition, the anaerobic digestion of faecal sludge has received limited research to date, and there is limited evidence on the methane potential of various types of faecal sludge. Similar to the anaerobic digestion of sewage sludge, the advantages of anaerobic digestion include less sludge and a smaller footprint than aerobic treatment, the production of methane and sludge for resource recovery, and the destruction of pathogens. The process is easily disrupted if the temperature and loading rate changes. This process operates most effectively under controlled and consistent conditions, and its operation requires extensive knowledge and skill.

Finding land that can be used to build treatment plants — while accounting for the "not in my back yard" (NIMBY) phenomenon — is a key challenge for FSTP construction in developing countries. This leads to large FSTPs commonly being built several kilometres away from emptying areas, generating high cost transports and in some cases making them inaccessible altogether to de-sludgers. As a result, faecal sludge is often dumped in more central open areas such as storm drains, sewers, and small fields. Implementing compact, decentralized systems in various cities will incentivize emptying businesses to use these sites and result in lower costs.

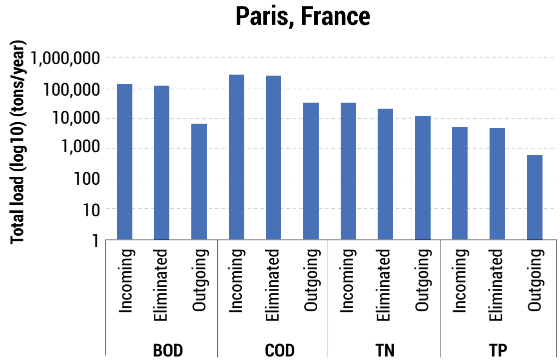
Table 16: Faecal sludge treatment facilities and technologies from select cities in the global mapping.

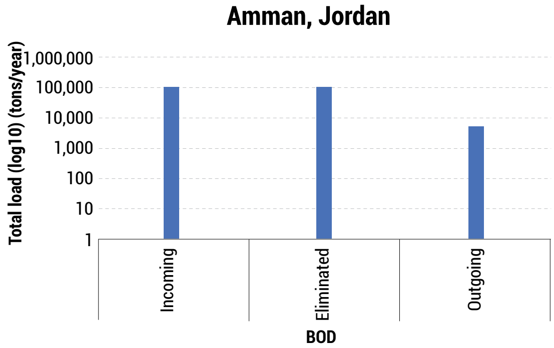
Country	City	Treatment facility	Treatment technology FS
Tanzania	Dar es Salaam	Mburahati DEWATS FSTP	bio-digester, anaerobic baffle reactor, expansion chambers and sludge drying beds
		Temeke Wailes DEWATS FSTP	bio-digester, anaerobic baffle reactor, expansion chambers and sludge drying beds
		Malakuwa DEWATS FSTP	bio-digester, anaerobic baffle reactor, expansion chambers and sludge drying beds
Thailand	Hatyai	Hatyai WWTP	Digesting pond
Burkina Faso	Ougadougou	Sourgoublia plant	Drying beds, lagoon system
		Zagtouli plant	Drying beds, lagoon system
Mali	Dioila	Dioila FSTP	Pre-treatment with anaerobic baffle reactor

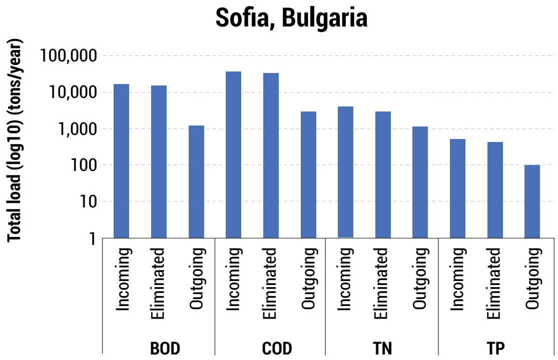
Table 17: Co-treatment of faecal sludge from select cities in the global mapping.

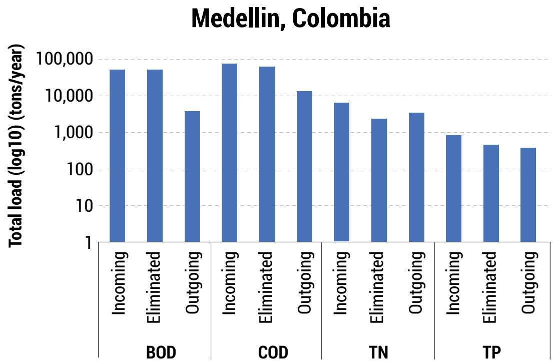
Country	City	Treatment facility	Treatment technology
Indonesia	Bandung	Bojongsoang WWTP	Stabilization ponds consisting of anaerobic, facultative and maturation pond
Vietnam	Hanoi	Cau Dien composting plant	Co-composting
Kenya	Nakuru	Njoro STP	No data
		Old Town STP	No data
India	Trichy	Pnajappur STP	Waste stabilization pond

