Mapping and Valuing Ecosystem Services for Sustainable Landscape Management in Zimbabwe

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Acronyms and Abbreviations

AET	Actual Evapotranspiration
AGB	Aboveground Biomass
AMD	Acid Mine Drainage
ANR	Assisted Natural Regeneration
ASA	Advisory Services and Analytics
ASCC	Annualized Social Cost of Carbon
BAU	Business-as-Usual
BGB	Belowground Biomass
CA	Conservation Agriculture
CAMPFIRE	Community Areas Management Programme for Indigenous Resources
CBD	Convention of Biodiversity
CSA	Climate-Smart Agriculture
CSAIP	Climate-Smart Agriculture Investment Plan
CBNRM	Community-Based Natural Resources Management
CN	Curve Number
DEM	Digital Elevation Model
EMA	Environmental Management Agency
ESA	European Space Agency
FAO	Food and Agriculture Organization
FSR	Future Suitability Ratio
FTLRP	Fast-Track Land Reform Programme
GCF	Green Climate Fund
GDP	Gross Domestic Product
GEF	Global Environment Facility
GLW3	Gridded Livestock of the World
GoZ	Government of Zimbabwe
GRanD	Global Reservoir and Dam Database
IAP	Invasive Alien Plant
InVEST	Integrated Valuation of Ecosystem Service Tradeoffs
LAI	Leaf Area Index
LDN	Land Degradation Neutrality
MAP	Mean Annual Precipitation
MAT	Mean Annual Temperature
MECTHI	Ministry of Environment, Climate, Tourism and Hospitality Industry
MLAFWRR	Ministry of Lands, Agriculture, Fisheries, Water and Rural Resettlement
NDVI	Normalized Difference Vegetation Index
NPP	Net Primary Productivity
NPV	Net Present Value
PES	Payments for Ecosystem Services
PUD	Photo User Day
PV	Present Value
ROI	Return on Investment
RUSLE	Revised Universal Soil Loss Equation
SADC	Southern African Development Community
SCC	Social Cost of Carbon
SDGs	Sustainable Development Goals

SDR	Sediment Delivery Ratio
SWY	Seasonal Water Yield
TLU	Tropical Livestock Unit
UN	United Nations
UNICEF	United Nations Children's Fund
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
WDPA	World Database on Protected Areas
WFP	World Food Programme
WWF	World Wide Fund for Nature
ZINWA	Zimbabwe National Water Authority
ZPWMA	Zimbabwe Parks and Wildlife Management Authority
ZTA	Zimbabwe Tourism Authority

Glossary of Key Terms

Biodiversity	The variability among living organisms and the ecological complexes of which they are part. This includes variation within species, the diversity of species within ecosystems, and the diversity of ecosystem types in nature.
Carbon Sequestration	The process of capturing and storing atmospheric carbon dioxide.
Catchment	An area where water is collected by the natural landscape. Precipitation that falls in a catchment runs downhill into creeks, rivers, lakes, oceans, or into built infrastructure, such as reservoirs. In this document, the terms catchment and watershed are used interchangeably.
Climate-Smart Agriculture	A broad term for reforming agricultural practices to achieve a more productive, resilient, and low-emission agricultural sector.
Conservation Agriculture	A farming system that promotes minimum soil disturbance, maintenance of permanent soil cover, and diversification of plant species.
Cost-Benefit Analysis	A conceptual framework and tool used to evaluate the viability and desirability of projects or policies based on their costs and benefits over time.
Discount Rate	The interest rate used in discounted cash flow analysis to determine the present value of future cash flows.
Ecosystem Services	The benefits people obtain from the earth's many life-support systems. The Millennium Ecosystem Assessment defines four categories of ecosystem services: provisioning, regulating, cultural, and supporting services.
Groundwater Recharge	Water added to an aquifer through the unsaturated zone after infiltration and percolation following any storm rainfall event.
Land Degradation	The reduction or loss in biological or economic productive capacity of the land resource base.
Land Degradation Neutrality	A state whereby the amount and quality of land resources necessary to support ecosystem functions and services remain stable or increase within specified temporal and spatial scales and ecosystems.
Net Present Value (NPV)	A calculation used to estimate the net benefit over the lifetime of a particular project. Net present value allows decision-makers to compare various alternatives on a similar time scale by converting all options to current dollar figures. A project is deemed acceptable if the net present value is positive over the expected lifetime of the project.
Payments for Ecosystem Services (PES)	A scheme where beneficiaries of ecosystem services compensate ecosystem managers (landowners or resource stewards) to change their practices, to secure those ecosystem services. This may involve desisting from damaging activities or adopting more expensive practices that are less damaging to the environment.
Return on Investment	A simple ratio of the gain from an investment relative to the amount invested. ROI is calculated by dividing net profit (current value of investment − cost of investment) by the cost of investment.
Riparian Buffer	Land occurring along watercourses and water bodies. For this study, it can be defined as the area within 30 m of the river channel.
Sustainable Resource Management	Managing the use and protection of natural resources in a way (or at a rate) which enables social, economic, and cultural well-being while ensuring these resources are sustained for future generations and any adverse effects on the environment are minimized.

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Key Messages and Recommendations

Understanding the value of ecosystems is key to Zimbabwe's future

1. **Valuing ecosystem services is an important step in devising interventions to achieve sustainable livelihoods and climate resilience.** The services provided by healthy ecosystems are essential for supporting life. Their loss would have a disproportionately large impact on developing countries. Zimbabwe is highly dependent on natural resources and related sectors for livelihoods and economic growth. However, the country is experiencing high levels of land degradation, which threatens the very resource base on which most of the nation's population depends. Already, land degradation costs up to 6.3 percent of the country's gross domestic product (GDP) annually, and this will worsen with climatic change. It is also heavily dependent on its groundwater, which is highly vulnerable relative to other African countries.

2. **Zimbabwe has committed to addressing land degradation and has recognized the need to better understand and invest in its biodiversity economy.** Zimbabwe is a signatory to several multilateral agreements concerning land degradation, biodiversity conservation, and climate change. It is also embarking on natural capital accounting as a means to more accurately assess and monitor the impact and dependence of economic activity on natural resources.

Understanding the drivers and value of ecosystems is key to Zimbabwe's future

3. **Zimbabwe is one of the climate change hotspots in Southern Africa, whereby large adverse impacts of climate change are predicted to coincide with a preponderance of poor people who are least able to cope.** The country ranks 174 out of 182 countries in the 2019 ND-GAIN Index, which indicates a greater vulnerability and reduced capacity to adapt to climate change. Observed climate change over the last three decades attests to a heightened frequency of extreme-weather events particularly droughts, flooding, late-onset and early-cessation rainfall, severe winds and tropical cyclones, and increased crop and livestock diseases. A recently revised agro-ecological map for Zimbabwe shows that the drought prone regions (IV and V) have become drier and increased in area at the expense of the major food producing regions (II and III). Global climate-change models (CGMs) predict with reasonable confidence that Zimbabwe is trending towards more arid (hotter) climatic conditions in the future. There is however a wide variation across climate projections on rainfall, with some GCMs projecting a wetter climate especially in the north-eastern regions. These predictions will likely increase evapotranspiration, and crop and livestock stress as well as pests and diseases of concern for both human and animal health expanding to previously non-endemic regions. These factors will conspire to reduce agricultural and ecosystem productivity.

The World Bank is supporting Zimbabwe to sustainably manage the ecosystem services provided by critical landscapes

4. **This study forms part of the technical assistance that the World Bank is providing on ecosystem services and landscape interventions in Zimbabwe.** The work is being carried out with financing from the Global Partnership for Sustainable and Resilient Landscapes (ProGreen). The objective of the study is to generate the evidence base for the development of a scaled-up, integrated biodiversity and sustainable production landscapes investment

project in the area. Targeted funding sources include ProGreen, the Global Environment Facility (GEF), and the Green Climate Fund (GCF).

5. **The Mazowe Catchment was selected as a key area for intervention in Zimbabwe.** A national screening assessment was undertaken to rapidly identify areas in Zimbabwe providing a high level of key ecosystem services as well as areas experiencing or at risk of significant land degradation. This assessment expanded on and added granularity to previous mapping of ecosystem services under the Land Degradation Neutrality Framework of the United Nations Convention to Combat Desertification (UNCCD). The national screening identified several candidate focal landscapes for more detailed assessment, including the 40,000 km^2 Mazowe Catchment north of Harare, which was estimated to provide a high level of ecosystem services and thus good opportunities for conserving and enhancing service provision. Drawing on the findings of the national-level screening assessment, the selection of the Mazowe Catchment as a focal landscape was undertaken by the government, considering its local knowledge of the candidate areas.

6. **The main outputs of the study are**

   1) An analysis of the ecological status and trends of the Mazowe Catchment and a high-level assessment of the drivers of environmental degradation;
   2) Methods for quantifying and valuing ecosystem services in the Mazowe Catchment that can be used in ecosystem services accounting going forward and that can be scaled up to the other catchment areas of Zimbabwe;
   3) Estimation and spatial mapping of the benefits of a range of provisioning, regulating, and cultural ecosystem services; and
   4) Quantification of the benefits and return on investment (ROI) of implementing sustainable land management and conservation-focused interventions.

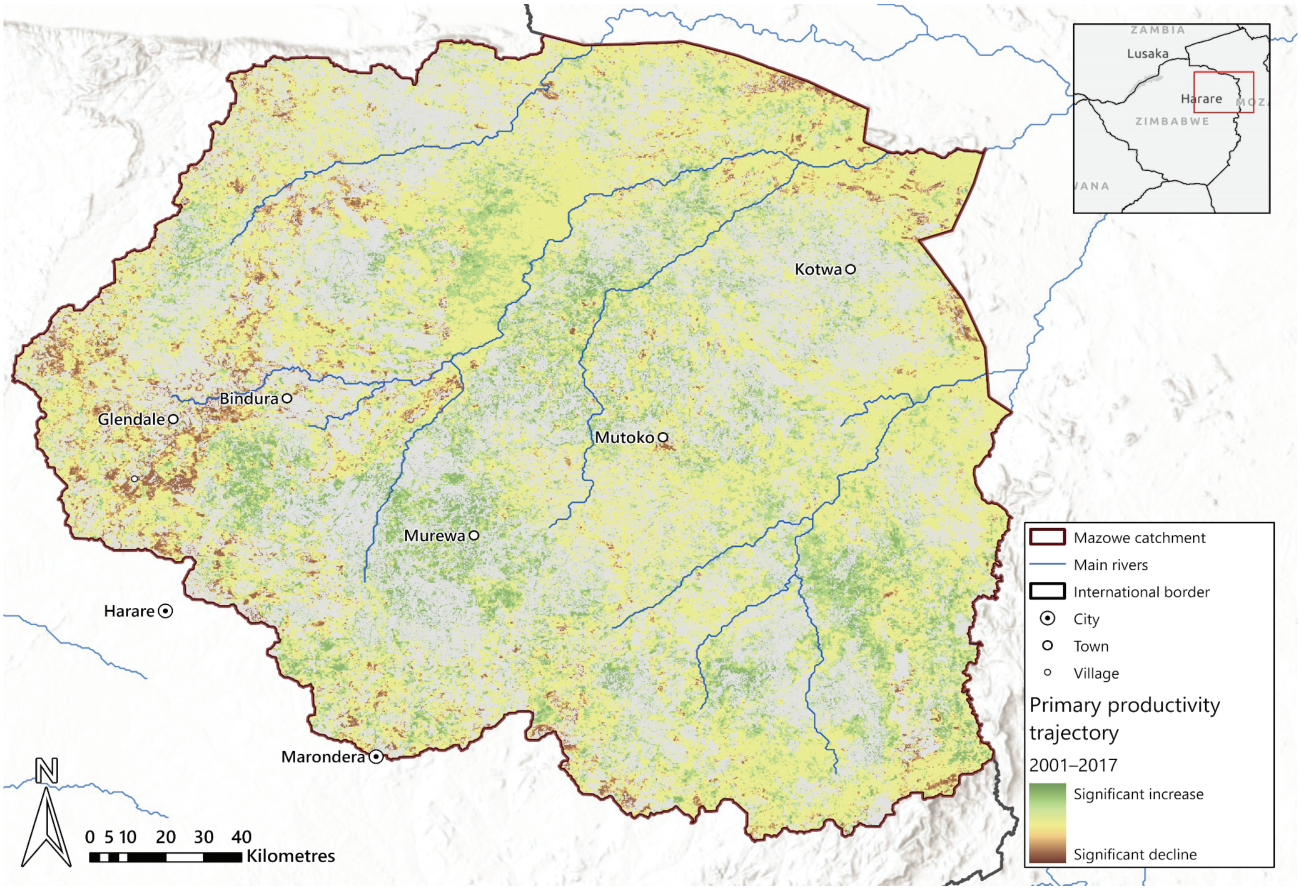
KEY MESSAGE 1. Productive natural ecosystems in the Mazowe Catchment are being lost and degraded by poorly planned and managed commercial and small-scale livelihood activities, and threats will be further exacerbated by climate change.

7. **The study area lost over 1,100 km^2 of its dense woodland and over 400 km^2 (90 percent) of its wooded grassland, mostly to dryland cultivation, in the last 25 years (1992–2018).** About 594 km^2 of forest and woodland (above 10 percent tree cover) experienced a loss of tree cover between 2001 and 2020. Some 9 percent of remaining natural areas have experienced significant losses in productivity between 2001 and 2017.

8. **Cultivation, fuelwood harvesting, mining, and invasive alien plants (IAPs) are the main causes of degradation.** Expanding cultivation is driven by the growth of the rural population and the reliance on extensification as the main strategy for increasing food production. Land scarcity and poor land management practices mean erosion rates from farmlands are often high, particularly in communal areas, contributing to water quality and sedimentation issues. Population pressure has also increased the harvesting of firewood and other natural resources and worsened grazing pressure on the increasingly small areas of remaining grazing land. The study area has high incidences of veld fires, often started to stimulate grass growth for livestock at the end of the dry season or to clear land for cultivation. Fires cause further degradation of natural habitats, which significantly increases erosion rates at the start of the rainy season. In addition, commercial and artisanal mining have a serious impact on surface and groundwater quality and add to the sedimentation issues arising from farming practices. In addition, catchment productivity is seriously affected by the invasion of lantana, alien grasses, and water weeds.

9. **The underlying drivers include poverty, population growth, and lack of secure property rights.** High poverty levels and limited economic opportunities mean most inhabitants have limited options, making their living off the

FIGURE E1: PRIMARY PRODUCTIVITY TRAJECTORY IN THE PERIOD 2001–2017 ON A SCALE FROM SIGNIFICANT INCREASE TO SIGNIFICANT DECLINE IN PRODUCTIVITY AS WELL AS AREAS OF RELATIVE STABILITY



Data source: Conservation International 2018. *Note:* This excludes agricultural and other modified land cover (shown in grey).

land through any opportunities that arise, legal or illegal. Poverty leaves households in a position of having a very short time horizon, in which the need for immediate survival obscures any need to plan for a sustainable income. Poverty is also a driver of high fertility rates and population growth. This becomes a problem in situations where land and resources are finite. Problems associated with mining are also linked to poverty and the country's economic collapse. Informal artisanal mining (both alluvial panning and reef mining) is not regulated by any legislation, and has become a critical, if not the largest, source of income for many households. In addition to population pressure, tenure insecurity is another underlying driver of poor land management, particularly in areas resettled during the Fast-Track Land Reform Programme (FTLRP), where perceived tenure security is lower, discouraging investments in sustainable land management.

10. **Climate change will directly affect ecosystem condition and services and will indirectly increase existing pressures.** Climate change could contribute to significant reductions in crop yield due to greater heat stress and more erratic rainfall patterns. Climate change is expected to reduce groundwater recharge and surface runoff in the Mazowe Catchment. Although this is expected to be moderate relative to other areas in Zimbabwe, water availability for agriculture and domestic use will be negatively affected by increased evaporation losses and unreliable rainfall patterns. Degradation of ecosystems in the study area is already compromising water security, food security, human health, and livelihoods. Climate change puts pressure on ecosystems in the same direction. If the drivers of degradation are not addressed through climate-resilient landscape management interventions, the population of the Mazowe Catchment could face catastrophic consequences under future climate conditions.

KEY MESSAGE 2. The services supplied by natural ecosystems are broader and more valuable than the agricultural production value of cultivated areas.

11. **Cultivated areas contribute a gross margin value of US$68 million per year, mostly from maize and tobacco.** The Mazowe Catchment is a key region for agriculture in Zimbabwe, particularly the southwest, which contains some of the best areas for crop production in the country. The catchment accounts for over 20 percent of national production of most crops, despite covering just 10 percent of Zimbabwe's area. Maize and tobacco account for the bulk of this value, reflecting the areal dominance of maize and the high value per ton of tobacco relative to other crops. About 127 km^2 of timber plantation are also supported in the study area.

12. **The remaining natural areas support a range of provisioning, regulating, and cultural ecosystem services** that provide current and potential benefits to local farmers and villagers, to the tourism sector, water utilities, and to Zimbabwean society as a whole. The provisioning services include ecosystem inputs to livestock production and harvested wild resources. Regulating services are the functions that ecosystems and their biota perform that benefit people in surrounding or downstream areas or even in distant areas. In this assessment, quantified and valued regulating services include avoided climate change costs attributable to land-based carbon storage, regulation of flows and groundwater recharge, and soil erosion and sedimentation control. The value of tourism (a cultural service) was also assessed. Together, these services alone provide benefits of over **US$429 million** to Zimbabweans annually, over three times the combined value of crop and livestock production in the catchment.

13. **Ecosystem inputs to livestock are estimated to be US$65 million per year.** The catchment has relatively high populations of cattle, due to its large rural population and the socioeconomic importance of cattle for rural households.

14. **Wild resource harvesting is estimated to be worth at least US$106 million per year.** Modelling of harvested wild resource use was based on (a) the capacity of the landscape to supply different types of resources and (b) the spatial distribution of the human demand for a given resource. A further factor considered is accessibility, with resources in protected areas assumed to be less available for harvesting. Five key harvested wild resources were modelled: wood, thatching grass, wild plant foods, mushrooms, and honey. Due to data limitations, our estimate excludes medicinal plants. Miombo woodland was estimated to have particularly high values for resource harvesting.

15. **Rural tourism attractions in the Mazowe Catchment were estimated to generate about US$43 million** in 2019 or 4.6 percent of national attraction-based tourism (that is, excluding expenditure on business tourism, visiting friends and family, and so on). Most of this value (US$36 million) is derived from natural ecosystem areas (as opposed to cultivated/planted areas or human settlements). The area includes Umfurudzi Safari Area and part of Nyanga National Park, as well as popular hiking spots such as Domboshawa.

16. **Maintaining natural ecosystem cover in the study area saves about US$250 million per year in water supply costs.** Vegetation cover mediates the infiltration of rainfall into the ground, which later emerges at springs to join streams and rivers ('baseflow') or replenishes groundwater or aquifers ('groundwater recharge'). Of these flow regulating functions, groundwater recharge is estimated to be particularly important in the study area, estimated to be worth US$84 million per year. Vegetative cover also supports water supply by reducing erosion and trapping sediments. Erosion rates in the Mazowe Catchment are relatively high, particularly from degraded natural habitats and communal farmland, causing serious reservoir sedimentation issues in parts of the study area. Sediment retention by the landscape was estimated to be worth US$166 million per year in terms of dredging cost savings.