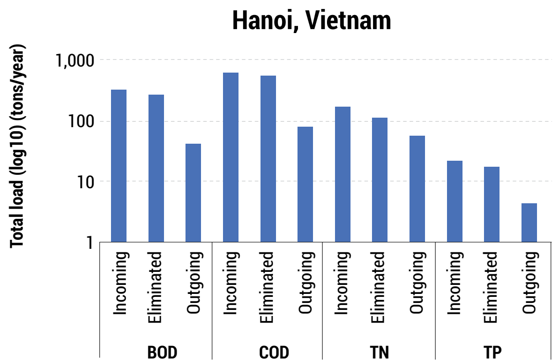
Appendix C: Global mapping – data on pollutant loads

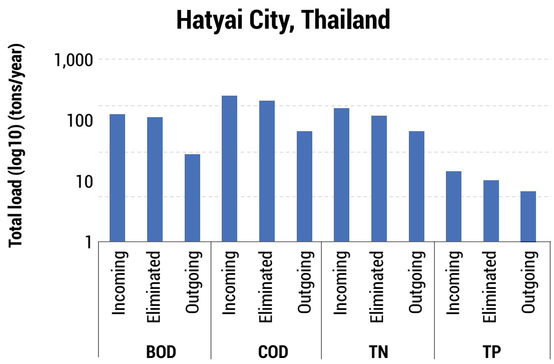


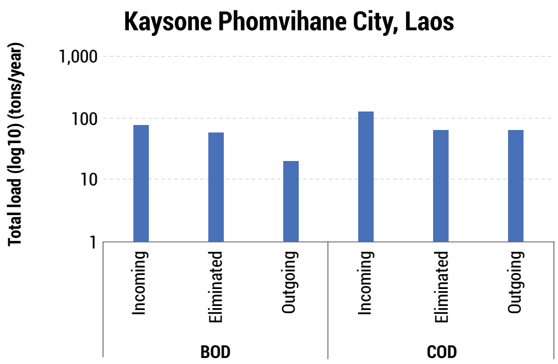


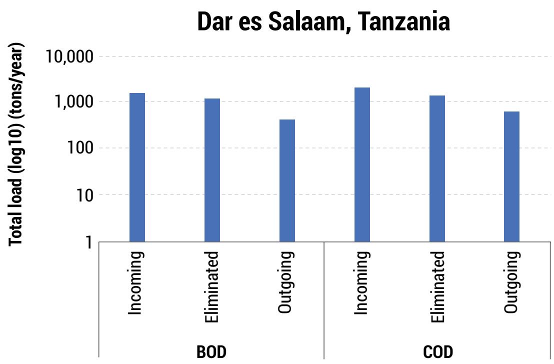


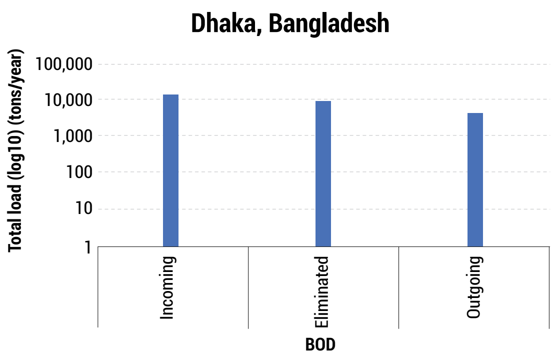


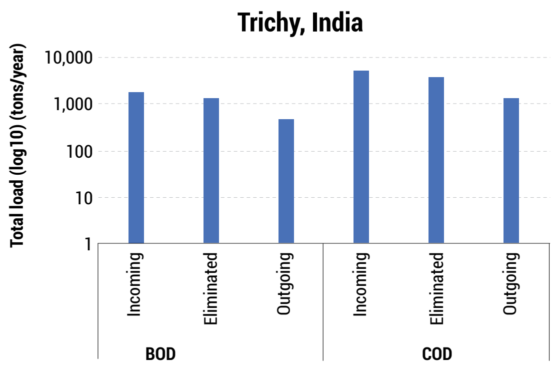


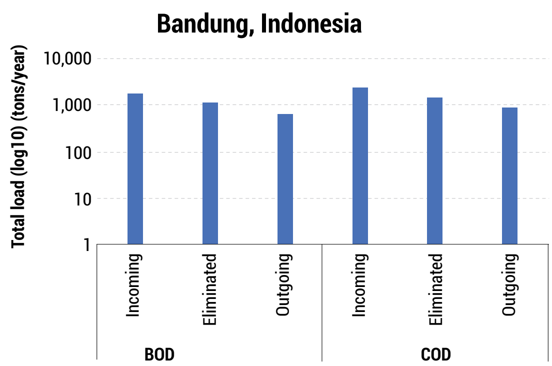







Dhaka, Bangladesh
Total load (log10) (tons/year)
100,000
10,000
1,000
100
10
1
Incoming
Eliminated
Outgoing
BOD


Trichy, India
Total load (log10) (tons/year)
10,000
1,000
100
10
1
Incoming
Eliminated
Outgoing
Incoming
Eliminated
Outgoing
BOD
COD


Bandung, Indonesia
Total load (log10) (tons/year)
10,000
1,000
100
10
1
Incoming
Eliminated
Outgoing
Incoming
Eliminated
Outgoing
BOD
COD

Appendix D: Global mapping – data sources

City	Source of data on wastewater and faecal sludge treatment levels
Amman	SAMRA
Bandung	▪ Bao, P.N (2020) Challenges and Opportunities for Septage Management in the Urban Areas of Indonesia – Case Study in Bandung City. ▪ Hendrawan, D et al (2013) Evaluation of centralized WWTP and the need of communal WWTP in supporting community-based sanitation in Indonesia. ▪ Prihandrijanti, M, Firdayati, M (2011) Current Situation and Considerations of Domestic Wastewater Treatment Systems for Big Cities in Indonesia (Case Study: Surabaya and Bandung). ▪ The Minister of Environment and Forestry Decree No. 68 (2016) Concern of Domestic Waste Water Standard. ▪ World Bank (2013) East Asia pacific region urban sanitation review: Indonesia case study.
Dar es Salaam	Energy and Water Utilities Regulatory Authority (EWURA)
Dhaka	Dhaka Water Supply and Sewerage Authority (DWASA)
Hamburg	Hamburg Wasser
Hanoi	▪ General data about Kim Lien WWTP, Truc Bach WWTP, and North Thang Long WWTP derived from JICA (Japan International Cooperation Agency) (2011) Study for Introduction of PPP for Sewerage Facilities in Hanoi – Final report. ▪ Influent and effluent quality data of Kim Lien WWTP, Truc Bach WWTP, and North Thang Long WWTP, and data of Cau Dien composting plant derived from Schoebitz, L, et al (2014) RRR-Project from Research to Implementation, Component 1 – Waste Supply and Availability Report – Hanoi.
Hatyai City	Hatyai City Municipality
Kampala	Kampala Capital City Authority (KCCA)
Medellin	Empresas Públicas de Medellín (EPM)
Nakuru	Nakuru Water and Sanitation Services Company (NAWASSCO)
Ouagadougou	Office National de l'Eau et de l'Assainissement (ONEA)
Paris	▪ Paris Municipality (2019) Annual Report on the price and quality of public drinking water and sanitation services. ▪ SIAAP (2020) Technical, financial, and Sustainable Development Indicators ▪ Progress and Sustainable Development Report. ▪ SIAAP (2021) Progress and Sustainable Development Report.
Sofia	Sofiyska Voda
Trichy	Trichy City Corporation (TCC)

Appendix E: Wastewater Treatment Technologies – Detailed Tabular Overview

Table E.1: Wastewater Treatment Technologies

Tech	Design Considerations	Treatment Principles	Context	Pros	Cons	Efficiency	Disposal/Use of the output	References
Septic tank H**, N** Blackwater, Greywater Primary	▪ Two watertight chambers, fully lined for storage as well as treatment ▪ Separation and polishing chamber	▪ Settling and anaerobic processes reduce solids and organics ▪ Heavy particles sink to the bottom, liquid flows, and scum (oil & grease) floats to the top	▪ Most widespread onsite treatment units worldwide	▪ Electric energy is not required ▪ Small land area requires (underground) ▪ Low capital cost ▪ requires little operation and maintenance ▪ Requires semi / unskilled labour ▪ Long service life	▪ Low treatment ▪ Regular desludging and further treatment required ▪ Desludging is an added expense for households	▪ Remove 50% solids ▪ 30-40% of BOD	▪ Sludge needs further treatment ▪ Effluent dispersed by using soak pit / leach field / further treatment	(Tilley et al., 2008; Nelson and Murray, 2008; Eawag, 2008)
Anaerobic Baffle Reactor H*, N** Blackwater, Greywater Primary Centralized	▪ Watertight tanks ▪ Septic tank followed by series of anaerobic tanks ▪ 3 to 6 up flow chambers connected with vertical piper or baffles	▪ First and largest tank removes most of the solids ▪ Forced flow of wastewater through baffles provide enhanced removal and digestion of organic matter ▪ Adding fresh cow dung or septic tank sludge can reduce start-up time to reach the full capacity	▪ Rural communities ▪ Area with relatively constant amount of blackwater and greywater generation	▪ Moderate land area required (underground) ▪ No electrical energy required ▪ Low capital cost when divided among members of small community ▪ Low operating and maintenance cost ▪ Low sludge production and consistent treatment	▪ Low reduction of pathogens and nutrients ▪ Requires expert design and construction ▪ Sludge and effluent	▪ 65-90% COD ▪ 90% removal of BOD ▪	▪ Sludge and Effluent require further treatment	(Tilley et al., 2008; Eawag, 2008)