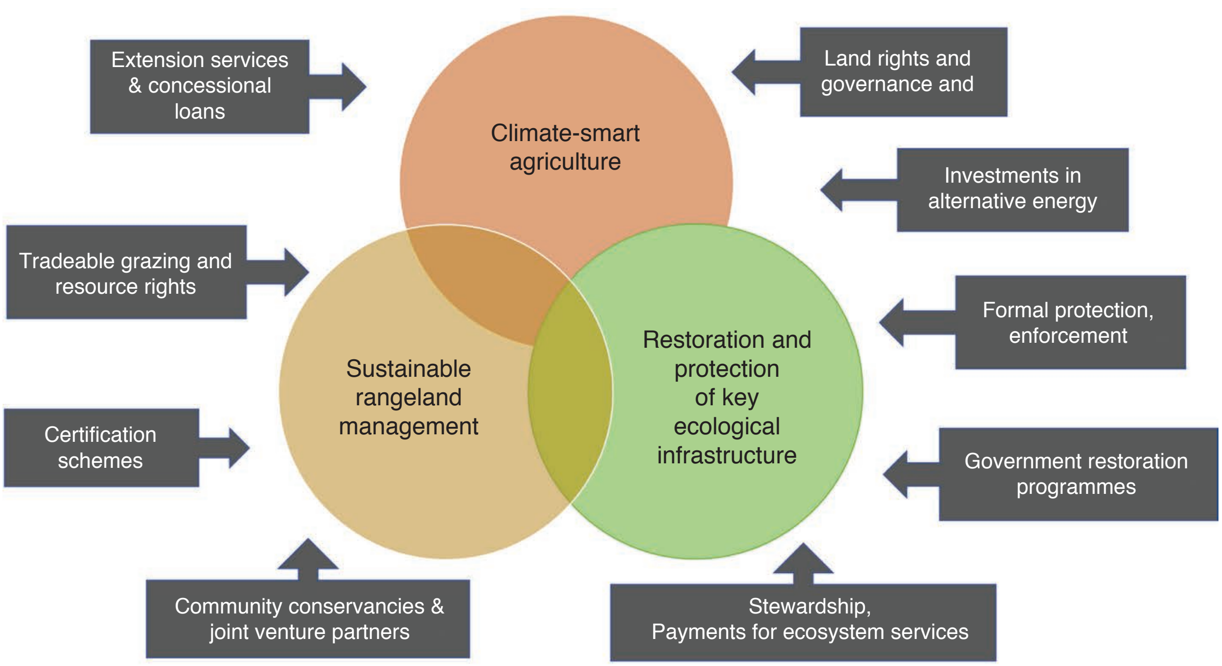
17. **Maintaining the remaining forest cover avoids billions of dollars of global climate change damages and offers a potential source of income for Zimbabwe.** Degradation and loss of natural habitats releases CO_2 into the atmosphere. While much of the Mazowe Catchment has low biomass due to historical conversion of natural habitat to agriculture, settlement, mining, and other uses, there are some notable areas of woody natural habitats remaining. This includes Umfurudzi Safari Area and densely wooded hilly terrain in the extreme northeast of the catchment. The landscape is currently storing about 31.7 tons of carbon per ha as aboveground and belowground biomass, resulting in avoided climate change-related losses of economic output to the world worth US$1.23 billion per year. This offers a potential source of income for Zimbabwe, which is explored in the scenario analysis.

TABLE E1: SUMMARY OF THE CURRENT VALUES OF SELECTED ECOSYSTEM SERVICES ASSESSED IN THIS STUDY, US$, MILLIONS PER YEAR

Types of services	Explanation	Value to whom	Value per year (US$, millions)
Wild resources	Value of wild harvested foods, fuel, and raw materials net of human inputs	Rural households	105.7
Cultivated production	Production value net of human inputs	Communal farmers	38.0
		Commercial farmers	30.2
Livestock production	Production value net of human inputs	Communal farmers	43.1
		Commercial farmers	21.6
Sediment regulation	Cost savings due to vegetation capacity to hold soil in place or trap eroded soils before entering streams	Water utilities and private dam owners	166.3
Flow regulation (baseflow and groundwater)	Cost savings in water resources infrastructure due to facilitation of recharge by vegetation	Water utilities and/or direct water users	83.9
Tourism	Net income generated as a result of tourism to natural attractions	Tourism sector	42.9
Carbon retention	Avoided climate change damages as a result of avoided CO_2 emissions from ecosystem degradation	Zimbabwe	30.0
		Rest of world	1,230.0

KEY MESSAGE 3. Public investment to scale up sustainable landscape management will make economic sense with every $100 invested in landscape management generating $170.

FIGURE E2: THE THREE BROAD INTERVENTIONS TO ACHIEVE SUSTAINABLE USE OF MAZOWE CATCHMENT AREA



18. **Conservation and sustainable landscape management practices are needed to sustain the livelihoods and economy of the catchment.** Currently, the benefits from the landscape are being undermined by environmental degradation, often for short-term gains such as the expansion of low-yielding agriculture or mining. Several interventions are needed to address and reverse this trend, to sustain these benefits into the future and to improve the local inhabitants' resilience to climate change.

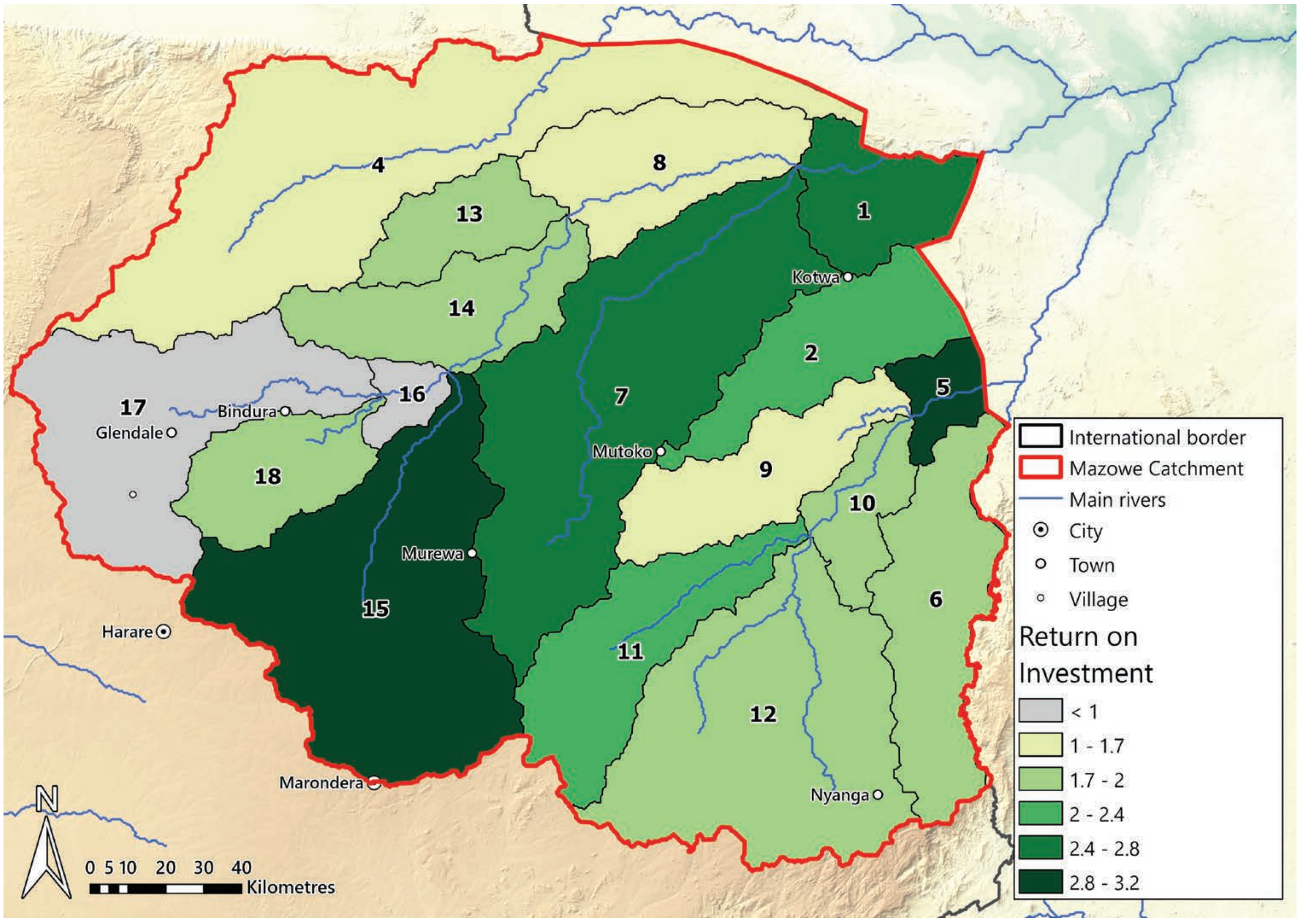
19. **Interventions to maintain soil, vegetation cover, biodiversity, and agricultural productivity are mutually supportive** and include supporting, regulating, and/or incentivizing (a) climate-smart agriculture (CSA) practices which increase the productivity of land and reduce rates of land conversion, soil loss, and water consumption; (b) limiting the use of grazing and wild resources to sustainable levels to maintain their productivity as well as other services; and (c) restoring and protecting key natural areas and their biodiversity to capitalize on their regulating and cultural services. Key natural areas include important wildlife habitat and natural riparian corridors that contribute to water security and play a key role in maintaining wild populations in the landscape.

20. **The choice of policy measures to achieve these results depends on how critical the outcome is, the relative costs and benefits to the actors versus the rest of society, and who the beneficiaries are.** Because CSA interventions are favorable for farmers, they may only need financial and technical assistance in the start-up phase. There are various incentives that can encourage farmers to adopt Climate Smart Agriculture (CSA) practices. Financial incentives such as subsidies for climate-resilient seeds, providing support for agroforestry and other practices that sequester carbon and promoting the adoption of rain harvesting and soil water conservation can motivate farmers to implement CSA practices. Training farmers on CSA practices, providing access to extension and agronomic advisory services, and providing support with marketing CSA products are additional strategies that can help incentivize farmers to adopt CSA practices. Educating farmers about the benefits of CSA can also raise awareness among policymakers and the public and increase its adoption. Lastly, ensuring easy access to CSA input and output markets can further improve its uptake.

21. **Curbing the unsustainable use of rangelands, trees, and wild resources and encouraging practices to allow their recovery requires stronger and ongoing regulation and/or incentives.** These can include payments for ecosystem services (PES) and supporting measures such as the planting of woodlots and/or investment in alternative or more efficient energy sources. Provision of secure land tenure and resource rights, for example, through conservancy establishment, could be a powerful incentive for the sustainable management of natural resources as well as a lever of private sector conservation funding.

22. **While conservation actions will take a number of years to bear fruit, economic analysis shows that this is worth doing.** The impact of conservation actions on ecosystem service values was compared to a business-as-usual (BAU) scenario in which further catchment degradation occurs. It was estimated that the increase in natural resource stocks from the full restoration of riparian buffers and degraded natural habitats could eventually increase the value of wild resource harvesting by US$3.5 million per year relative to BAU. These interventions, along with the increased uptake of soil carbon through conservation tillage, could also sequester carbon worth at least US$13.5 million per year, using a conservative estimate of the price of carbon on the voluntary carbon market. Despite the reduction of cropland in riparian areas, CSA interventions could increase small-scale crop production by US$21.1 million per year or 9.5 percent. The proposed interventions would collectively increase groundwater recharge by 4.5 percent, worth around US$11.8 million per year in terms of water supply. Improved erosion and sedimentation control arising from these interventions could reduce erosion across the catchment by 48 percent and sediment export to dams by 62 percent relative to BAU. This results in cost savings of US$10.2 million per year in avoided sediment control costs in reservoirs. Erosion from communal farmland would be roughly halved, bringing erosion rates closer to tolerance levels. Overall, well-implemented restoration and conservation interventions could produce benefits that outweigh their costs. The NPV over 25 years is estimated to be US$288 million, with an ROI of 1.7 over the Mazowe Catchment as a whole. Notably, ROI exceeds parity in all but 2 of the 17 sub-catchments, with the highest ROI of 3 in sub-catchment #5 (Figure I). At the subcatchment level, investment costs are primarily driven by the size of subcatchments, the extent of land degradation of the subcatchments, land cover types,

FIGURE E3: ROI PER SUB-CATCHMENT WITH IMPLEMENTATION OF THE PROPOSED LANDSCAPE INTERVENTIONS



Data source: This study.

and the type of sustainable land management investment relevant for a given subcatchment. On the other hand, ecosystem services benefits at the subcatchment level are driven by positive changes in land resources management following CSA adoption, availability of water resources, presence of intact forests and wetlands, and presence of high biodiversity within the ecosystem. Six sub-catchments have an ROI of 2 or greater, suggesting interventions would be most cost-effective in these parts of the study area.

Key recommendations of the study

23. **This study has shown that degradation in the Mazowe Catchment is increasing, and this will undermine not only biodiversity but the well-being of its inhabitants and of Zimbabweans in general.** It is clear that the environmental issues in the catchment need to be addressed. The study has also identified the priority areas for intervention. However, there are several information gaps that also need to be addressed in moving forward. Bearing this in mind, and the fact that similar issues are threatening livelihoods and the economy across the country, the key recommendations from this study are as follows.

24. **(a) Support further adoption of CSA interventions** following the recommendations of the Zimbabwe's CSA Investment Plan which aims to strengthen the country's agriculture sector's resilience to climate change. Priority investments recommended by the CSAIP include on-farm investments in improved crops, fertilizers, irrigation, and animal management to increase farmer production and build resilience; off-farm investments in

TABLE E2. PRESENT VALUE OF COSTS AND BENEFITS OF LANDSCAPE INTERVENTIONS IN MAZOWE CATCHMENT

	$ million
Costs	**422.0**
Restore degraded natural habitats	200.5
Establish conservancies	0.8
Implement climate-smart agriculture (50% adoption)	179.7
Install riparian buffers	41.0
Benefits	**709.9**
Avoided dredging (sediment)	107.8
Avoided dam costs (change in recharge)	125.0
Gains in wild harvested resources	21.1
Changes in agricultural production	258.7
Revenue from carbon credits	191.9
Tourism gains	5.2
Net present value	287.9
B:C ratio / ROI	**1.7**
ROI for Farmland interventions	**1.44**
ROI for natural land interventions	**1.86**

Duration is 25 years at 4.56%.

storage, processing, marketing, and research & development to increase the agricultural value chain's productivity and efficiency; and cross-cutting investments in land reform and water management to help the country realize its full agricultural potential.

(b) **Enforce riparian protection.** Government should act to enforce the already-existing laws prohibiting use of the riparian zone. Riparian protection is critical to landscape health and to the persistence of biodiversity across the landscape. This should include protection from in-stream mining activities as well as from agriculture and wood harvesting in the riparian zone. To enforce riparian protection, first there is a need to develop a riparian restoration plan to identify areas that needs ANR, those that can recover naturally, as well as the threats and drivers of degradation. A riparian restoration plan could also inform REDD financing opportunities. Second, develop the riparian zone as a resource to conserve biodiversity and increase tangible benefits to farmers. Third, there is a need to work with farmers and communities to develop local-level solutions and ownership

(c) **Enable conservancy establishment.** Zimbabwe has a comparative advantage in terms of its wildlife heritage and parts of the study area (as well as many other areas in Zimbabwe) still hold the potential for wildlife-based land use. The government needs to amend its policies and legislation to support the establishment of communal conservancies with land and resource rights that allow for commercially viable joint venture conservation-based business arrangements.

(d) **Undertake strategic environmental assessments to inform proactive planning.** Proper spatial planning is required to balance conflicting activities such as agriculture, mining, wildlife-based land uses, and the provision of ecosystem services to society. It is recommended that the government undertake detailed strategic environmental assessments for these different activities to plan where they should and should not be allowed to take place.

(e) **Improve and enforce environmental safeguards.** Some of the threats to the study area, such as mining, are difficult to address because of combination of easy access, the promise of a quick return, and the lack of enforcement of environmental standards that would make the operations more costly. Such activities need to be closely regulated and need to involve the use of appropriately specified performance bonds that will fully cover the restoration of environmental damages. The internalization of these costs could go a long way toward addressing the environmental problems in the study area. Environmental safeguards should be set in place for all types of development.

(f) **Invest in sustainable forest management.** The high rate of deforestation observed in this study requires investment in sustainable forest management to maintain the health and integrity of forest ecosystems, conserve biodiversity, mitigate climate change, and provide livelihoods for communities that depend on forests. Investing in sustainable forest management will also help conserve ecosystem services, provide social and community benefits, and align development efforts with the growing trend of green investments and impact investing for a green economy. Key investments for consideration in this regard include reforestation and afforestation of severely degraded land, conversion, and passive reforestation of marginal agricultural land into silvo-pastoral systems for adapted livestock species or community conservancies, encouraging private investments in commercial forestry for all socioeconomic category of farmers down to smallholder commercial woodlots thereby enhancing household income diversification and resilience

(g) **Design and pilot payments for ecosystem services (PES).** The analysis has generated first-order evidence to support the design and implementation of two pilot schemes for payment for ecosystem services (PES) based on appropriate global examples. The first is sustainable landscape management to reduce land degradation and soil erosion on catchments of water-supply dams for urban settlements in Mazowe Catchment. Candidate urban settlements include Bindura, Murewa and Mutoko. The second is sustainable landscape management scheme to verifiably generate and sell carbon credits through carbon funds. A carefully selected catchment could include hard investments and governance arrangements to generate and sell carbon credits from an integrated combination of climate-smart agriculture, sustainable forestry management, biodiversity conservation and sustainable landscape management.

25. The private sector has a critical role to play in biodiversity conservation and sustainable landscape management in Zimbabwe by i) financing projects that contribute to the conservation, restoration, and sustainable use of landscape; and ii) directing financial flows away from projects with negative impacts on biodiversity and ecosystem services. However, government holds the key to harnessing the power of the sector to mobilize the needed private finance at scale to protect nature. Government can support the integration of biodiversity criteria in private sector decision making by adopting natural capital accounting and making relevant data available as public good. Second, environmental fiscal policy reforms that value natural capital can provide incentives for the private sector to co-invest in the sustainable use of natural resources and contribute toward net domestic resource mobilization. Third, government can drive the green transition by promoting policies such as greening the supply chain to drive changes in corporate behavior. Lastly, there is a need for multi-sectoral, people centered approach to natural resources management by ensuring the integration of natural capital consideration into planning, budgeting, implementation, and decision-making at the national and local levels will help build resilience.

1.

Introduction

1.1 Background

26. **Healthy ecosystems provide multiple, essential services to life on the planet, such as water cycle regulation, carbon sequestration, and habitat for biodiversity.** They also sustain livelihoods, providing food, fuel, shelter, and jobs. However, the ecological integrity of landscapes is under significant and increasing threat due to deforestation and land degradation driven by land conversion for agriculture, infrastructure, mining, and other activities and unsustainable management of natural resources.

27. **Like most other African countries, Zimbabwe has a largely rural population and a high degree of dependence on natural resources and related sectors for livelihoods and economic growth (ZIMSTAT 2019).** Alarmingly, the country is considered a land degradation and climate change hotspot. These pressures are undermining the very resource base on which most of the nation's population depends. Land degradation has been particularly prevalent in the country's densely populated communal land areas, due to long-standing and worsening land shortage issues, unsustainable farming practices and poor natural resource management practices, including excessive veld fires and a rise in mining and gold panning activities. Already, land degradation costs up to 6.3 percent of the country's gross domestic product (GDP), with the impacts set to worsen under future climatic conditions (UNCCD 2018). Zimbabwe is also heavily dependent on its groundwater, which is also highly vulnerable relative to other African countries.

28. **Zimbabwe is a signatory to several multilateral agreements concerning land degradation, biodiversity conservation, and climate change issues.** This includes the Convention of Biodiversity (CBD); United Nations Framework Convention on Climate Change (UNFCCC); and, of particular relevance to landscape management and land degradation, the United Nations Convention to Combat Desertification (UNCCD). The latter was ratified by Zimbabwe in 1997, leading to the production of the country's first National Action Plan to avoid and reduce land degradation and restore degraded areas. In 2017, Zimbabwe set ambitious land degradation neutrality (LDN) targets in a bid to halt and reverse degradation of cultivated areas and natural habitats and achieve LDN by 2030 (GoZ 2017). These targets include restoration of the tree cover of large areas of forest and woodland, conservation farming and agro-forestry on cropland, improved management and appropriate stocking rates to improve vegetation cover in sparsely vegetated lands, restoration of degraded wetlands, and control of alien plant species (GoZ 2017). The country's LDN commitments also include associated measures such as improvement in the regulation of illegal mining, provision of alternative energy sources, expansion of the energy for the tobacco program, and other important measures.