Tech	Design Considerations	Treatment Principles	Context	Pros	Cons	Efficiency	Disposal/Use of the output	References
Anaerobic Filter H*, N** Blackwater, Greywater Primary / Secondary	▪ Fixed-bed biological reactor with filtration chambers in series ▪ Large surface area of filter is ideal to prevent clogging ▪ Common filter materials are gravel, crushed rocks or bricks, cinder ▪ Vented tanks to release odours and harmful gases	▪ Sedimentation tank (first chamber) removes majority of settleable solids ▪ Up flow operation ▪ As wastewater flows, filters trap particles (12 to 55 mm) ▪ Organic matter is degraded by the active biomass attached to the surface of the filter material	▪ Areas with constant generation of blackwater and greywater	▪ Moderate land area required (underground) ▪ No electrical energy required ▪ Low operating costs ▪ Long service life ▪ Low sludge production ▪ High reduction of BOD and solids	▪ Requires expert design ▪ Low removal of pathogens and nutrients ▪ Risk of clogging	▪ 90% ▪ BOD removal ▪ 15% nitrogen removal ▪	▪ Sludge and Effluent require further treatment	(Tilley et al., 2008)
Biogas / Anaerobic Reactor H**, N**, C** Blackwater, Sludge, Organics Primary / Secondary	▪ Airtight Chamber built as fixed dome or floating dome digesters ▪ Brick constructed domes or prefabricated tanks	▪ Anaerobic degradation pf blackwater, sludge and biodegradable waste that produce biogas in the fermentation processes in the reactor ▪ The gas collects at the top of the chamber, mixing slurry as it rises	▪ Where regular feeding is possible ▪ Rural areas of developing countries like China, India ▪ Mostly in Asia, Africa, South America ▪ European countries like Germany, Italy, France, Switzerland, and the UK	▪ Small area required (underground) ▪ Production of energy ▪ No electric energy required ▪ Low operating costs ▪ Minimal repair if designed and build properly ▪ Long service life ▪ Generation of renewable energy ▪ Digestate rich in nutrients	▪ Requires expert design and skill construction ▪ Requires further treatment ▪ Limited gas production below 15-degree Celsius	▪ From total housing manure collected, 70% may be treated	▪ Digested slurry that can be used as a fertilizer ▪ ▪ Biogas used for energy	(Tilley et al., 2008) (Jain et al., 2019)

Tech	Design Considerations	Treatment Principles	Context	Pros	Cons	Efficiency	Disposal/Use of the output	References
Nature Based Solutions								
Tech	▪ Design Considerations	▪ Treatment Principles	▪ Context	▪ Pros	▪ Cons	▪ Efficiency	▪ Disposal/Use of the output	References
Waste Stabilization Pond N*, C** Blackwater, Greywater, Secondary (Centralized)	▪ Large manmade water bodies used individually or linked in a series for natural and improved treatment ▪ Three different types of ponds i) anaerobic ii) facultative and iii) aerobic ▪ The ponds should be fully lined to prevent leaching	▪ Organic load treated in anaerobic pond (deep) through sedimentation and anaerobic digestion. ▪ Transferred to facultative pond where further BOD is removed (both aerobic and anaerobic processes). ▪ Aerobic pond is the shallowest of ponds that ensures sunlight to the depth for photosynthesis to occur.	▪ Most common and efficient method of wastewater treatment around the world	▪ No electrical energy required ▪ Low operating and maintenance costs ▪ Treat high-strength wastewater and achieve high quality effluents ▪ High reduction of solids, BOD and pathogens	▪ Requires a large land area ▪ High capital cost depending on the price of land ▪ Require expert design and construction	▪ 75% BOD removal ▪ When combined with algae and/ or fish, removes majority of nitrogen and phosphorus	▪ Effluent can be directly used for irrigation or aquaculture ▪ Can be discharged directly to surface water ▪ Sludge requires proper removal and treatment	(Tilley et al., 2008; Eawag, 2008; Strande et al., 2014; Nelson and Murray, 2008)

Tech	Design Considerations	Treatment Principles	Context	Pros	Cons	Efficiency	Disposal/Use of the output	References
Aerated Pond N*, C** Effluent, Blackwater, Greywater Secondary	▪ Large, mixed, aerobic reactor ▪ Ponds can be deeper (2 to 5 m) and should be fully lined	▪ High rate of organic degradation with mechanical aerators that provide oxygen ▪ It keeps the aerobic organisms suspended and mixed with water	▪ Rural and peri-urban environments ▪ Areas with inexpensive land	▪ High reduction of BOD and pathogens ▪ Resistant to organic and hydraulic shock loads ▪ Insects or odours removed if designed and maintained correctly	▪ Requires a large land area ▪ Constant source of electricity required high energy consumption ▪ High capital and operating costs ▪ Skilled manpower required for operation and maintenance ▪ Require expert design and construction	▪ Less than 60% BOD removal	▪ Sludge and Effluent require further treatment	(Tilley et al., 2008; Cisneros, 2011)
Free-Water Surface Constructed Wetland H*, N**, C** Effluent Stormwater Advanced treatment (After secondary/ tertiary)	▪ Channel or basin lined with an impermeable barrier covered with rock, gravel and soil and planted with native vegetations (cattails, reeds) ▪ Compartmentalized in at least two flow paths ▪ Water exposed to the atmosphere and direct sunlight	▪ Particle settle, pathogens are destroyed, and organisms and plants utilize the nutrients as water slowly flows through the wetland	▪ Areas with inexpensive land ▪ Appropriate for small sections of urban areas and peri-urban and rural communities	▪ No electrical energy required ▪ Low operating and maintenance costs ▪ Can be built with locally available materials ▪ Cheaper and less complex technology ▪ Economic benefits	▪ Requires large land area ▪ Long start-up time to work at full capacity ▪ Requires expert design and construction ▪ Regular maintenance to ensure the water flow is not blocked and the vegetation is periodically cut out	▪ High removal of suspended solids and moderate removal of pathogens, nutrients, and other pollutants (heavy metal)	▪ Cultivate fish and duck	(Tilley et al., 2008; García-García et al., 2015; Cisneros, 2011)

Tech	Design Considerations	Treatment Principles	Context	Pros	Cons	Efficiency	Disposal/Use of the output	References
Horizontal Subsurface Flow Constructed Wetland H*, N**, C* Effluent Blackwater Greywater Secondary	▪ Gravel and sand filled basin, planted with wetland vegetation ▪ ▪ Bed should be lined with an impermeable liner ▪ Small, round (3 – 32 mm diameter) gravel mostly used to fill the bed (0.5 – 1m depth)	▪ As wastewater flows horizontally through the basin, the filter material filters out particles and microorganisms degrade the organics	▪ Communities that have primary treatment (septic tanks) ▪ Suited for warm climate	▪ No electrical energy required ▪ Low operating costs ▪ High reduction of BOD, suspended solids, and pathogens	▪ Requires large land area ▪ Requires expert design and construction ▪ Risk of clogging ▪ Long start up time to work at full capacity	▪ High quality effluent ▪ Removal of COD 91.8, BOD 97, TSS 100% nitrogen compounds, phosphorous and different microorganisms		(Tilley et al., 2008)
Vertical Flow Constructed Wetland H*, N**, C* Effluent, Blackwater, greywater Secondary	▪ Swallow excavation or an above ground construction ▪ Planted filter bed, drained at the bottom ▪ Layer of gravel (min. 20 cm) followed by layer of sand and gravel ▪ Each filter should have an impermeable liner and an effluent collection system	▪ Mechanical dosing system pour wastewater from above ▪ Water flows vertically down through the filter and is collected in a drainage pipe ▪ Intermittently dosing of wetland (4 to 10 times a day) creates different phases of aerobic and anaerobic conditions ▪ The top layer is planted which helps maintain permeability in the filter and provide habitat for microorganisms.	▪ Communities that have primary treatment (septic tanks) ▪ Suited for warm climate	▪ Requires less land area and less clogging than other nature-based solutions ▪ Low operating cost	▪ requires constant source of electrical energy ▪ Requires more frequent maintenance ▪ Requires expert design and construction system ▪ Long start up time to work at full capacity	▪ High reduction of BOD, suspended solids, and pathogens ▪ Ability to nitrify due to good oxygen transfer		(Tilley et al., 2008)