29. **Valuing ecosystem services is an important step in devising interventions to address land and ecosystem degradation in the pursuit of sustainable livelihoods and climate resilience.** Through a detailed analysis of a selected landscape in Zimbabwe, the Mazowe Catchment area, this study highlights the value of existing ecosystems and the potential value that can be gained through supporting effective landscape management interventions that restore and maintain biodiversity and the supply of ecosystem services.

1.2 Study objectives

30. **The objectives of this study were as follows:**

(a) Undertake a high-level spatial assessment of selected ecosystem services and their beneficiaries at the national scale to select a focal landscape for the study.

(b) Undertake a desk assessment of ecosystem changes in the focal landscape over the last 30–40 years, the key drivers of change, and impacts on local livelihoods.

(c) Estimate the value of ecosystem services of the focal landscape using a spatial approach.

(d) Identify investment approaches and interventions that could restore degraded landscapes for conservation and production.

(e) Assess and recommend possible governance/institutional improvements to support improved landscape/ecosystem services management.

1.3 Structure of the report

31. **The remainder of report is set out as follows:**

32. **Chapter 2: Selection of the focal landscape** describes the high-level spatial assessment of selected ecosystem services and their beneficiaries that was undertaken at the national scale to inform the selection of a focal landscape for the study by government stakeholders.

33. **In Chapter 3: The Mazowe Catchment Area,** a detailed description of the geographical, ecological, and socioeconomic characteristics of the Mazowe Catchment area is provided as context for the study.

34. **In Chapter 4: Ecological trends, drivers and impacts,** the ecological pressures and trends in the study area are described as far as possible, based on available literature and analysis of satellite data. The chapter then postulates what the main drivers of ecosystem change have been, based on the literature and expert input, and it summarizes some of the impacts that these changes have had on the local population in qualitative terms.

35. **Chapter 5: Ecosystem services, beneficiaries, and value** begins with an overview of the ecosystem services provided by different ecosystem types in the study area and specifies the types of services that the study is focused on. Each of the selected services is then described, modelled, and mapped across the Mazowe landscape in physical terms, and its value is estimated. A summary is provided of the value of each of these services to different beneficiaries in and beyond the study area.

36. **In Chapter 6: Enhancing the asset value of the Mazowe landscape: a scenario analysis,** a range of potentially suitable interventions are identified, and a future implementation scenario is outlined. The impacts of this scenario are then modelled and compared with the outcomes of a business-as-usual scenario. A high-level cost-benefit analysis is undertaken to identify which areas should be prioritized for intervention. Finally, recommendations are made for the actions to follow this study.

2.

Selection of the Focal Landscape

2.1 Overview

37. **A screening assessment was performed at a national scale to identify areas that provide a high level of five key services: food production, erosion control, water regulation, carbon storage, and ecotourism potential.** The assessment also evaluated where there are likely to be many beneficiaries connected with those services and where recent trends in land degradation are threatening to further reduce the provision of these services.

38. **Having a transparent and data-driven process for selecting the candidate landscape was considered crucial to ensure that the government's efforts are directed toward a geography where sustainable land management is likely to significantly affect the provision of (or access to) ecosystem services.** PES programs are more likely to be durable when they deliver tangible benefits to payers, and such tangible benefits are more likely to result when activities are directed to the places where they are most effective. Selecting a priority landscape based on technical criteria derived from a national screening analysis will help ensure that the final outputs of the study will result in a strong case for the feasibility of any subsequent PES schemes in the selected landscape.

39. **The screening analysis involved the collection of spatial data that relate to ecosystem condition, including land cover, land productivity, soil types and extents, elevation and slope, and climate.** In addition, proxy data reflecting the users potentially benefitting from each service were collected and systematized to reflect the degree of dependence on ecosystem services.

40. **Selecting a landscape that provides multiple benefits across sectors will serve to foster opportunities for intersectoral collaboration on the topics of agro-ecology, climate resilience, and environmental management in subsequent work under the Advisory Services and Analytics (ASA).**

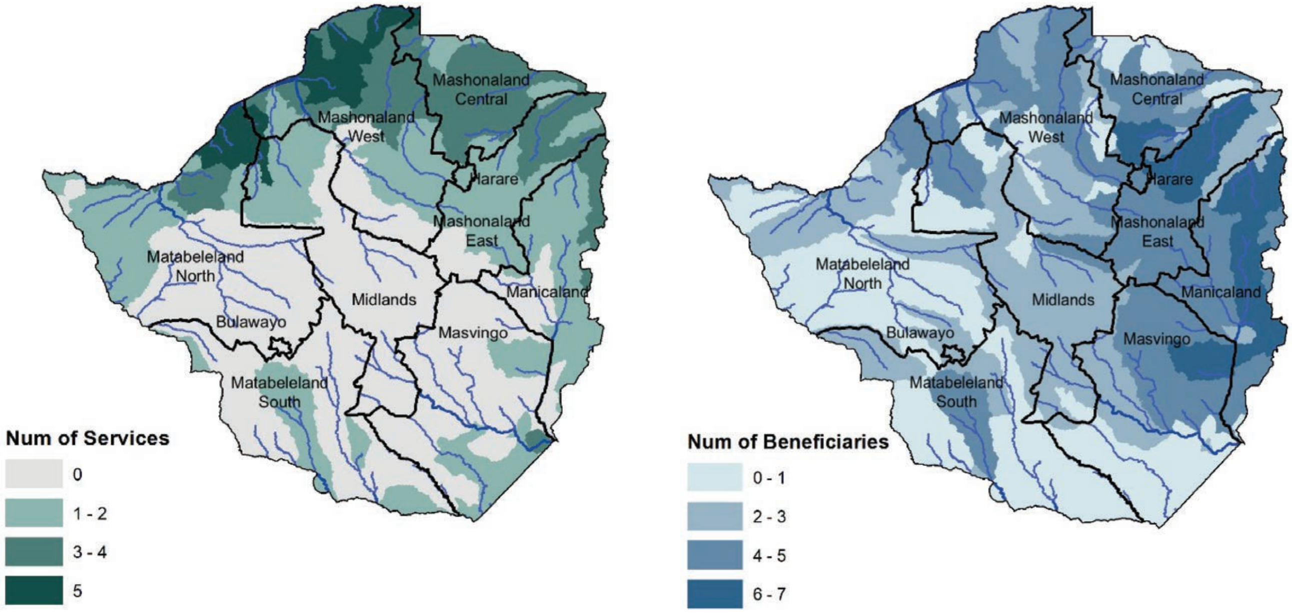
2.2 High-service provision areas

41. **The following maps show high-level results of the national scale assessment of five ecosystem**

KEY POINTS

- Landscape interventions can be fruitful in (a) areas where services are currently high and where there are a lot of people and other sectors depending on them or (b) where landscapes are currently degraded and not providing a high level of ecosystem services to people and other sectors who depend upon them.
- High-service and high-value areas tended to be in the north and northeast of the country.
- High degradation areas were widespread, but more in the central, south, and southeastern areas.
- Seven candidate areas for intervention were identified.
- Based on the broad assessment of ecosystem service values, degradation trends, and local knowledge of the study areas, government stakeholders in the Ministry of Lands, Agriculture, Fisheries, Water and Rural Resettlement (MLAFWRR) and Ministry of Environment, Climate, Tourism and Hospitality Industry (MECTHI) selected the Mazowe Catchment as the focal landscape for this study.

FIGURE 1: RESULTS OF THE NATIONAL SCREENING ANALYSIS OF FIVE KEY ECOSYSTEM SERVICES: FOOD, EROSION CONTROL, WATER, CARBON, AND ECOTOURISM, AND THEIR POTENTIAL BENEFICIARIES



Note: The number of services for which each watershed falls in the top 25 percent (left) and the number of beneficiaries that fall in the top 25 percent considering all services (right).

services. Indicators for (a) the provision of each ecosystem services and (b) the number of beneficiaries depending on those ecosystem services were summed to the watershed level (see Appendix 1 for details).

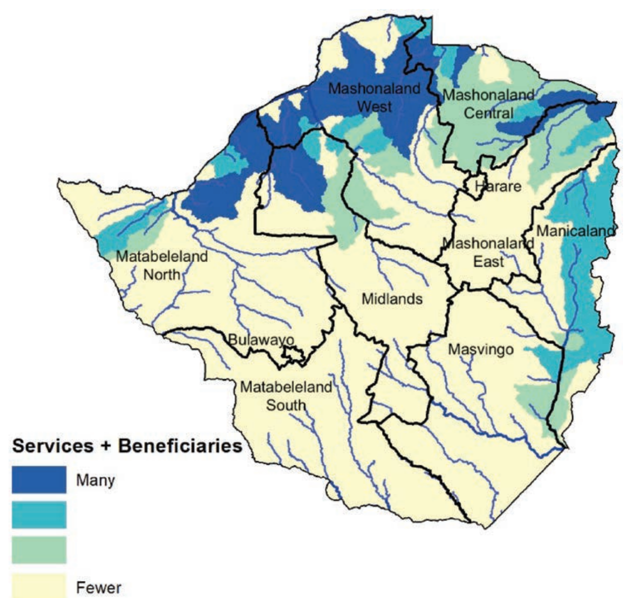
42. **The values represent the number of ecosystem services for which the watershed was in the top 25 percent, compared to all watersheds across the country; in other words, darker colors represent areas that provide the highest level of ecosystem services across all five services considered (food, erosion control, water, carbon, and ecotourism) and across all beneficiaries considered (people, dams, agriculture, livestock, and so on).**

43. **Figure 1 highlights the areas where ecosystem services are greatest (left) and where sectors are most in need of ecosystem services (right).** Figure 2 puts the two together, showing watersheds that provide both a high level of ecosystem services and where sectors depend on those services the most.

2.3 High degradation areas

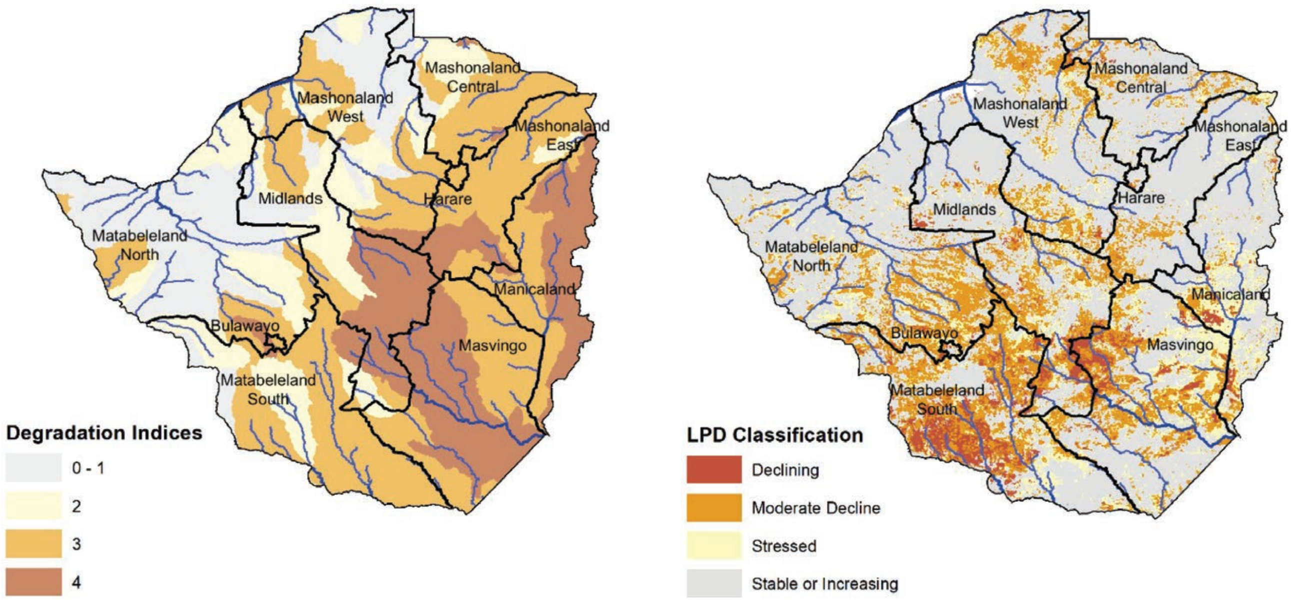
44. **The next set of results focusses on historical trends in land and water degradation, based on a trends analysis of remote sensing data on productivity**

FIGURE 2: RESULTS OF THE NATIONAL SCREENING ANALYSIS OF FIVE KEY ECOSYSTEM SERVICES: FOOD, EROSION CONTROL, WATER, CARBON, AND ECOTOURISM, AND THEIR POTENTIAL BENEFICIARIES



Note: This map shows the overlap of ecosystem services and benefit 'hotspots' - watersheds that provide the most services and where the most beneficiaries potentially rely on them.

FIGURE 3: COMPARISON OF AREAS IN TOP 50 PERCENT OF LAND AND WATER DEGRADATION INDEXES (LEFT) WITH LAND PRODUCTIVITY DYNAMICS RESULTS FROM THE UNCCD LDN STUDY (RIGHT)



Source: Land Degradation Neutrality Report 2017.

Note: Degradation indexes (left) are based on the slope of a 20-year trend analysis and indicate a high rate of loss of vegetation productivity (net primary productivity [NPP]), reduction in evapotranspiration, reduction in soil moisture and baseflow, and increasing surface runoff (source: this study). Land Productivity Dynamics (right) are based on data from the Environmental Management Agency.

and water use by vegetation, baseflow, surface runoff, and soil moisture (see Appendix 1 for details). Results from this study are compared with results from the Land Degradation Neutrality Report (2017) of the Government of Zimbabwe (GoZ). It is clear that while some of the areas that are highlighted in Figures 1 and 2 are experiencing land degradation, the most acute degradation is happening in areas where ecosystem service provision is relatively low (Figure 3, left panel). Therefore, areas in Figure 3 that show the highest degradation trends are those where ecosystem services may need restoration and recovery.

45. **The results also reveal a somewhat different pattern than the LDN study (Figure 3, right panel).** Our analysis used remote sensing data, which reveal patterns in water availability, runoff, and water use by vegetation, as proxies for vegetation health. There is a 51 percent agreement at the watershed level between watersheds with a higher-than-average degradation (from this study) and those with stressed or declining land productivity dynamics (from the LDN study), the current study results tend to highlight more areas in the central and eastern part of the country whereas the land productivity dynamics results are more concentrated in the south.

2.4 Selection of focal landscape

46. **Table 1 presents a set of geographies that emerged from the national screening analysis as candidates for further deep-dive analysis into the benefits, tradeoffs and potential feasibility of a PES program.** Feedback from stakeholders in the MLFAWRR, MECTHI, and various environment and agriculture agencies (that is, Forestry Commission, Environmental Management Agency [EMA], Zimbabwe Parks and National Wildlife Authority [ZPWMA], Zimbabwe National Water Authority [ZINWA], Community Areas Management Programme for Indigenous Resources [CAMPFIRE], and AGRITEX) was solicited to finalize the selection of a focal landscape for the next phase of analysis. The proposed geographies fall into three main categories: (a) those where ecosystem services are currently high, but there are indications of degradation; (b) those where ecosystem services are currently high with less acute threats of degradation; and (c) those where ecosystem services are relatively low, and degradation is acute.

47. **It is interesting to compare the results of this analysis with findings reported in the Land**

TABLE 1: CANDIDATE PRIORITY LANDSCAPES FOR CONSIDERATION FOR DEEP-DIVE ASSESSMENT OF ECOSYSTEM SERVICES BENEFITS AND TRADEOFFS RELATING TO LANDSCAPE MANAGEMENT INVESTMENTS

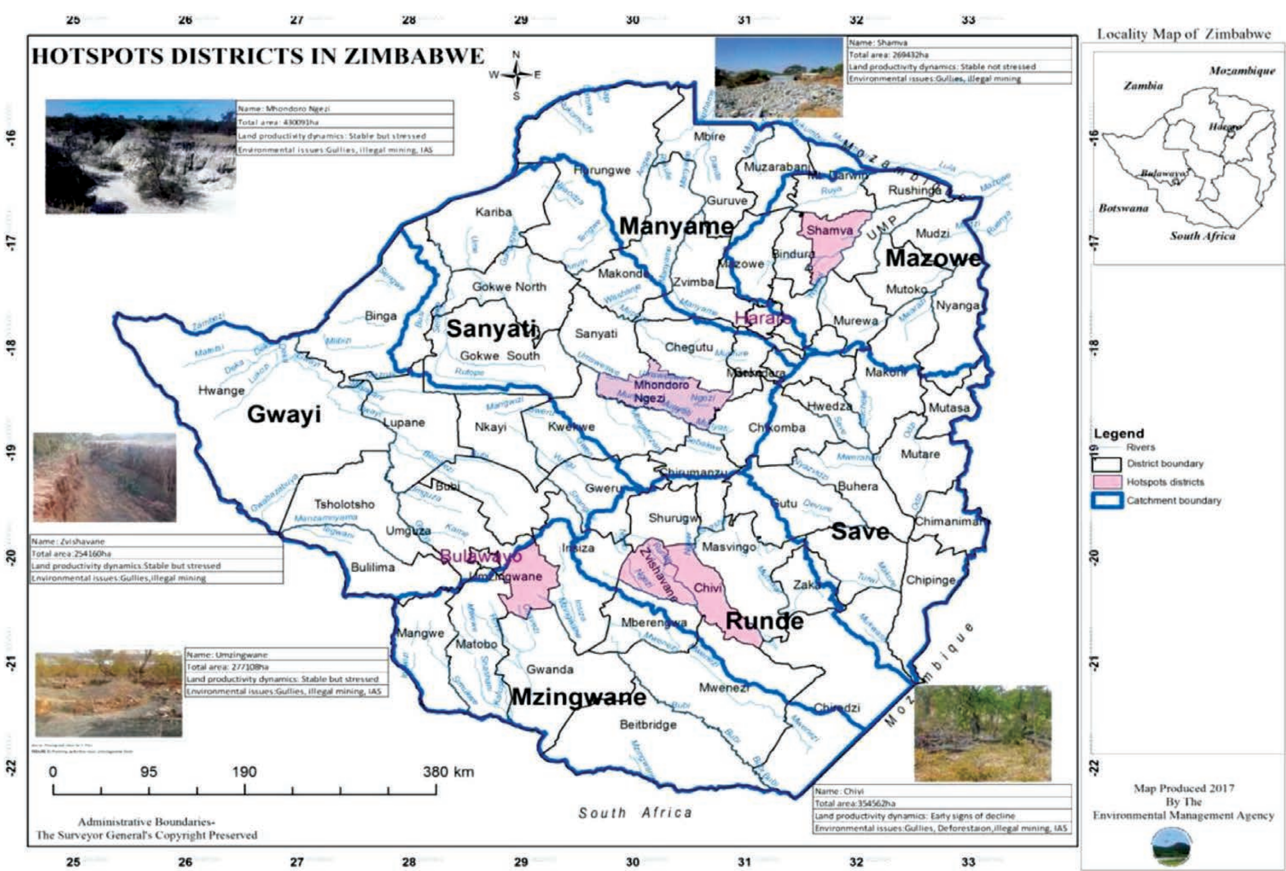
No.	Region or landscape	Associated district(s)	Ecosystem services status and opportunity	Degradation trend
Type I: Landscapes with high provision of ecosystem services, low to moderate degradation				
1	Lower Zambezi River Valley (Hunyani Catchment)	Hurungwe	Ecosystem services level = HIGH Opportunity to conserve and enhance existing high-quality ecosystem services in headwaters draining into protected areas	Low but stressed
2	Hwange-Sanyati Biological Corridor	Hwange*, Binga, Kariba, and Gokwe North	Ecosystem services level = HIGH Opportunity to conserve and enhance existing high-quality ecosystem services, scale up existing efforts, and protect headwaters	Low but stressed, moderate decline in some areas
3	Mazowe Catchment	Shamva*, Mount Darwin, Rushinga, Mudzi, Murehwa Uzumba-Maramba-Pfungwe and Bindura	Ecosystem services level = HIGH Opportunity to conserve and enhance existing high provision of ecosystem service	Moderate decline in land and water indicators
Type II: Landscapes with moderate provision of ecosystem services, moderate to high degradation				
4	Chimanimani	Chimanimani	Ecosystem services level = MODERATE Opportunity to enhance and improve ecosystem services in a productive landscape	Strong decline in land and water indicators
5	Savé Valley	Bikita, Chipinge, and Chiredzi	Ecosystem services level = MODERATE Opportunity to enhance and improve ecosystem services in a productive landscape	Moderate decline in land and water indicators
Type III: Landscapes with low provision of ecosystem services, high degradation				
6	Runde and Tokwe River Catchments	Zvishavane*, Insiza, Shurugwi, Gweru, Chirumhanzu, Masvingo, and Chivi*	Ecosystem service level = LOW, but high demand. Opportunity to restore services of erosion control, water regulation, and soil carbon in productive landscapes, and to benefit downstream dams	Steep decline in land and water indicators
7	Umzingwani and Thuli River Catchments	Gwanda, Umzingwane*, Matobo, and Beitbridge*	Ecosystem service level = LOW Opportunity to restore services of erosion control, water regulation, and soil carbon in productive landscapes	Moderate to steep decline in land and water indicators

Note: *Districts included in the eight priority LDN hotspots identified for further investment in the GoZ's Land Degradation Neutrality Report, August 2017.