Tech	Design Considerations	Treatment Principles	Context	Pros	Cons	Efficiency	Disposal/Use of the output	References
Mechanical Solutions								
Tech	▪ Design Considerations	▪ Treatment Principles	▪ Context	▪ Pros	▪ Cons	▪ Efficiency	▪ Disposal/Use of the output	References
Trickling Filter N*, C** Effluent Blackwater Greywater Secondary	▪ Fixed-bed, biological reactor that operates under aerobic conditions ▪ Usually 1 – 2.5 m deep, filters packed with lighter plastic filling can be up to 12m deep ▪ Filled with high specific surface area material (95% of them should have 7 – 10 cm dia) such as rocks, gravel, shredded PVC bottles	▪ Pre settled wastewater is continuously 'trickled' or sprayed over the filter letting the water to migrate through the pores causing degradation of the organics by the bio film covering the filter material	▪ Best suited for peri-urban or large, rural settlements ▪ Suitable for almost all environments	▪ Small land area required ▪ Efficient nitrification	▪ Electrical energy is constantly required ▪ High capital cost, skilled personnel for operation and maintenance ▪ Requires expert design and consideration ▪ Risk of clogging	▪ 80 – 90% BOD removal		(Tilley et al., 2008)
Up flow Anaerobic Sludge Blanket Reactor N*, C** Blackwater, Greywater Primary / Secondary	▪ Single tank process with a suspended sludge blanket comprising microbial granules (1-3 mm dia) ▪ Main elements are influent distributor system, gas-solids separator, and the effluent with drawl design ▪ Slope walls to deflect material downwards, that reaches the top of the tank	▪ Microorganisms degrade organic compounds ▪ Rising bubbles mix with the sludge without the assistance of any mechanical parts ▪ Clarified effluent extracted from the top of the tank	▪ Urban areas with constant water supply or electricity ▪ Mostly used for large-scale industrial wastewater treatment	▪ Biogas can be used for energy ▪ Can withstand high organic and hydraulic loading rates	▪ Electrical energy is constantly required ▪ Requires expert design and consideration ▪ skilled personnel for operation and maintenance ▪ Long start up time ▪ Effluent and sludge require further treatment / appropriate drainage	▪ Removes 80-90% of COD ▪ High reduction of BOD	▪ Release of gases (methane and CO2), used as energy	(Tilley et al., 2008; Eawag, 2008)

Tech	Design Considerations	Treatment Principles	Context	Pros	Cons	Efficiency	Disposal/Use of the output	References
Activated Sludge N*, C** Effluent Blackwater Greywater Secondary (Centralized)	▪ Multi-chamber reactor unit continuously supplied with oxygen ▪ Surface aerators or pumping of air/ oxygen provided for aeration and mixing in an aeration tank ▪ Accurate estimation of the wastewater composition and volume is required for the design	▪ Use of highly concentrated microorganisms (aerobic bacteria, facultative bacteria) to degrade organics and remove nutrients (aerobic conditions) ▪ Gravity settling used to remove the agglomerations of sludge particles for tertiary treatment of to recycle back to the reactor	▪ Treatment with large volume of flows ▪ Appropriate in every climate	▪ High reduction of BOD and high nutrient removal possible ▪ Can be modified to specific discharge limits ▪ Resistant to organic and hydraulic shock loads	▪ Electrical energy is constantly required, high energy consumption ▪ High capital and operating costs ▪ Requires expert design and consideration ▪ skilled personnel for operation and maintenance ▪ Effluent and sludge require further treatment / appropriate discharge ▪ Possibility of complicated chemical and microbiological problems	▪ Different adaptation and modifications required to achieve effluent goals for BOD, nitrogen and phosphorous ▪ High reduction of BOD and pathogens (up to 90%)		(Tilley et al., 2008)

Tech	Design Considerations	Treatment Principles	Context	Pros	Cons	Efficiency	Disposal/Use of the output	References
Tertiary Filtration and Disinfection N*, C** Effluent Tertiary	▪ Depth Filtration or Surface filtration processes for post-treatment ▪ Chlorine is widely used disinfectant	▪ Deep filtration removes residual suspended solids by passing through filter bed ▪ If activated carbon is used, it removes organic and inorganic compounds as well as taste and odour ▪ Surface filtration removes particulate material by mechanical sieving as the liquid passes through the filter layer (membrane filtration)	▪ Depends upon the desired end use of the effluent	▪ Additional removal of pathogens and chemical contaminants	▪ High capital and operating costs ▪ Some technology requires constant electrical energy ▪ Skill, technology, spare parts may not be locally available ▪ Filter materials need regular backwashing or replacement		▪ Direct reuse of treated wastewater	(Tilley et al., 2008)