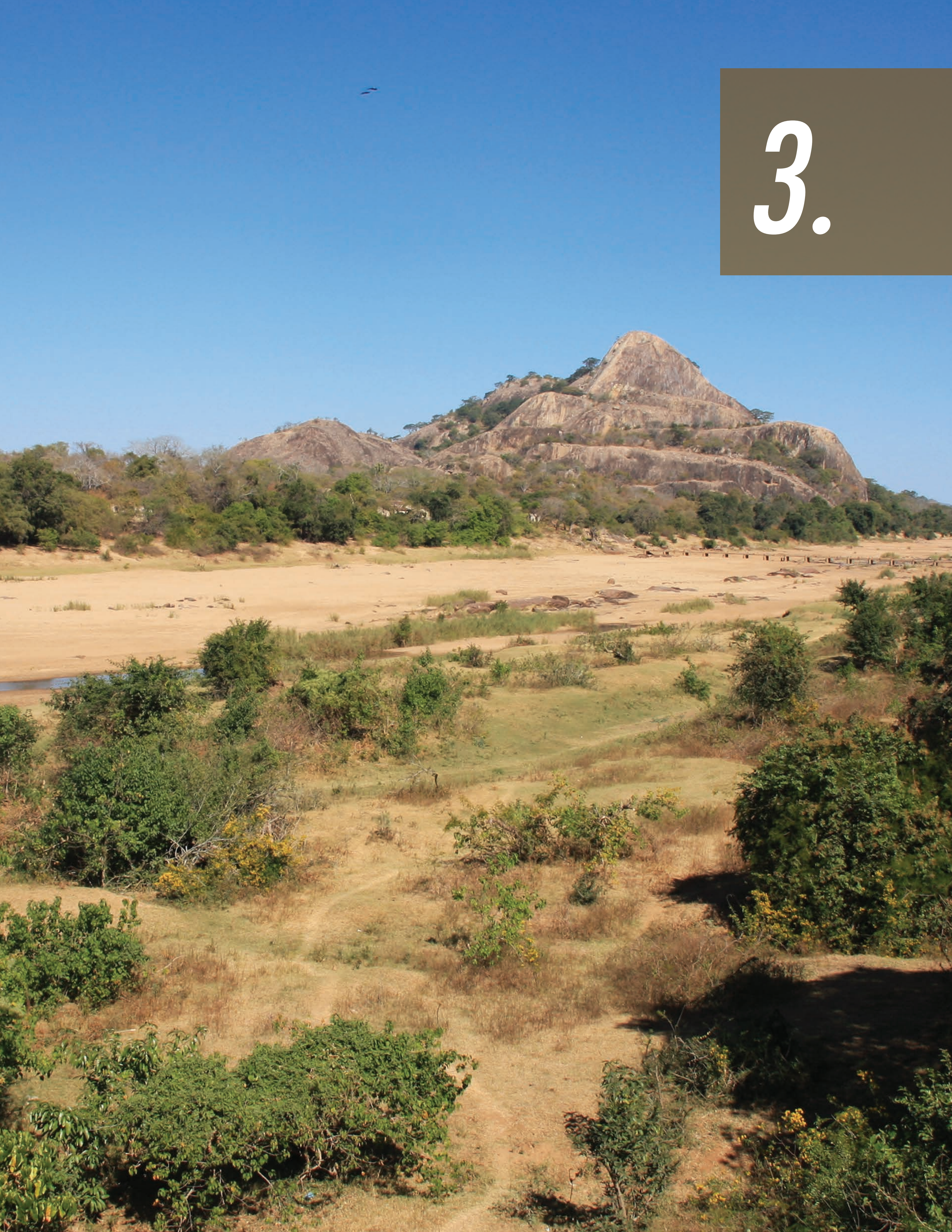
Degradation Neutrality Report that the Ministry of Environment, Water and Climate released in 2017. That report highlighted areas where land productivity is threatened from both natural drivers (for example, changing climate patterns) and human-driven land degradation (for example, spread of invasive alien species, gullies, illegal mining, and poor land management). Eight priority LDN hotspots were identified for further investment in the Shamva, Mhondoro, Chivi, Zvishavane, Umzingwane, Hwange, Chikomba, and Beitbridge districts (Figure 4). Note that six out of these eight districts also emerged from the current analysis as potential focal areas for this ASA (Table 1). Four of these (Zvishavane, Chivi, Umzingwane, and Beitbridge) correspond with areas of low ecosystem service provision and high degradation, consistent with the LDN methodology. The other two (Hwange and Shamva) fall into Type I landscapes in this study: those with high ecosystem service provision and moderate declines. Because this study focused specifically on ecosystem services beyond land productivity (namely erosion control, water regulation, carbon storage, and tourism potential) and incorporated the number and types of beneficiaries that depend on these services, our results (Table 1) highlight a broader set of landscapes than those selected in the LDN report.

48. **Based on the broad assessment of ecosystem service values, degradation trends, and local knowledge of the study areas, stakeholders from MECHTI and MLAFWRR selected the Mazowe Catchment as the focal landscape for this study.**

FIGURE 4: SELECTED LDN HOTSPOTS, IDENTIFIED BY THE MINISTRY OF ENVIRONMENT, WATER AND CLIMATE



Source: GoZ 2017.



3.

The Mazowe Catchment Area

49. **The capacity for an area to generate ecosystem services is highly related to its physical features and climate, while the value of these services relates in part to the way in which the area is populated, managed, and used.** This section provides an overview of the biophysical characteristics of the Mazowe Catchment area, the land tenure, population characteristics, livelihoods, and economy. This provides the background information that informs the way in which people have changed the landscape and the way in which they depend on its ecosystem services, which are described in the subsequent chapters.

3.1 Topography, drainage and climate

50. **The Mazowe River rises 14 km north of Harare and flows into Mozambique, where it joins the Zambezi River (Figure 5).** Its three main tributaries—the Ruya, Ruenya, and Gairezi—join the main stem in Mozambique, about 40 km upstream of the Zambezi. The entire catchment has an area of 54,577 km^2, of which 39,857 km^2 is within Zimbabwe.

51. **The catchment is relatively hilly and undulating.** Altitude ranges from almost 2,600 m at Mount Nyangani to 80 m at the Mazowe and Zambezi confluence (Figure 5).

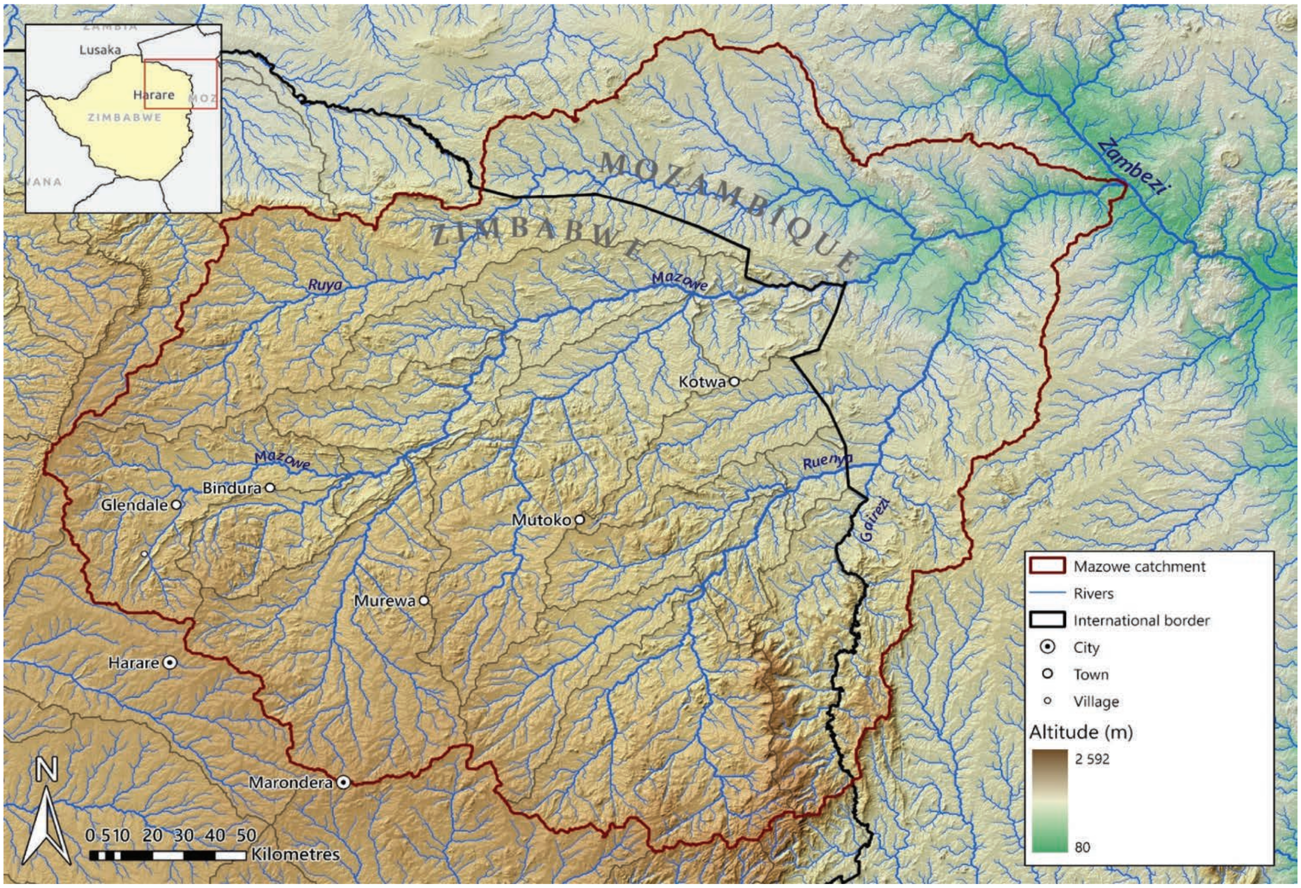
52. **The area has warm to hot, wet summers and cool to mild, dry winters.** The highest temperatures are in November to January, while July is the coolest month. Mean annual temperature (MAT) increases as altitude declines. The most southerly areas of the catchment have the lowest MAT, between 12°C and 15°C. The low-lying northeast parts of the catchment have an MAT above 22°C.

53. **Rainfall tends to be highest in January and lowest in August.** Mean annual precipitation (MAP) is also closely correlated with altitude, with the highest

KEY POINTS

- The Mazowe Catchment extends over roughly 40,000 km^2 of northeast Zimbabwe.
- Natural vegetation varies from miombo woodland in the wet upper reaches of the catchment to mixed Acacia-Terminalia woodland in the drier lower reaches, with small patches of montane forest and grassland in the Nyanga Mountains.
- Extensive transformation of natural vegetation has occurred, with cultivation covering 33 percent of the catchment.
- Prime agricultural areas in the southwest are mostly commercial farmland, many of which were resettled under the FTLRP. The north and east of the catchment mainly consist of communal land.
- Around 2.3 million people live within the catchment, with an average population density of 58 people per km^2. Around 93 percent of this population is rural.
- Crop cultivation is the most important livelihood activity in the wet upper reaches of the catchment, while livestock is increasingly important in the drier lower reaches.
- Numerous small to medium dams are located in the catchment, mostly on commercial farmland in the south and west. However, groundwater is the main water source for most of the area's inhabitants.

FIGURE 5: THE LOCATION AND GENERAL TOPOGRAPHY OF THE MAZOWE CATCHMENT



Source: HydroRivers (Lehner and Grill 2013), Topography/Digital elevation model (Farr et al. 2007), Towns (https://www.openstreetmap.org/)

rainfall in the catchment being around 1,000 mm per year. These areas experience among the highest rainfall in Zimbabwe. The lowest parts of the catchment experience 620 mm of rainfall per year.

54. **Like the rest of Zimbabwe, significant changes in climate are predicted for the Mazowe Catchment, though the projected changes are not as severe as those predicted for the south and west of the country (World Bank 2021).** Mean annual temperatures in the Mazowe Catchment could rise by around 2°C under the representative concentration pathway (RCP) 8.5 emissions scenario. Changes in precipitation are less certain, but modelling projections suggest changes will be modest. However, higher temperatures in the absence of significant increases in precipitation will increase potential evapotranspiration, resulting in greater heat and water stress. The likelihood of severe drought is also expected to increase (World Bank 2021).

3.2 Geology, vegetation and land cover

55. **The catchment comprises predominantly primarily crystalline basement rocks that typically have a low permeability and porosity.**[1] Parts of the area, particularly in the north, comprise basic igneous rock of the greenstone belt, which is the oldest geology in the region. Most of the upper and middle catchment area comprises intermediate igneous granitoid rocks while the lower catchment is predominantly made up of acid metamorphic rock of the Orogenic belt. There are patches where schist and gneiss are the most dominant rocks (Anderson et al. 1993; FAO and ISRIC 2013; Wilson and Nutt 1990).

56. **Soils are predominantly shallow, greyish brown, coarse-grained sands, to similar sandy loams,**

[1] http://www.zinwa.co.zw/catchments/mazowe-catchment/

over reddish browns and clay loams on granitic rocks. The dominant soils within the catchment are varied but luvisols, lixisols, arenosols, and cambisols are the most widespread (Department of the Surveyor-General 1979; FAO and ISRIC 2013). Soils are primarily between 100 cm and 150 cm deep with shallower soils in the Ruya and Ruenya/Rwenya river valleys. Soil moisture is generally high across the catchment (Mantel 1994). Only areas with shallower soils are considered to have a severe soil moisture deficit.

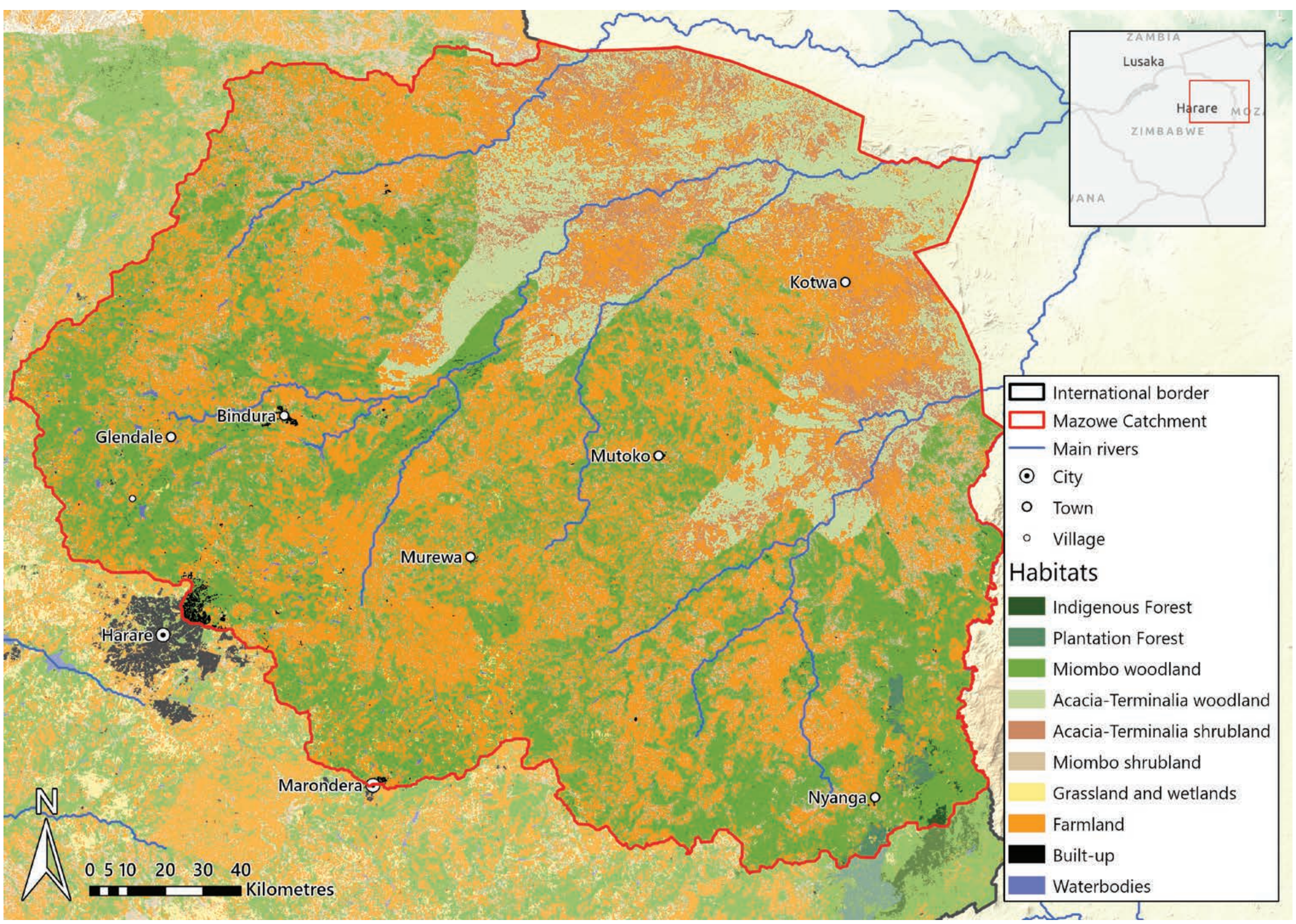
57. **Historically, the Mazowe Catchment was dominated by open miombo woodland, particularly in the upper and middle reaches, while mopane shrubland and Acacia-Terminalia savanna occupied most of the lower reaches.** Denser miombo vegetation was primarily found in the upper Mazowe sub-catchment east of Bindura, while there were fragments of indigenous forest in the Nyanga Mountains in the extreme southeast. The area includes many wetlands.

58. **The landscape has since been extensively transformed, with many areas having been cleared for anthropogenic uses, resulting in a highly fragmented landscape with few large, contiguous areas of natural or near-natural vegetation (Figure 6).** Cultivated land accounts for roughly 33 percent of the study area. Most cultivation is subsistence or small scale (ZIMSTAT 2019). There is irrigated cultivation adjacent to major rivers.