Table E.2: Sludge Treatment Technologies

Tech	Design Consideration	Treatment Technology	Context	Pros	Cons	Efficiency	Output	References
Sedimentation / Thickening Ponds N*, C** Sludge Secondary	▪ Two tanks operating in parallel ▪ Each tank is only loaded 50% of the time ▪ Loading and resting periods should not exceed 4-5 weeks	▪ Settling ponds that allow sludge to thicken and dewater ▪ Fundamental mechanisms: settling, thickening and flotation ▪ Settled solid retained at the bottom, scum floats on the surface	▪ Inexpensive land available, far from homes and businesses ▪ Hot and temperate climates ▪ Dakar (Senegal), Accra (Ghana)	▪ Electrical energy is not required ▪ Relatively low capital and operating costs ▪ Can be built and repaired with locally available materials ▪ Thickened sludge is easier to handle	▪ Requires a large land are ▪ Requires expert design and consideration ▪ Odours and flies ▪ Require desludging	▪ ▪ 50-60% efficiency ▪ Can be improved to 80%	▪ Effluent and sludge require further treatment	(Tilley et al., 2008; Strande et al., 2014)
Unplanted Drying Beds N*, C** Sludge Secondary	▪ Shallow filters filled with sand and gravel with an under drain at the bottom to collect leachate ▪ The top sand layer should be 250-300 mm thick	▪ When loaded with sludge, liquid is drained through the sand and gravel to the bottom and allows the sludge to dry by evaporation	▪ Small to medium communities ▪ Best suited for rural and peri-urban areas with inexpensive land ▪ Large ones also exist for huge urban agglomeration ▪ Dry and hot climates (Ghana)	▪ Electrical energy is not required ▪ Relatively low capital and operating costs ▪ Can be built and repaired with locally available materials ▪ Simple operation with minimum maintenance	▪ Requires a large land area ▪ Requires expert design and consideration ▪ Odours and flies ▪ Labour intensive removal	▪ 50 – 80% of the sludge volume drains off and 20-50% is evaporated ▪ ▪ Limited stabilization and pathogen reduction	▪ Lechate requires further treatment	(Tilley et al., 2008; Strande et al., 2014)

Tech	Design Consideration	Treatment Technology	Context	Pros	Cons	Efficiency	Output	References
Planted Drying Beds N*, C** Sludge Secondary	▪ Like unplanted drying beds but filters do not need to be desludged after each feeding/ during cycle ▪ Layering bed with 250 mm of coarse gravel (20mm dia grain), 520 mm of fine gravel (5mm dia grain) and 100-150mm of sand ▪ Ventilation pipes connected to the drainage system contribute to aerobic conditions in the filter	▪ Combination of physical and biochemical treatment ▪ The plants and their root systems maintain the porosity of the filter, stabilise the beds, increase moisture loss and transfer oxygen to the sludge layer ▪ Reeds, cattails, antelope grass and papyrus are suitable plants	▪ Appropriate for small to medium communities but can also be used for bigger cities ▪ Tropical climate, initially adopted in Europe and US ▪ Increasingly attractive for low to middle income countries	▪ Electrical energy is not required ▪ low capital, maintenance and operating costs ▪ Can be built and repaired with locally available materials ▪ Can handle high loading	▪ Requires a large land area ▪ ▪ Requires expert design and consideration ▪ Odours and flies ▪ Labour intensive removal and long storage times	▪ Sludge volume down to 50% ▪ Denitrification	▪ Leachate requires further treatment	(Tilley et al., 2008; Strande et al., 2014)

Tech	Design Consideration	Treatment Technology	Context	Pros	Cons	Efficiency	Output	References
Co-composting N*, C** Sludge, Organics Centralized	▪ Covered to prevent excess evaporation and/or provide protection from rain and wing ▪ Ratio of 1:2 to 1:3 of sludge to solid waste should be used ▪ Carbon to nitrogen between 20-30:1 to ensure biological availability, 5-10% of oxygen concentration to ensure aerobic microbiological decomposition, 50-60% moisture content to ensure biodegradation	▪ Controlled aerobic degradation of organics using faecal sludge and organic solid waste ▪ Biological process that involves microorganisms ▪ Open co-composting: piled into long heaps called windrows and left to decompose aerobically ▪ In-vessel: requires controlled moisture, air supply and mechanical mixing	▪ Appropriate if source of well sorted biodegradable solid waste is available ▪ Sludge that has undergone dewatering is suitable ▪ ▪ Kumasi (Ghana)	▪ Electrical energy is not required ▪ low capital and operating costs ▪ Can be built and repaired with locally available materials	▪ Requires a large land area ▪ ▪ Requires expert design and consideration ▪ ▪ Labour intensive removal and long storage times	▪ High removal of helminth egg is possible	▪ Beneficial soil conditioner ▪ Organic fertilizer	(Tilley et al., 2008; Strande et al., 2014)