59. **Towns such as Bindura and Mutoko, as well as the outskirts of Harare and Marondera which are on the catchment watershed, account for the urban/built-up land cover which makes up less than 1 percent of the total area.**

60. **Although they occupy a relatively small surface area, there are several mines in the Mazowe Catchment including some of Zimbabwe's largest mining operations (Chandiwana 2016).** These

FIGURE 6: HABITATS, INCLUDING LAND COVER AND VEGETATION TYPES IN THE MAZOWE CATCHMENT



Source: Ecosystem (vegetation), types (Olson et al. 2001), and land cover (Buchhorn et al. 2020).

include Bindura Nickel Corporation, Trojan, Mazowe, Ashanti, Arcturus, and Madziwa mines. The dominant minerals mined in the catchment are nickel and gold (contained largely in the greenstone belt and extracted primarily through alluvial mining).

3.3 Administrative areas, land tenure, and protected areas

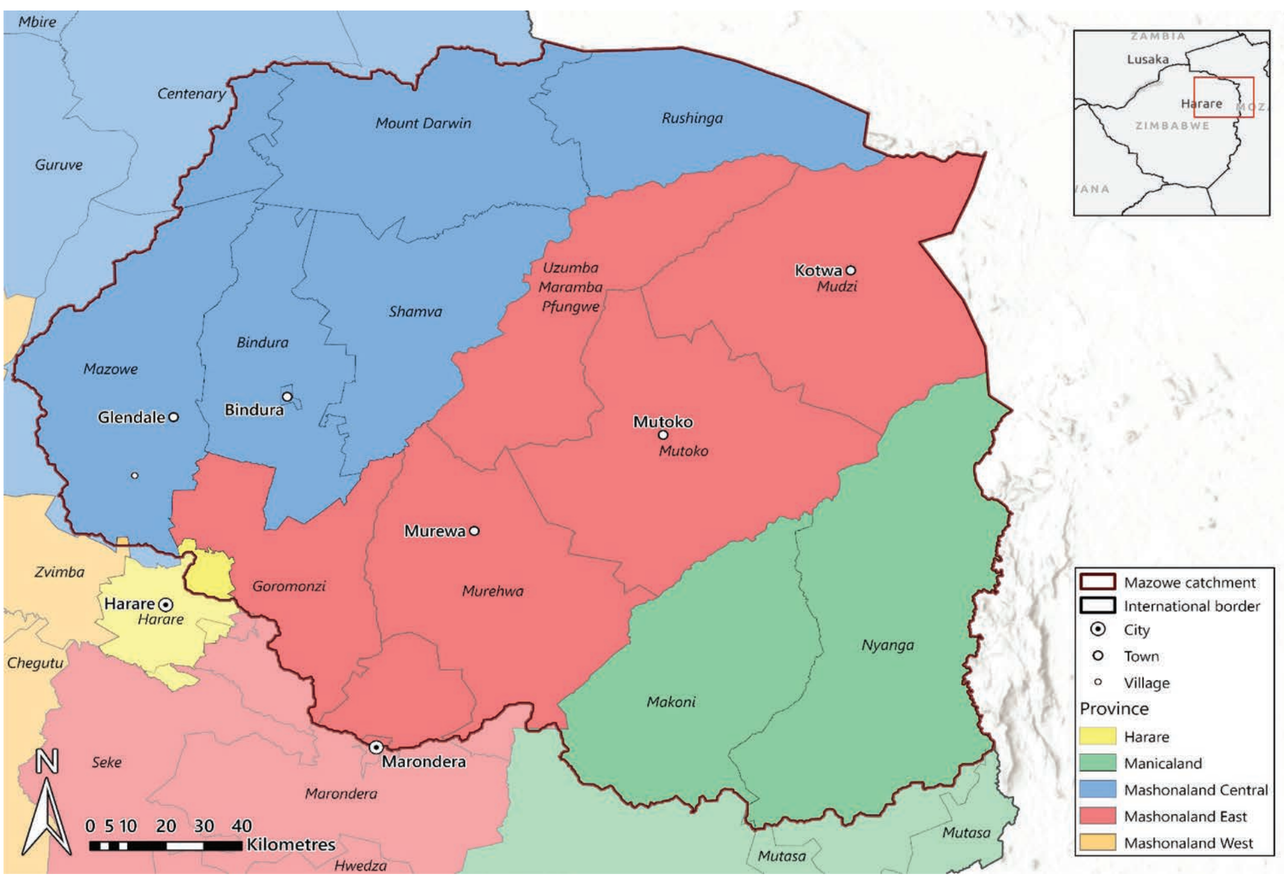
61. **The catchment lies mainly within Mashonaland East, Mashonaland Central, and Manicaland (Figure 7).** Within these provinces, 15 rural districts fall inside the study area.

62. **Much of the area is under communal land tenure, particularly in the lower reaches (Figure 8).** These areas generally have lower rainfall and crop production (Mutami 2015). Plot sizes are small, with landholdings typically 2 ha or less (Chimhowu and Woodhouse 2008). Much of the south and west of the catchment consisted of large-scale private commercial farms before 2000. Under the FTLRP of 2000–2009, many of these farms were subdivided into small (±20 ha) A1 family farming units and medium-scale (±300 ha) A2 commercially oriented farming units (Moyo 2011; Scoones et al. 2011; Sukume, Mahofa, and Mutyasira 2022).[2] The intensity of production of these farms varies, with some having converted to smaller-scale operations (Scoones et al. 2018).[3]

63. **Many of these areas still have insecure and uncertain land tenure arrangements.** For example, A1 households cannot use their land as collateral security, which affects their access to credit (Mugabe et al. 2014).

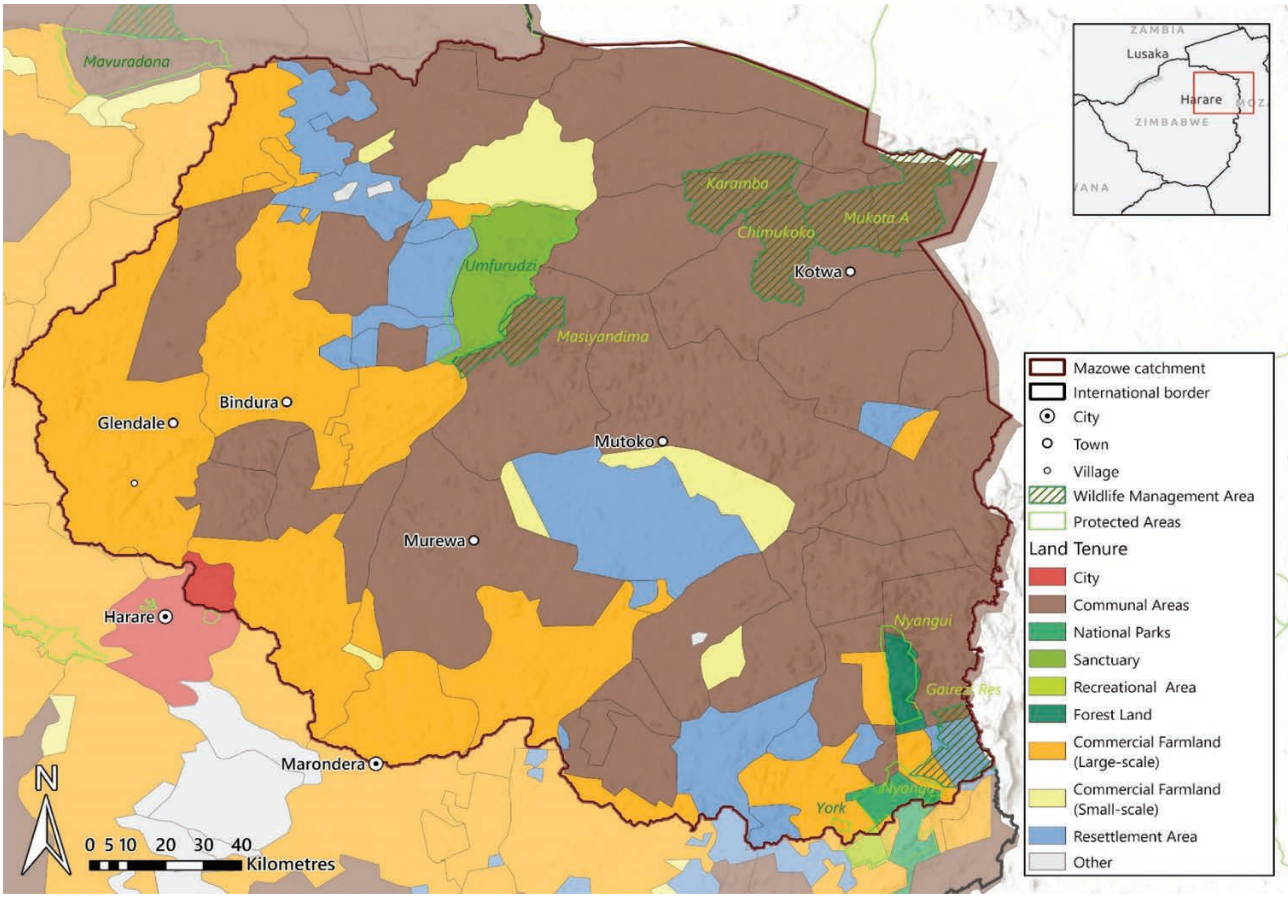
64. **This, combined with other financial constraints and limited agricultural training of the new tenants,**

FIGURE 7: PROVINCES AND DISTRICTS INTERSECTING THE MAZOWE CATCHMENT. DISTRICTS ARE LABELLED



² A1 farms have individual family farm of 6 ha plus a common livestock grazing area (ZIMSTAT 2019).
³ Large-scale farms are said to have declined in area from 15.5 percent of the country's surface area in 1980 to 3.4 percent in 2010 (Scoones et al. 2011).

FIGURE 8: LAND TENURE IN THE MAZOWE CATCHMENT



Sources: GOZ-SADC-FANR (2003); UNEP-WCMC (2022).

has often resulted in low crop production and underutilization of land, with many areas falling fallow (Godwin et al. 2011; Mugabe et al. 2014). A survey of Mazowe District estimated that 50 percent of resettled small-scale commercial farmland was fallow in 2013.

65. **Nevertheless, A1 farmers now account for 26 percent of marketed maize and 41 percent of registered flue-cured tobacco producers (MoLAWFRR 2021; Sukume, Mahofa, and Mutyasira 2022; TIMB 2020).**

66. **The study area also contains some state-owned and communal conservation areas.** The largest protected area is the Umfurudzi Safari Area on the western side of the Mazowe River. This is the largest contiguous area of natural or near-natural land cover in the study area (ESA 2017), but it is surrounded by dense settlements, grazing areas and crops (Muposhi et al. 2016) and has at least one commercial mine within its boundary. The southern part of the catchment includes part of the Nyanga National Park, which protects areas of montane grassland, woodland, and small indigenous forest patches. Two state forest areas, York and Nyangui, also fall within the southern part of the catchment. Although listed as protected areas by UNEP-WCMC[4], these areas are used primarily for plantation forestry production.

67. **There are also several wildlife management areas (WMAs).** The mapped WMAs represent wards participating in CAMPFIRE, which helps communities to benefit from wildlife-related tourism activities such as hunting. In Mazowe, the largest of these (Karamba, Chimukoko, and Mukota A) are in the relatively remote lowest parts of the catchment (Figure 8) and border the Nyatana Game Park, a community conservation

[4] https://www.protectedplanet.net/

area overseen by the three regional district councils of Mudzi, Rushinga, and Uzumba Maramba Pfungwe (Amon 2011). Other WMAs are Gairezi situated near Nyanga National Park and Masiyandima adjacent to Umfurudzi Safari Area. Although they are classified as protected areas, they function as multi-use landscapes rather than being strictly focused on biodiversity conservation.

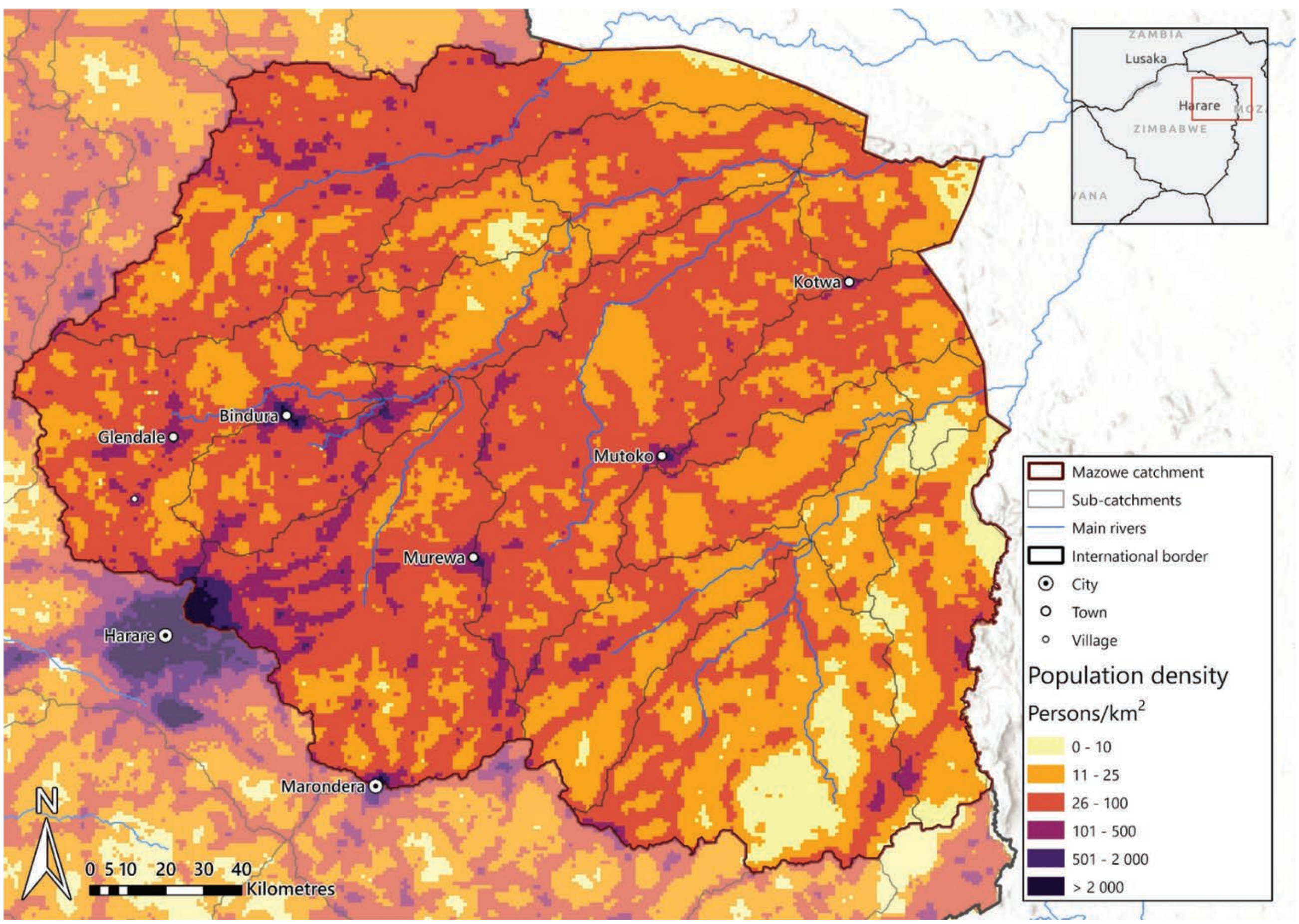
3.4 Population

68. **The Mazowe Catchment area, encompassing the outskirts of the capital city, Harare, and the nearby town of Marondera, is one of the most densely populated regions of Zimbabwe (Figure 9).** In 2000, the population of the catchment was approximately 1.58 million. By 2020, this had increased by 45 percent (annual growth of approximately 15 percent) to about 2.3 million (Bondarenko et al. 2020). This is just under 17 percent of the country's total population.

69. **The average population density of the catchment is around 58 people per km², with most areas above 25 people per km² and very few sparsely populated areas.** The largest towns wholly within the catchment are Bindura, Mutoko, and Murewa, which had populations of around 46,000, 17,000, and 12,000 in 2012 (ZIMSTAT 2012). Notably, all of these towns are located near or on one of the main rivers. These towns and the outskirts of Harare had the greatest population density increase from 2000 to 2020.

70. **Approximately 93 percent of the people living in the catchment area are in rural areas,[5] with the communal land areas being the most densely populated.**

FIGURE 9: POPULATION DENSITY OF MAZOWE CATCHMENT



Source: WorldPop (Bondarenko et al. 2020)

[5] Calculated using the number of people as per Bondarenko et al. (2020) dataset intersecting with land cover classified as anything aside from urban/built-up.

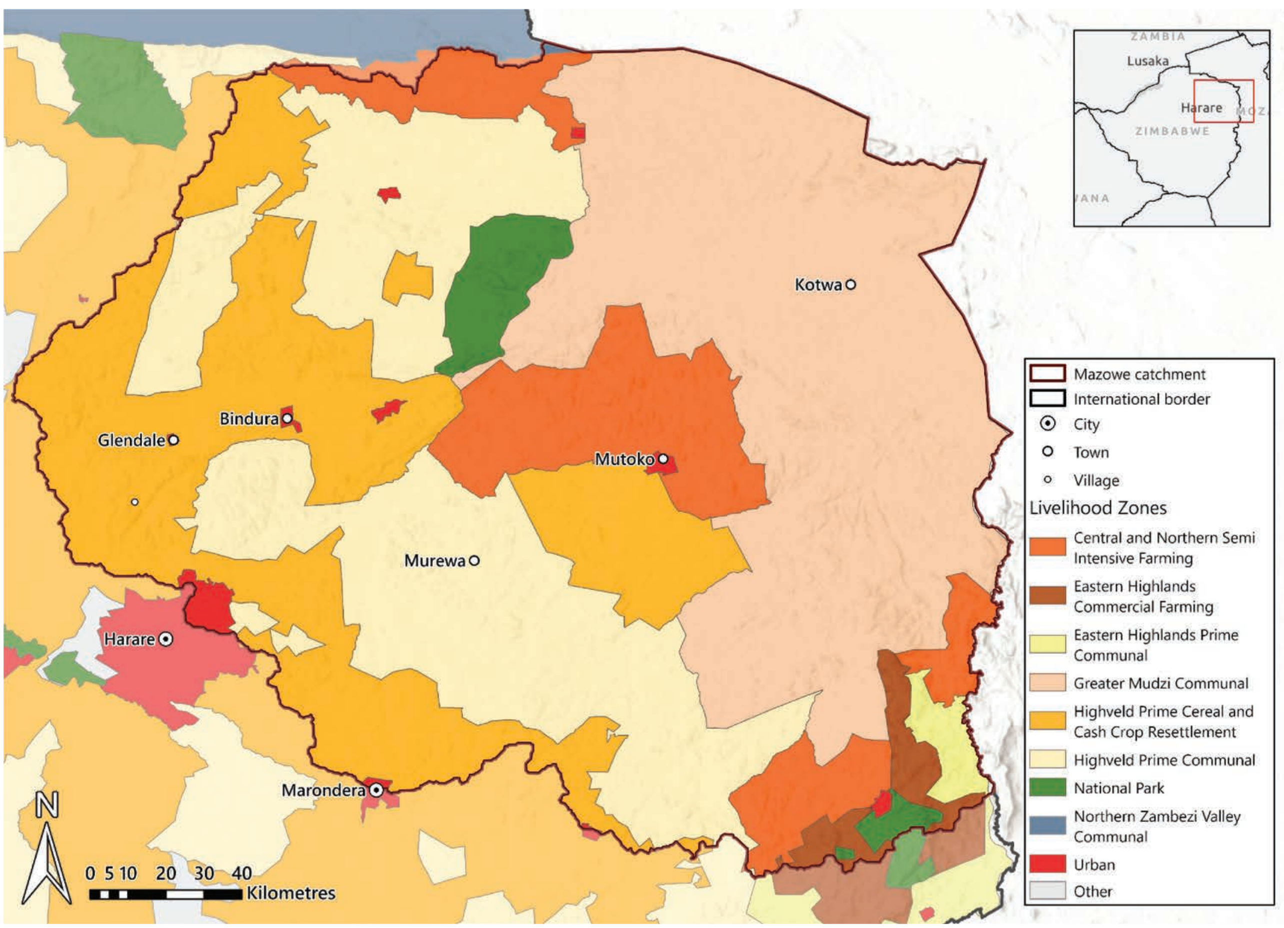
71. **The main ethnic group and language in the study area is Shona.** Manyika, a Shona subgroup with a slightly different dialect, is dominant across some of the catchment's eastern parts. Finally, a small population of Nsenga people lives in part of the catchment along the Mozambican border (Eberhard, Simons, and Fennig 2022; Muturzikin 2007).

3.5 Livelihoods and socioeconomic status

72. **Most people in the study area are rural and relatively poor.** The study area has four main livelihood zones—Central and Northern Semi-Intensive Farming, Highveld Prime Communal, Highveld Prime Cereal and Cash Crop Resettlement, and Greater Mudzi Communal (ZimVAC 2011, Figure 10, Appendix 1).

73. **Subsistence or small-scale farming is the main livelihood, particularly in communal and resettlement areas, with maize being the dominant food crop (ZimVAC 2021).** Small-to medium-scale commercial farming has become more prevalent in the south and west of the catchment (that is, the Highveld Prime Cereal and Cash Crop Resettlement Zone). Overall, over 80 percent of rural households in the study area grow maize, while tobacco is the most important cash crop (Sukume, Mahofa, and Mutyasira 2022; ZimVAC 2021). Many farmers also practice agropastoralism, though livestock ownership is not as widespread as crop cultivation. According to the most recent ZimVAC assessment, around 30–40 percent of households in the constituent provinces of the catchment own cattle or goats (ZimVAC 2021). Market access, ecosystem degradation, and natural hazards, combined with the weak national economy, are the main inhibitors of improving agricultural livelihoods (GoZ and WFP 2017).

FIGURE 10: LIVELIHOOD ZONES IN THE MAZOWE CATCHMENT



Source: Zimbabwe Rural Livelihood Baseline Profiles (ZimVAC 2011).

74. Poorer households depend on multiple sources of income including sale of handcrafts, petty trading (fish sales and beer brewing), and artisanal mining (GoZ and WFP 2017; Myambo 2017; ZimVAC 2011). Mining in particular has become an increasingly prevalent livelihood strategy in recent years, particularly in gold-rich areas such as Mazowe District, due to a combination of poverty, unemployment, and declining agricultural yields (Nyavaya 2021). The majority of formal employment is in agriculture (including forestry), followed by retail trade, mining, and quarrying. The Makaha/Benson mine is a key employer in the rural Mudzi District (ZimVAC 2011). There is also a small degree of employment in ecotourism around protected areas (Chirenje 2017).

75. Average monthly income among rural households in the study area ranges around US$30–80 (ZimVAC 2021). According to ZIMSTAT data, poverty generally increases moving from southwest to northeast in the catchment (ZIMSTAT 2019), mirroring the decline in rainfall and agricultural suitability. Over 60 percent of households live below the poverty line across all rural districts in the catchment, with Rushinga District having the highest poverty levels in the study area, as well as being one of the poorest districts in the country. Over 90 percent of households in Rushinga live in poverty and 59 percent in extreme poverty (ZIMSTAT 2019). At an aggregate level, Mazowe District was estimated to have the highest number of poor households in the catchment, due to a combination of a high poverty rate (82 percent) and large number of households living within it. Despite the high levels of poverty, literacy rates are high by regional standards, at over 85 percent (UNESCO 2022[6]; ZIMSTAT 2018), and at least a primary school level of education has been attained by more than 85percent of adults in the intersecting provinces (ZimVAC 2021).

76. Of the provinces within the study area, Mashonaland Central (half of which is in the northern Mazowe Catchment) has the worst food poverty levels, with the highest incidences of hunger out of any province in the country (ZimVAC 2021). However, according to projections of district-level cereal insecurity data for the 2020/2021 season, Mudzi (Mashonaland East) had the highest proportion (about 50 percent) of cereal-insecure households in the study area, followed by Makoni District (38 percent) (ZimVAC 2021). Food insecurity becomes even more serious in lower rainfall seasons, with 75 percent of households in Mudzi estimated to be cereal insecure in the drier 2019/2020 season (ZimVAC 2020). In the same season, a further nine districts within the study area (Rushinga, Mutoko, Mazowe, Uzumba Maramba Pfungwe, Mount Darwin, Muzarabani, Goromonzi, Shmava, and Marondera) experienced cereal insecurity rates above 50 percent, highlighting the extent of food poverty issues in the catchment.

77. Based on information collected by the EMA, illegal mining is most prevalent in the mineral-rich Highveld Prime Cereal and Cash Crop Resettlement Zone, particularly north and east of Harare and around Glendale and Bindura. There is also significant illegal mining in the northern parts of the Greater Mudzi Communal Zone around Kotwa. Gully erosion recorded by the EMA is almost entirely limited to communal livelihood zones, with highest incidences of gully erosion around Murewa (Highveld Prime Communal Zone) and Mutoko (Central and Northern Semi-intensive Farming Zone).

78. Household energy sources are not available at a detailed level, but the Poverty Income Consumption and Expenditure Survey report of 2017 indicates that at a national level, wood accounts for 93.8 percent of rural households' energy for cooking (ZIMSTAT 2018). In urban areas, the main source of energy for cooking is electricity (64.5 percent), wood (16.7 percent), and gas (10.8 percent). At the provincial level (rural and urban households combined), reliance on wood as the primary cooking source ranges from 82 percent to 90 percent across the constituent provinces within the catchment.

79. Sanitation in Zimbabwe is vastly different between urban and rural areas. On average, 91.5 percent of urban dwellers have access to a flush toilet, compared to only 4 percent of rural dwellers (ZIMSTAT 2018).

80. Access to 'improved' drinking water, that is, water protected from fecal contamination, ranges from 80 to 85 percent in the study area provinces, which is above the national average. The proportion of households relying on water from wells, springs, or directly from surface water source (for example, rivers,

[6] http://uis.unesco.org/

ponds, or streams) is between 15 and 19 percent, which is among the lowest in the country (ZimVAC 2021).

3.6 Water supply

81. **The Mazowe Catchment contains a number of man-made reservoirs.** The total dam storage capacity is approximately 543.6 Mm^3 in 260 reservoirs (Messager et al. 2016). However, dams are not evenly distributed across the catchment, with most falling within commercial farming areas in the south and west of the study area. Dams in the catchment supply water to Harare and other towns, as well as to several irrigation schemes, namely Kanhukamwe, Naymaropa, Marondera, Nyanga, and Glendale (ZINWA 2022). Nevertheless, there is an annual water supply deficit of 143 megaliters (ML) for the Mazowe supply area.

82. **There are seven medium-to-large dams (>10 Mm^3) in the Mazowe Catchment, all located in the southwest of the study area.** The 39.4 Mm^3 Mazowe Dam (the catchment's second largest dam by surface area) was built in 1920, initially to supply water for irrigation to surrounding citrus estates. Presently, the dam supplies various agricultural crops and orchards as well as water for livestock (Ernettie 2014; Nhedzi 2008).

83. **Reservoir levels have declined over the last few decades due to increased demand and regular intense droughts which at times left the dam almost completely empty (Downing 2013; Viriri and Musariri 2006).** Abstraction from elsewhere has also affected groundwater flow into the reservoir. The Rushinga and Mudzi districts in the lower catchment have been particularly hard hit by droughts in the last few years (GoZ and WFP 2017; ZimVAC 2021).

84. **While dams provide an important source of water for agriculture, particularly in commercial farmland, groundwater is the main water source for rural communities in the catchment.** The proportion of households depending on boreholes and wells as their main source of drinking water across the constituent provinces of the catchment (excluding Harare) ranges from 74 to 89 percent, while use of surface water ranges from 3 to 9 percent of households (ZIMSTAT and UNICEF 2019).

4.

Ecological Trends, Drivers, and Impacts

4.1 Overview

85. **This section provides an analysis of how the ecological status of the study area has changed over the past two or three decades, focusing on aspects relating to ecosystem health and the landscape capacity to deliver ecosystem services.** Ecological trends were analyzed using satellite data, including changes in land cover, tree cover, and land productivity. The chapter also mentions some environmental pressures that have not been quantified in any way, but which are known to have affected ecosystems or pose a threat to them in future.

86. **The environmental trends observed in the Mazowe Catchment have been brought about by a complex array of factors.** Some of the well-known proximate causes of ecosystem degradation and loss have been land use change, overexploitation of resources, poor land management, uncontrolled mining and industrial activities, and poor sanitation.

87. **These problems find their roots in a set of interrelated underlying drivers, including a low level of government services, insecure land tenure and weak governance, poverty, and population growth.** In particular, lack of secure property rights takes away any incentive to invest in land and protect one's assets. Resulting persistent poverty drives up fertility rates and fuels a downward spiral.

88. **The pressures on the environment are also certainly exacerbated by global climate change (IPBES 2018; IPBES and IPCC 2021), but at this stage, it is clear that poor land and ecosystem management is the bigger problem.** If this is not addressed, then the additional stress imposed by increasing climate change will have particularly severe

KEY POINTS

- Based on land cover data, the study area lost over 1,100 km^2 of its dense woodland and over 90 percent (400 km^2) of its wooded grassland, mostly to dryland cultivation, in the last 25 years (1992–2018).
- According to Forest Watch data, some 594 km^2 of forest and woodland (above 10 percent tree cover) experienced a loss of tree cover between 2001 and 2020.
- Some 9 percent of remaining natural areas have experienced significant losses in productivity, while 29 percent have shown an increase between 2001 and 2017.
- Commercial and artisanal mining is having a serious impact on surface and groundwater quality and causing significant sedimentation problems.
- Catchment productivity is seriously affected by the invasion of lantana, alien grasses, and water weeds.
- Climate change will have a direct impact on ecosystem condition and water supply and will indirectly increase all of these pressures.
- Environmental problems in the catchment are primarily due to expansion of cultivated lands, tobacco curing, and small-scale mining. Ultimately, they are due to the related problems of poverty, population growth, and lack of secure property rights.
- The combination of the above trends with future climate change will likely be catastrophic for the well-being of catchment inhabitants.

consequences for livelihoods in the coming decades, including worsened food insecurity from higher frequency of drought and other extreme events, higher risks of water scarcity, and contraction of areas suitable for rainfed crop production (IPCC 2020; World Bank 2019).

4.2 Ecological status and trends

4.2.1 Land cover change

89. **Habitat loss through anthropogenic changes in land cover is the primary driver of biodiversity loss worldwide, reducing the ability of landscapes to sustain ecosystem services (CBD 2020).** For this study, land cover changes were quantified for the 26-year period from 1992 to 2018, using uniformly developed and classified land cover data from the European Space Agency (ESA 2017). This period saw significant political changes that, in the early 2000s, in particular, resulted in major changes in land tenure which led to changes in land use and condition across the country, including the Mazowe Catchment.

90. **The detailed changes in land cover are presented as land cover accounts for the Mazowe Catchment in Appendix 2.** The greatest net losses in this period were by far the extents of dense woodland (−1,226 km^2) and wooded grassland (−402 km^2). The extent of rainfed cultivation (765 km^2) and herbaceous vegetation (597 km^2) increased the most in this period. Wooded grassland in the catchment has been almost completely transformed to other land cover types, losing 90 percent of its 1992 extent. The area under irrigated crops tripled, although it is likely that some areas have been misclassified as rainfed agriculture and the figure underestimated the actual extent of irrigated crops both in 1992 and 2017. Urban/built-up land cover increased by 87 percent from 34 km^2 to 64 km^2. Open woodland also increased during this time, by just over one-fifth of its 1992 extent.

91. **Using a land cover change matrix (see Appendix 2), it is possible to determine the different transitions that have taken place within the landscape.** Dense woodland, for example, has lost over 580 km^2 to cultivation while over 1,200 km^2 shifted to shrubland or herbaceous vegetation, indicative of a loss of tree cover in these areas. Rainfed cultivation has also replaced over 260 km^2 of wooded grassland. Urban/built-up land cover has increased primarily at the expense of dense woodland, followed by rainfed cultivated land and shrubland.

4.2.2 Deforestation and vegetation loss

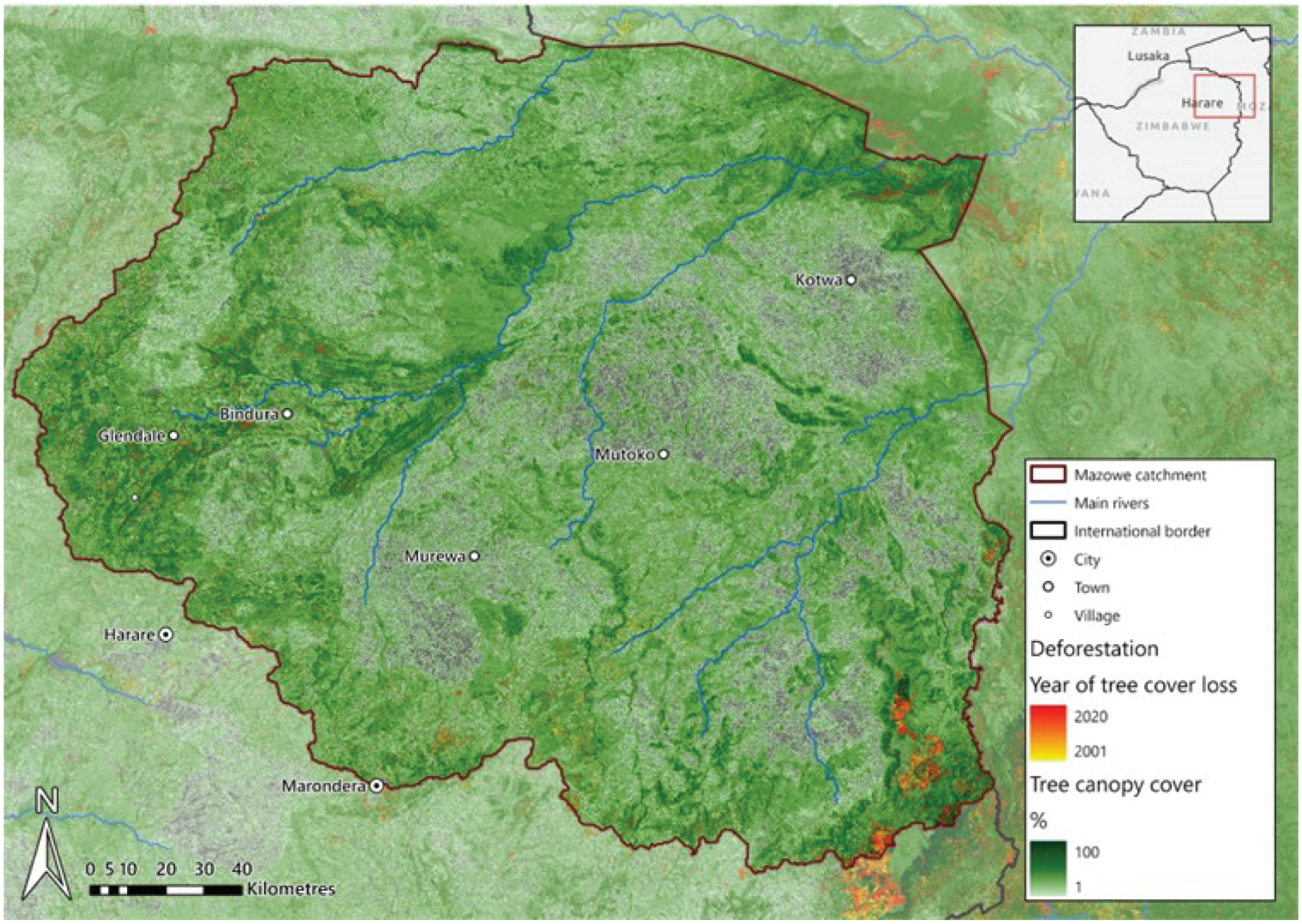
92. **Deforestation is a major concern, particularly in tropical and sub-tropical environments.** The loss of woody vegetation has repercussions for ecosystem functioning and affects several processes that underpin ecosystem services. It also leads to the emission of greenhouse gases that accelerate climate change globally. According to FAO, Zimbabwe as a whole, has had some of the world's highest rates of deforestation (for canopy cover exceeding 10 percent) with a forest loss rate of 3,090 km^2 per year leading up to 2010[7]. Between 1990 and 2015, it is estimated that 37 percent of the country's 'forested' land was cleared[8]. Based on Global Forest Watch data (Hansen et al. 2013) it was estimated that 594 km^2 of natural forest and woodland (above 10 percent tree cover) was lost from Mazowe Catchment from 2001 to 2020 (Figure 11, Figure 12).

93. **Tree loss was also examined for each sub-catchment in the study area.[9]** The greatest loss has been in the Upper Mazowe Catchment with just over 3 percent of all non-plantation areas showing detected loss in forest or woodland canopy cover (Figure 13). This is followed by the Kairezi sub-catchment with 2.8 percent and then the Upper Rwenya sub-catchment with 1.8 percent.

94. **Most vegetation loss has been within miombo woodland areas and is largely from clearing for agriculture.** Many vegetated areas were cleared to make way for subsistence and small-scale agriculture

[7] www.globalforestwatch.org
[8] Unregulated Deforestation May Be Decimating Zimbabwe's Timber Industry (globalpressjournal.com)
[9] As per the HydroSHEDS layer, not administrative sub-catchment councils.

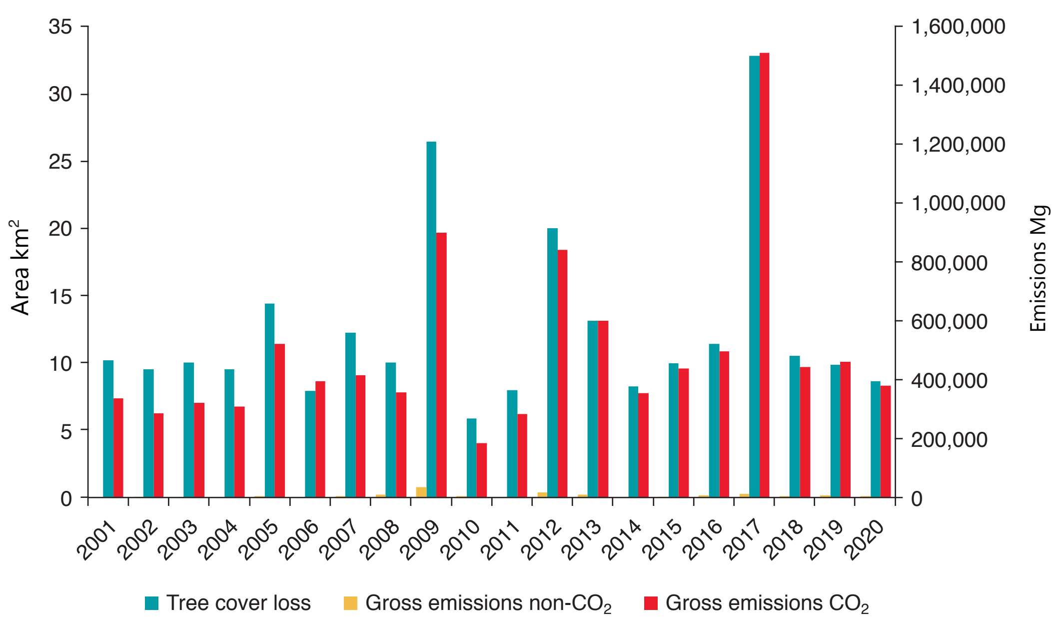
FIGURE 11: AREAS OF TALL TREE CANOPY COVER (TREES > 5M HEIGHT) LOSS BETWEEN 2001 AND 2020, SHOWN BY YEAR IN YELLOW-RED SCALE, SUPERIMPOSED ON A MAP OF TREE CANOPY COVER AS 2010



Source: Global Forest Watch (see Hansen et al. 2013 for desciption of methods).