Table E.3: Sewer Systems (technologies and hardware)

Technology	Collection/ Context	Design Consideration	Pros	Cons	References
Condominium Sewers N, C	▪ Around Brazil ▪ Densely populated informal settlement	▪ Smaller diameter pipes (100mm) laid at shallower depth 40 to 65 cm ▪ Flatter gradient o.5% ▪ PVC pipes recommended	▪ Low capital cost ▪ Extendable ▪ Does not require onsite primary treatment units	▪ Frequent repairs and removal of blockages ▪ Leakage risk and difficult to identify	(Tilley et al., 2008; Eawag, 2008; Nelson and Murray, 2008)
Solid Free Sewers N, C		▪ Network of small diameter pipes	▪ Used in limited water supply ▪ Low capital and operating cost ▪ Doesn't require a minimum gradient or flow velocity ▪ Can be extended	▪ Space required for inceptors ▪ Regular desludging to prevent clogging ▪ Requires training and acceptance ▪ Expert design and construction required ▪ Leakage and ground infiltration risk	(Tilley et al., 2008; Eawag, 2008; Nelson and Murray, 2008)
Combined Gravity Sewers N, C Input: Blackwater, yellow water, greywater, stormwater	▪ Collection for (Semi) Centralized Treatment	▪ Large network of underground pipes ▪ Designed with many branches and a constant downhill gradient must be maintained for self-cleansing flows	▪ Less maintenance as compare abovementioned other two ▪ Greywater and possibly stormwater can be managed ▪ Girt and other solids and large volumes of flow can be maintained	▪ Very high capital cost, high operation, and maintenance cost ▪ Requires deep excavation ▪ Difficult and costly to extend ▪ Expert design and consideration required ▪ Leakage, wastewater exfiltration and groundwater infiltration risks	(Tilley et al., 2008; Eawag, 2008; Nelson and Murray, 2008)
Separate Sewer System N, C	▪ Europe, Vancouver	▪ Separating rainwater and the sewer system ▪ Storm drains from stormwater and a separate pipe for household sewage and wastewater	▪ Prevents pollution by eliminating combined sewer overflow ▪ Mitigate the problem of flooding ▪ Increase the performance of WWTPs ▪ Reuse of stormwater	▪ Very high capital cost, high operation, and maintenance cost ▪ Construction process will disrupt the urban areas ▪ Incomplete or improperly separated sewer system poses further risks	(Wavin, 2017; De Toffol et al., 2007)

Appendix F : Global Mapping – data on wastewater, faecal sludge and co-treatment volumes.

	Amman, Jordan	Medellin , Colombia	Paris, France	Sofia, Bulgaria
Total population	**4,642,000**	**2,612,958**	**2,140,000**	**1,307,439**
Estimated % of total population connected to the sewer network	80.0%	96.0%	100.0%	97.0%
Estimated % of city population relying on onsite systems	20.0%	4.0%		3.0%
FS treatment m3/d				
WW treatment m3/d	378,314	499,784	896,986	345,042
Cotreatment m3/d				

	Dhaka, Bangladesh	Hanoi, Vietnam	Bandung, Indonesia	Trichy, India	Nakuru, Kenya
Total population	**22,478,116**	**8,246,500**	**2,638,000**	**916,674**	**533,686**
Estimated % of total population connected to the sewer network	20.0%	10.0%	35.0%	27%	27.0%
Estimated % of city population relying on onsite systems	80.0%	90.0%	65.0%	73%	73.0%
FS treatment m3/d					
WW treatment m3/d		11,000			
Cotreatment m3/d	150,000	30	31,979	50,000	9,700

	Dar es Salaam, Tanzania	Ouagadougou, Burkina Faso	Hatyai City, Thailand	Kaysone Phomvihane City Laos
Total population	**7,526,235**	**2,453,496**	**313,269**	**133,857**
Estimated % of total population connected to the sewer network	12.0%	1.0%	90.0%	62.0%
Estimated % of city population relying on onsite systems	88.0%	99.0%	10.0%	38.0%
FS treatment m3/d	15	620	30	
WW treatment m3/d	38,119	800	67,324	4,200
Cotreatment m3/d				

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