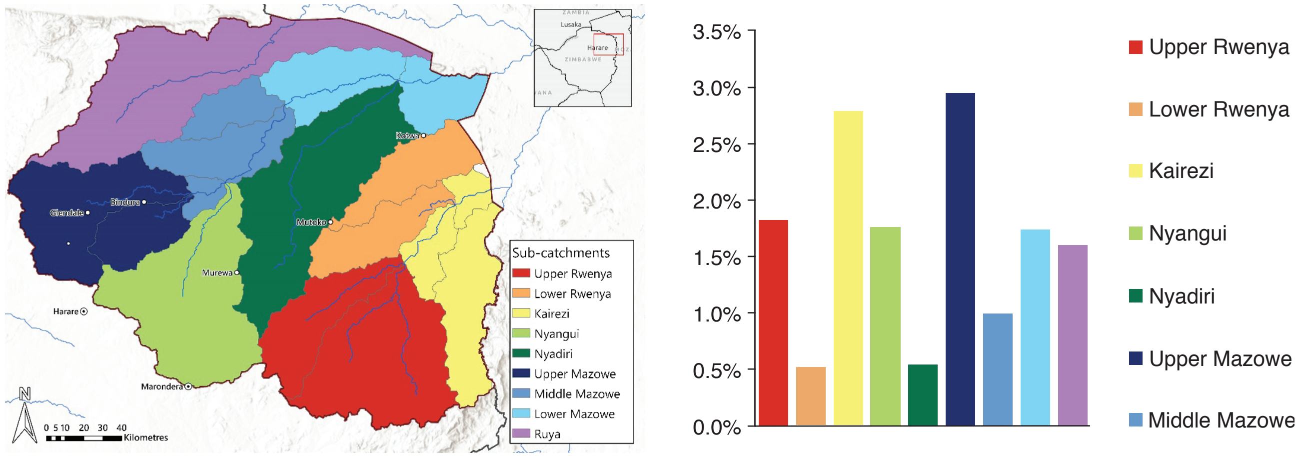
Note: Grey areas indicate zero tall tree cover. Because of the tree size, this is mainly detected in commercial plantations and is likely to be part of normal harvesting cycles.

FIGURE 12: LOSS OF TALL TREE COVER AND ASSOCIATED GROSS GREENHOUSE GAS EMISSIONS IN MAZOWE CATCHMENT BETWEEN 2001 AND 2020 (FOR VEGETATED AREAS WITH 30 PERCENT CANOPY COVER OR MORE)



Source: Hansen et al. 2013.

FIGURE 13: MAZOWE SUB-CATCHMENTS AND THE PERCENTAGE OF THE TOTAL AREA THAT HAS BEEN CLASSIFIED AS HAVING LOST TALL TREE COVER BETWEEN 2001 AND 2020



Source: HydroSHEDS, Lehner and Grill 2013; Hansen et al. (2013b).

after the FTLRP of the 2000s.[10] High rates of recent deforestation within miombo woodland areas of the upper catchment have been confirmed by more localized studies. For example, almost half of the woodland cover in Ward 32 of Mazowe District was lost between 2000 and 2018 while the size of cultivated and bare areas more than doubled (Matsa et al. 2020). This has negatively affected livelihoods, with the vast majority of local respondents complaining of a reduction in trees for firewood and building materials, loss of wildlife and fruit trees that were previously harvested for food, and increased conflict over resource access in the face of worsening scarcity.

4.2.3 Land degradation

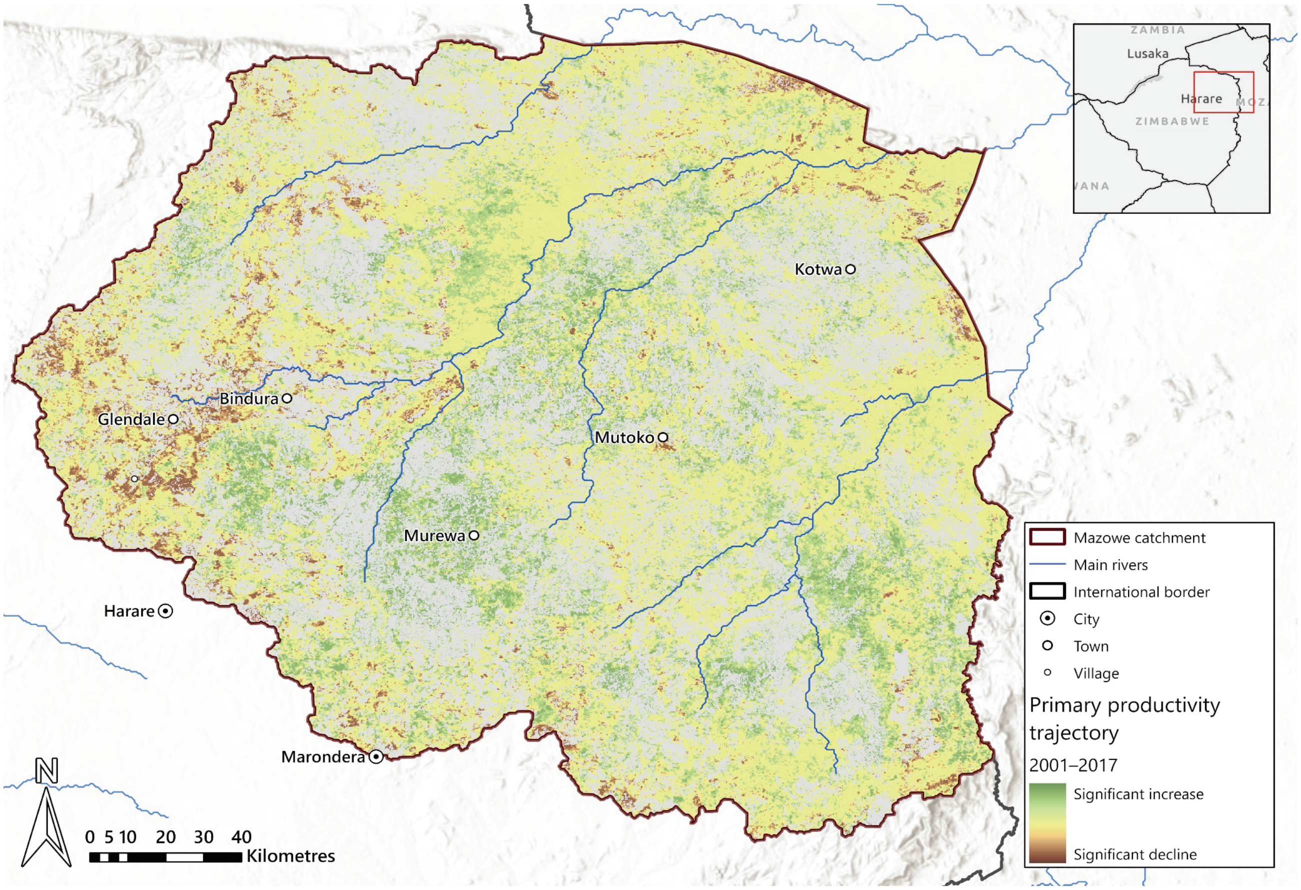
95. Land degradation was assessed using satellite-derived trends in land productivity, using the Normalized Difference Vegetation Index (NDVI) as the measure of productivity. Areas that exhibited a statistically significant decline in productivity after accounting for the impacts of precipitation trends were considered to be degraded (Nkonya, Mirzabaev, and von Braun 2016). Due to the availability of satellite imagery with sufficiently high resolution, this analysis was limited to the period between 2001 and 2018, and thus only captures relatively recent degradation. Further methodological details on the analysis performed are given in Appendix 3.

96. Based on the analysis of NDVI trends, some 9 percent of remaining natural areas exhibited significant losses in productivity, while 29 percent showed an increase from 2001 to 2018 (Figure 14). While areas with increasing NDVI may reflect recovering vegetation in some cases, it is also likely to represent the atmospheric fertilization effect, where increased carbon dioxide in the atmosphere stimulates increased photosynthesis in plants (Nkonya et al. 2016). Areas experiencing the greatest degradation over this period were around Glendale and Bindura in the west of catchment and near the Mozambique border north of Kotwa (Figure 14). The former area includes many of the catchment's largest dams (including Brecon, Umrodzi, Pote, and Jumbo). An analysis of historical satellite imagery indicates that many of the regions exhibiting a decline in NDVI are the result of the partial clearance of natural vegetation for agriculture in areas that had not been cultivated previously.

97. Since the Mazowe Catchment encompasses some of the wettest parts of the country, the inherent risks of soil erosion by water across much of the Mazowe Catchment are among the highest in the country. According to Berg and Tempel (1995), the water erosion risk for most of the catchment is moderate to very high and is particularly high risk for areas under rainfed maize crops. The mean soil erosion in the Mazowe Catchment has been estimated to be as high as 54 tons per ha per year (Tundu, Tumbare, and Onema 2018), which is well

[10] The FTLRP facilitated redistribution of farms owned by white citizens to black Zimbabweans, especially war veterans from the independence wars of the late 1970s. Many of these farms included commercial timber plantations and natural woodland where livestock and game were kept.

FIGURE 14: PRIMARY PRODUCTIVITY TRAJECTORY IN THE PERIOD 2001–2017 ON A SCALE FROM SIGNIFICANT INCREASE TO SIGNIFICANT DECLINE IN PRODUCTIVITY AS WELL AS AREAS OF RELATIVE STABILITY



Source: Conservation International 2018. *Note:* This excludes agricultural and other modified land cover (shown in grey).

above the soil erosion tolerance limit of 10 tons per ha per year for agricultural land. High erosion rates reduce topsoil depth, deplete soil nutrients, and reduce soil water and organic carbon content. This imposes a cost on farmers by forcing them to rely on fertilizer inputs to replace lost nutrients, while in extreme cases, the soil may become too shallow to support crop production.

98. **High erosion rates have not only led to a loss of important topsoil for agriculture but have also led to sedimentation that has diminished storage capacity in reservoirs and limited their ability to provide intended quantities of water for domestic, industrial, and irrigation uses (Godwin et al. 2011; Tundu, Tumbare, and Onema 2018).** For example, siltation has resulted in a 39 percent reduction in the capacity of Chimanda Dam in Rushinga District (Tundu, Tumbare, and Onema 2018) and a 67 percent loss in storage capacity for Chesa Causeway Dam in Mount Darwin (Godwin et al. 2011).

4.2.4 Water pollution

99. **Water quality in the Mazowe Catchment has been affected by mining, agriculture, and human settlements.** Drainage from commercial mining activities (tailings) has had a particularly serious impact on surface and groundwater quality through poorly managed wastewater runoff (Chandiwana 2016; ZINWA 2022). Mining discharges release chemicals that do not degrade easily, such as heavy metals, mercury, and cyanide used for gold extraction, into waterbodies (Jackson et al. 2001). Acid mine drainage (AMD) has been reported in the Pote River in the upper Mazowe Catchment (Lupankwa et al. 2006; Muposhi et al. 2015). Lower down in the Mazowe Catchment, cyanide, mercury, and other poisonous substances released by mining operations in Mudzi District have been blamed for causing cattle deaths along the Ruenya

River.[11] Pollution of rivers in the area has become so serious that Mozambique has reportedly been compelled to lodge a formal complaint to the Zimbabwean authorities.

100. **In addition to the release of toxins into the environment, small-scale and artisanal mining has resulted in several rivers' natural flow being disrupted following degradation of rivers and riparian areas by alluvial gold panning.** Sedimentation and increases in turbidity have also resulted from artisanal alluvial mining. Artisanal gold panning is said to be the leading cause of high sediment yields in the Middle Mazowe sub-catchment (Tundu, Tumbare, and Onema 2018). Sedimentation in rivers has also resulted from re-mining of old mine dumps and erosion of unused mine dumps. These mine dumps are not well vegetated, resulting in limited control of erosion and runoff of chemicals, dust, and other rock material into riparian areas, river channels, and groundwater. Although there are regulations in place that require rehabilitation of mine dumps, there is very little compliance (ZINWA 2022).

101. **Effluent from industries, including textile manufacturers and smelters, is often above the stipulated acceptable range of waste disposal regulations.** In addition, seepage from landfill sites contributes to groundwater pollution, while lack of water supply and sanitation further contributes to river pollution and solid waste pollution is also a problem (ZINWA 2022). This has led to an increase in chemicals and fecal microbes contaminating rivers.

102. **It is likely that there is some runoff of nitrogen and phosphorus from the application of fertilizers to crops in commercial crops in the upper catchment.** Even small-scale farming may result in such impacts. During the wet season, soil and fertilizers often flow from subsistence farms in and adjacent to the riparian zones into rivers resulting in increased sedimentation and eutrophication.

4.2.5 Invasive alien plants

103. **The presence and spread of invasive alien plants (IAPs) can have long-lasting and severe impacts on ecosystem functioning (van Wilgen and Wilson 2018).** While some IAPs are relatively benign, certain species, once established, can negatively affect species composition, outcompeting native species due to the lack of natural predators or enemies (Keane and Crawley 2002) and eventually reduce ecosystem functioning.

104. **IAPs can lead to the reduction of stream flows and groundwater, displace native biodiversity, and reduce areas available for grazing.** The financial impacts of IAPs on agricultural output in Africa have been in the order of the tens of billions of US dollars (Eschen et al. 2021), while the financial impact on livestock production has been estimated to be in the region of US$21 million in South Africa (O'Connor and van Wilgen 2020).

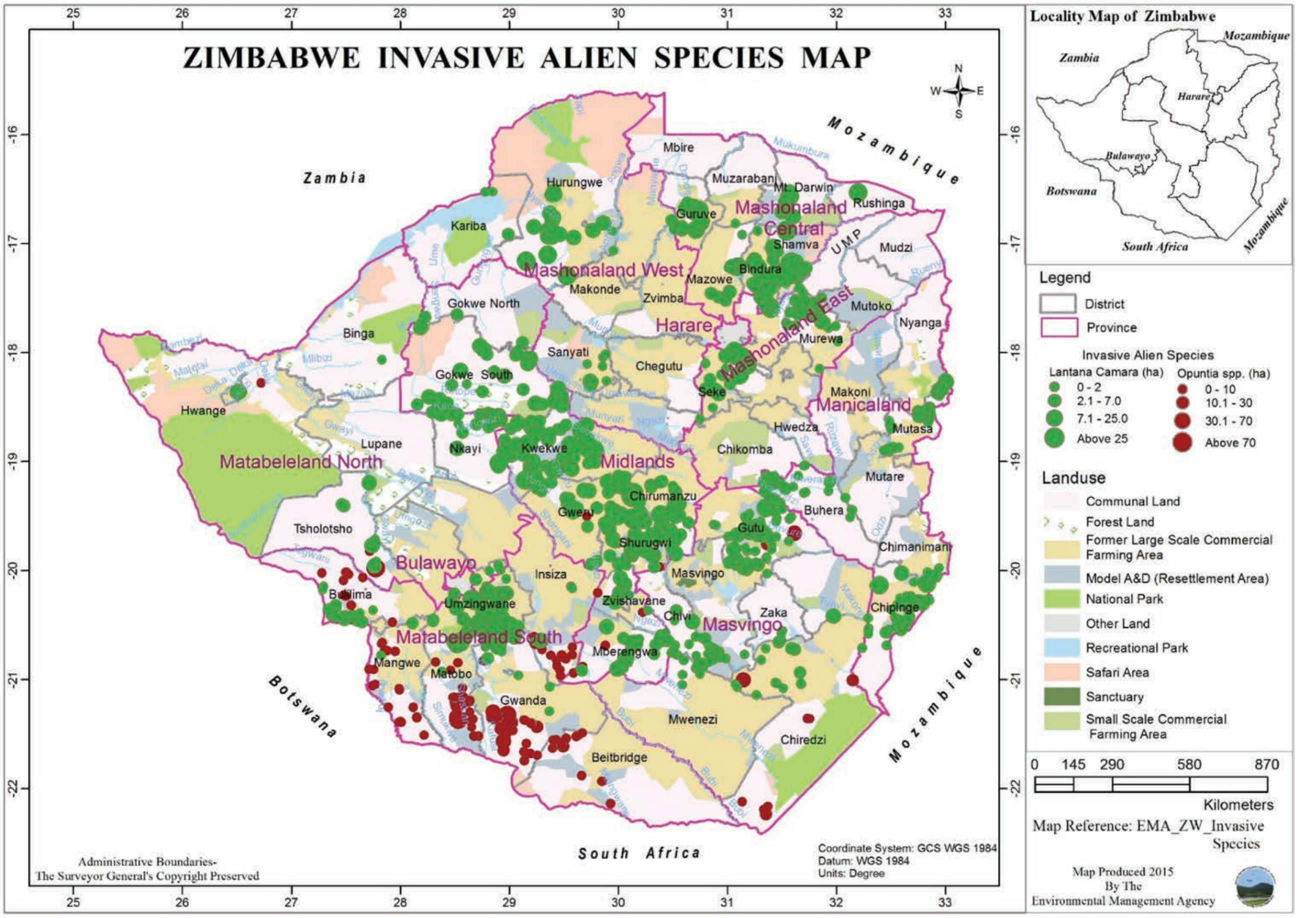
105. **IAPs are a problem in the Mazowe Catchment, with lantana (*Lantana camara*) invasions being particularly widespread (Masocha 2009, Figure 15), with dense thickets along the Mazowe and Mwenje Rivers.** Lantana is a destructive species with little or no benefit (Ncube et al. 2020). It reduces native species diversity, negatively affects wildlife habitats, and can reduce rangeland productivity by over 50 percent (Shackleton et al. 2017). Its leaves are poisonous to livestock[12]. It can also reduce annual surface water runoff by as much as 1,250 m^3 per condensed ha[13] (Middleton and Bailey 2008). It is also difficult to harvest for fuelwood. The habitat suitability of lantana is expected to increase under climate change (Ncube et al. 2020).

106. **Aquatic weeds, such as water hyacinth (*Eichhornia crassipes*), red water fern (*Azolla filiculoides*), and parrot's feather (*Myriophyllum aquaticum*) are problematic in some of Zimbabwe's larger reservoirs.** These increase evapotranspiration and affect dissolved O_2 and pH levels in the waterbodies, with detrimental impacts on fish and other aquatic life (Chamier et al. 2012; Mujaju, Mudada, and Chikwenhere 2021). Up-to-date impacts on dams within the catchment are not available.

107. **Most of the country's focus in terms of IAP management is on biological control of aquatic weeds.** There is also legislation which specifically prohibits the cultivation of lantana anywhere and weeding any individual plants of the species is

[11] https://www.pressreader.com/zimbabwe/the-standard-zimbabwe/20220710/281590949275389.
[12] https://www.cabi.org/isc/datasheet/29771#tosummaryOfInvasiveness
[13] IAPs occur at varying densities, so measures are standardized to the equivalent area at 100 percent cover.

FIGURE 15: LANTANA (L. CAMARA) AND PRICKLY PEAR (OPUNTIA SPP.) DISTRIBUTION AND EXTENT ACROSS ZIMBABWE



Source: Environmental Management Agency.

compulsory. Certain forestry companies clear spreading IAPs around timber plantations and there are programs to control IAPs in certain vulnerable areas and national parks (Sithole and Chikwenhere 2003). This is especially worthwhile for IAPs that are heavy water users (Marais and Wannenburgh 2008; Morokong et al. 2016; The Nature Conservancy 2019).

4.3 Key drivers

4.3.1 Proximate causes

108. **The main proximate causes of ecosystem degradation and loss are the conversion of virgin land to cropland, poor cultivated and rangeland management, and overexploitation of harvested resources and mining.**

4.3.1.1 Agriculture practices

109. **In the Mazowe Catchment, the vast majority (67 percent) of tree cover loss since 2001 is estimated to be due to the expansion of agriculture Curtis et al. (2018).**

110. **Poor land management has led to widescale erosion and sediment loading into rivers and reservoirs across Zimbabwe.** This includes the clearing of riparian vegetation to grow crops, which has been particularly evident in communal and resettlement areas in the middle and upper Mazowe Catchment (GoZ and WFP 2017). Indeed, communal land tenure areas appear to have the worst rates of soil loss relative to other land tenure types across Zimbabwe (Tundu, Tumbare, and Onema 2018; Whitlow 1988).

111. **Smallholder farmers in Zimbabwe typically try to compensate for low yields through expanding cropping areas (extensification) rather than intensifying production on existing fields (Marongwe et al.** 2011). Often, the expansion of cropland into increasingly marginal areas is accompanied by very limited investment in erosion control measures.

112. **Another factor which contributes to erosion is the typically bare state of fields at the start of the rainy season, which is often characterized by violent, erosive rain storms (Makwara and Gamira 2012).** Due to shortages of dry season grazing, crop residues are typically consumed by livestock, resulting in bare fields by the end of the dry season. Additionally, planting in communal areas typically occurs late, resulting in greater exposure of bare soil to rain in the early part of the rainy season (Whitlow 1988). Conventional tillage, most commonly involving mechanical ploughing of land with an animal-drawn mouldboard plough, remains prevalent among most smallholder farmers (ZCATF 2009). While the practice has benefits, the associated mechanical disturbance of the soil structure increases its susceptibility to erosion, though there has been some promising progress in the uptake of reduced- and no-tillage approaches across the country (Marongwe et al. 2011; World Bank 2019).

113. **Subsistence farms are also often located near streams and rivers, to reduce watering effort and costs (Figure 16).** This reduces the sediment retention capacity of the riparian zone, thus further contributing to sedimentation problems.

114. **Similarly, wetlands are heavily used for crop production and livestock grazing, due to the enhanced water availability and forage production they provide (Matiza 1994; Musasa**

FIGURE 16: SATELLITE IMAGE SHOWING THE SUBSISTENCE FARMING AREA ADJACENT TO THE NYADIRE RIVER IN THE MAZOWE CATCHMENT

Source: Google Earth.

and Marambanyika, 2020; Svotwa, Manyanhaire, and Makombe, 2008). While year-round growth of crops on wetlands has been an important livelihood strategy since precolonial times, wetland cultivation has expanded to unsustainable levels in recent decades, undermining the very benefits which make wetlands attractive for cultivation and grazing in the first place. Crop cultivation tends to increase water abstraction relative to natural wetland vegetation, while livestock grazing and trampling further reduce vegetation cover and weaken soil structure, making it prone to erosion (Musasa and Marambanyika 2020). As of 2015, it was estimated that 65 percent of wetlands in the Mazowe Catchment were in a moderately degraded state and 21 percent in a severely degraded state, highlighting the severe impact of land management practices (Musasa and Marambanyika 2020).

115. **There is little information on stocking rates of livestock in relation to grazing capacity.** However, it is likely that there is an increasing squeeze on the shrinking area of grazing lands, because livestock keeping remains an important aspect of rural livelihoods in the region. This will affect grass cover, drive invasion of unwanted species, and incentivize burning.

116. **Burning is usually carried out to clear lands for cultivation, clear moribund vegetation and crop residue on small-scale farms (Mupotsa 2014), and promote green growth for livestock grazing or hunting at the end of the dry season when fresh grass is scarce and crop residues unavailable (World Bank 2019).** However, late dry season burning can cause massive increases in runoff once the first rains arrive, significantly increasing erosion rates (Roose 2008). The Mazowe area has some of the highest incidences of intentional wildfires in Zimbabwe, and the issue seems to be increasing in severity (GoZ and WFP 2017). An upsurge in wildfires occurred during the FTLRP period across Zimbabwe, presumably to clear land for cultivation, and in view of an underdeveloped social contract for nascent farming communities.

4.3.1.2 Fuelwood harvesting for household consumption and tobacco

117. **The inhabitants of the Mazowe Catchment still depend heavily on harvested natural resources for livelihoods, particularly firewood.** Firewood is used as the primary cooking fuel by 94 percent of rural households, with an additional 0.1 percent of households using charcoal (ZIMSTAT and UNICEF 2019). The high dependence on firewood places significant pressure on woody resources, particularly in more densely populated parts of the catchment.

118. **Additionally, the rate of firewood exploitation has reportedly greatly increased in areas where people are engaging in small-scale contract tobacco farming, since firewood is needed for tobacco curing (GoZ and WFP 2017).** This is despite the fact that harvesting of indigenous fuelwood for tobacco curing is prohibited. According to the Forestry Commission, tobacco harvesting is estimated to account for one-fifth of national deforestation each year, with the authority conceding that enforcement of restrictions on harvesting indigenous fuelwood has been limited.[14]

4.3.1.3 Mining

119. **Another serious driver is the expansion of poorly regulated and illegal mining in the area, which is having devastating impacts on both upland and riparian systems.** This is often by outsiders that have unfettered access to the area. Indeed, the gold-rich nature of the Mazowe area has resulted in a significant influx of both locals and people from other parts of the country to mine in the catchment (Nyavaya 2021). Furthermore, the problems are not limited to small-scale mining. There has also been an explosion of commercial mining operations, often by Chinese-owned firms. These new operations have been notorious for their disregard of both the environment and human rights.[15]

[14] https://news.mongabay.com/2022/02/zimbabwes-forests-go-up-in-smoke-to-feed-its-tobacco-habit/.
[15] https://www.theguardian.com/global-development/2022/jan/07/zimbabwe-china-mines-pollution-evictions. https://www.pressreader.com/zimbabwe/the-standard-zimbabwe/20220710/281590949275389.

120. Quarrying and mining involves the direct removal of vegetation and disturbance of sediments, which contributes to soil erosion and the formation of gullies. This includes sand mining, which is a major contributing factor to wetland shrinkage in the Mazowe Catchment (Chikodzi and Mufori 2018). Mining and gully formation are especially serious in the Marondera, Mutoko, Goromonzi, and Mount Darwin Districts (GoZ and WFP 2017).

121. Mining also has a serious impact on water quality through pollution as well as sedimentation. The particular environmental impacts depend on the nature of the ore, the type of mining, and the size of the mining operation (Lupankwa et al. 2006). Both nickel and gold, the two most common metals mined in the Mazowe Catchment, are associated with AMD (Lupankwa et al. 2004; Pratt 2011). This is the outflow of mine drainage that has a high heavy metal concentration, making it acidic. AMD can have serious environmental impacts in aquatic habitats, particularly on fish and other aquatic organisms (Hogsden and Harding 2012).

122. Artisanal mining also contributes to air pollution; erosion; and removal of crops, arable land, and natural vegetation (Chandiwana 2016; Tundu, Tumbare, and Onema 2018), all of which exacerbate resource scarcity and food insecurity. In addition, it comes with socioeconomic issues such as poor community relations leading to conflict and mistrust, crime, prostitution, and corruption, which are also common where artisanal mining is practiced. Gang violence and elaborate patronage networks have been reported around Jumbo Mine in Mazowe (International Crisis Group 2020). These issues are underpinned by an alleged culture of impunity and poor regulation at a state level (Hlungwani, Yingi, and Chitongo 2021).

4.3.2 Underlying Drivers

4.3.2.1 Poverty and economic decline

123. The degradation of the catchment is largely driven by a combination of poverty and population growth. Poverty levels in the study area are high and can be blamed in large part on the country's economic collapse in the 2000s and failure to recover subsequently. Although the population has benefited from one of the best education systems on the continent, the potential benefits of this investment could not be realized as a result of a lack of opportunity. There are few economic opportunities in urban areas, and without any system of welfare, much of the population has no option but to make a living off the land and grab any opportunities that arise, legal or illegal. Poverty leaves households in a position of having a short time horizon, in which the need for immediate survival obscures any need to plan for a sustainable income. In addition, poor households will be more likely to take risks, such as disregarding the law, to make ends meet.

124. Poverty has contributed to an upsurge in uncontrolled harvesting of natural resources. Since the 2000s, the country's rural poor have reportedly increasingly resorted to activities like hunting wildlife and harvesting and selling firewood for sale to urban markets (Miller and Gwaze 2012). This places further pressure on woody resources, which are already heavily exploited as a fuel source for subsistence use due to poverty and the unavailability of alternative energy sources.

125. Poverty and the country's economic collapse are also key underlying drivers of the upsurge in small-scale mining within the catchment, which has become a significant income opportunity in the context of high unemployment and low wages (Chandiwana 2016; International Crisis Group 2020). Declining crop production has been an additional contributing factor. A further massive jump in illegal mining occurred with worsened unemployment resulting from the COVID 19 pandemic (Nyavaya 2021).

126. The initial expansion of small-scale and artisanal mining followed the closure of several commercial mining operations as a result of the economic crisis between 2000 and 2008, and the opportunity that this presented in a climate of economic decline (Chandiwana 2016; Masocha et al. 2019). These commercial mining operations were generally better regulated and had better technologies to manage the external damages associated with mining than the small-scale operations that followed. Furthermore, the many Chinese-owned firms in the commercial mining sector are also notorious for failing to mitigate negative environmental impacts from their activities. In the Mazowe Catchment, informal artisanal mining now dominates (both alluvial panning and reef mining) and is largely unregulated. Of the 1.5 million small-scale miners estimated to be operating in Zimbabwe, only around 50,000 are formally registered according to the Zimbabwe Miners Federation (Nyavaya 2021), highlighting the difficulty of managing the impacts of the mushrooming small-scale mining sector. This lack of regulations means that provisions for land rehabilitation and the development of mine closure plans are not followed.

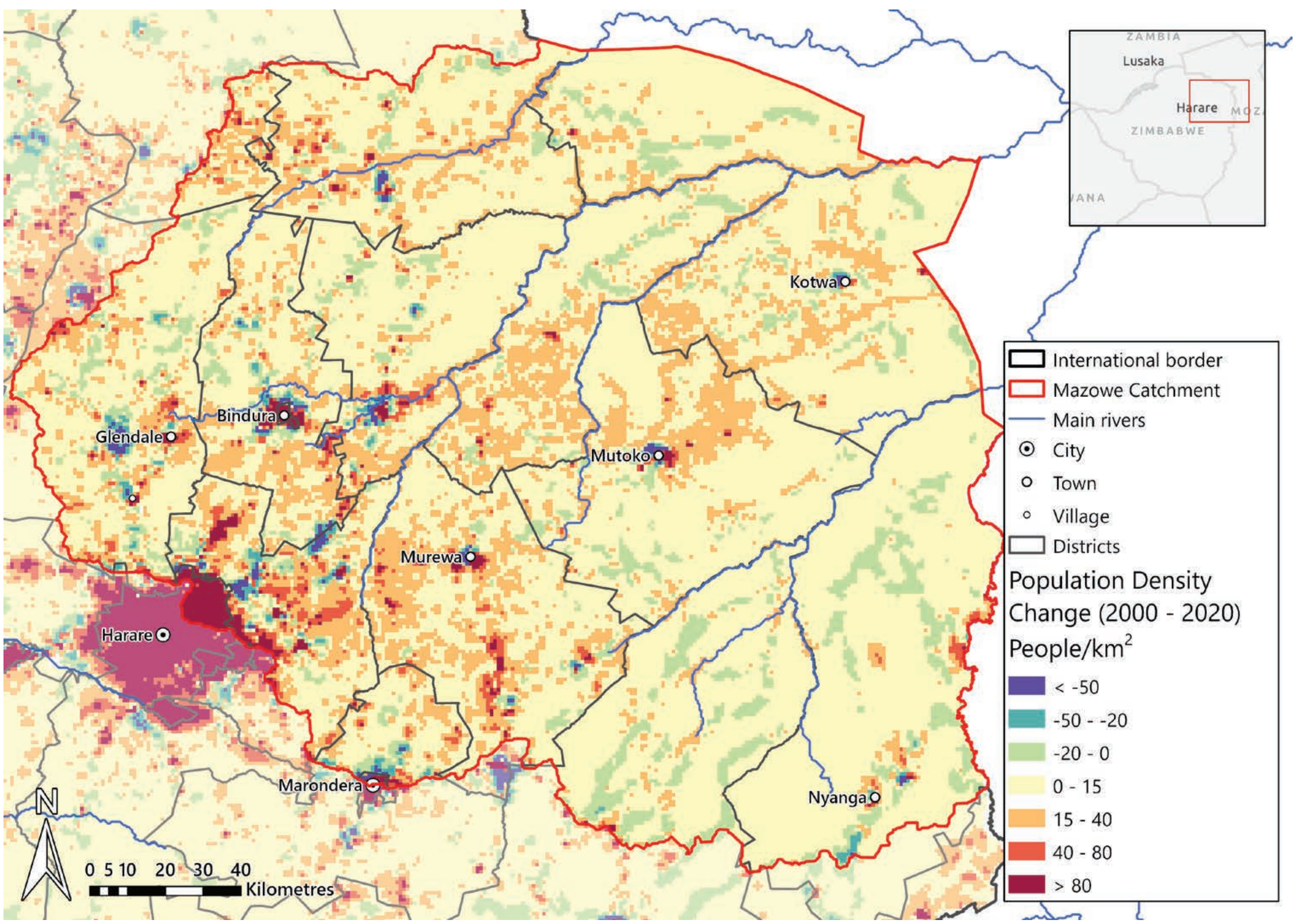
4.3.2.2 Population growth

127. **Between 2000 and 2020, the population of the Mazowe Catchment is estimated to have increased by roughly 717 000 (www.worldpop.org).** This represents a 45 percent overall increase and an average annual population growth rate of 15 percent. Most population increases have been in the upper catchment around Harare and the other main towns, as well as in the Mount Darwin District lower down in the catchment. Changes in population density across the catchment between 2000 and 2020 are shown in Figure 17.

128. **The expansion of the farming population in the catchment is a key underlying factor which has contributed to the growth of human settlements, conversion of natural land to agriculture, increased harvesting of resources, grazing pressure on the remaining land, and an increased rate of burning.**

129. **Issues related to population pressure on land resources in communal lands date back to colonial land tenure policies which confined the black rural population to overcrowded communal areas.** As a result, many of these areas have experienced high levels of land degradation for some time (Whitlow 1988). Indeed, in a nationwide assessment, population density was one of the key predictors of erosion

FIGURE 17: CHANGES IN POPULATION BETWEEN 2000 AND 2020, EXPRESSED IN TERMS OF CHANGE IN THE NUMBER OF PEOPLE PER KM²



Data source: Population density, 2020 (Bondarenko et al. 2020) risk in Zimbabwe, contributing to the much higher levels of erosion in communal land (Whitlow 1988). Since many rural households own at least some livestock, higher population densities also tend to worsen overstocking and overgrazing, which are compounded by the increasing scarcity of rangeland as cultivation expands to meet local food requirements (Makwara and Gamira 2012; Whitlow 1988). Intense land shortages also mean farmers cannot allow depleted soils to rest and recover despite falling yields (Roose 1996). These factors collectively contribute to significant elevation of erosion rates.

130. **Most remaining unfarmed land in crowded communal areas is in increasingly sensitive and marginal zones such as steep slopes, riparian areas, and wetlands (Makwara and Gamira 2012).** Indeed, population growth is cited as a key reason for the overexploitation of wetlands by agriculture and livestock (Chikodzi and Mufori 2018; Svotwa et al. 2008). All else being equal, the expansion of the rural population will result in further conversion of remaining natural land to agriculture, in the absence of sustainable agricultural intensification,

131. **Given that 94 percent of rural households depend on firewood as their main cooking fuel (ZIMSTAT and UNICEF 2019), population growth has also contributed to increased harvesting pressure on woody resources.**

4.3.2.3 Land reform

132. **Population growth has been accompanied by widescale deforestation to make way for small-scale agriculture, particularly in the early 2000s under the FTLRP (Tundu, Tumbare, and Onema 2018).** Land remains underutilized in many resettled commercial farms (Mugabe et al. 2014). However, in other cases, the influx of new farmers on to large commercial farms has resulted in the conversion to cultivation of natural areas that had been formerly reserved for grazing (Matsa et al. 2020). In many formerly white-owned commercial farming areas, this has significantly increased the pressure on land and natural resources (Musasa and Marambanyika 2020). According to Matsa et al. (2020), the resettlement of commercial farms has been a major driver of the substantial loss of natural habitats and wildlife in Mazowe District since 2000, which included the loss of almost half of the existing woodland cover in Ward 32 between 2000 and 2018.

133. **In some cases, farms have been resettled by new owners who lack a background in commercial farming management.** For example, a number of new A2 farm owners are business people, civil servants, or other people with urban backgrounds (Miller and Gwaze 2012). This has contributed to a failure to adopt sustainable agricultural practices on some resettled farms.

4.3.2.4 Lack of secure property rights

134. **In addition to population pressure, tenure insecurity is a major contributing factor to poor land management, particularly in areas resettled during the FTLRP.** According to a study conducted in Mazowe District, perceived tenure insecurity following the FTLRP has contributed to reduced adoption of soil conservation measures among Model A1 farmers (Zikhali 2010), which is likely to have increased erosion in these areas. Farmers who have no ownership of their land and resources are not likely to invest in them. There are also no opportunities to obtain rights over wildlife for investing in wildlife-based land uses which could be more viable than farming in some marginal areas.

4.4 Implications for a future under climate change

135. **The growth of agriculture and mining in the study area has provided important sources of livelihoods.** However, it has also undermined some of the benefits provided by ecosystems. Ecosystems in the study area provide a range of ecosystem services that benefit not only the local inhabitants but also the rest of the country and world at large.

136. **Communities living off the land are being faced with increasing scarcity of the natural resources that they collect or hunt, and also face water scarcity.** For example, the removal of woody vegetation has affected provisioning services associated with woodlands and forests. Matsa et al. (2020) reported, in a local study in the upper Mazowe Catchment, that

respondents had noted a reduction in high-energy tree species; fewer animals that constitute consumed bushmeat (that is, local extinction); and lower availability of fruit trees, medicinal plants, firewood, and construction materials. The scarcity of resources had also resulted in conflict among community members. Loss of grassland and open woodland areas has reduced grazing areas and forage quality which, in some instances, has resulted in declining meat quality, which invariably will limit the potential to generate income for livestock farmers.

137. **Ecosystem degradation poses threats to water security by affecting water supply infrastructure and treatment costs or by posing direct threats to human health.** The combination of food and water insecurity also exacerbates human health issues. While food, water, and health are primary concerns, degradation of the environment also carries a cost to human quality of life beyond material benefits. Not only does it affect local users, but it could affect the potential for tourism in the area. At this stage, tourism development is relatively low, but its potential for development will become more limited with an increasingly irreversible scale of degradation.

138. **Finally, one of the greatest looming threats to the area is that of climate change.** While the degradation of ecosystems in the study area will contribute to further climate change, an even greater concern is that their ability to buffer the population from the impacts of climate change is being eroded. Maintaining resilience through ecosystem-based adaptation may be one of the most important motivations for addressing ecological degradation in the area.

139. **Climate change is predicted to have a profound impact on ecosystems and livelihoods the world over (IPBES 2019).** Zimbabwe is expected to be particularly hard hit, even relative to other countries in southern Africa. Increases in mean annual temperature of up to 2.2°C and up to 4.4 percent decrease in annual median precipitation is expected by 2060 (World Bank 2021). Over the same period, the annual probability of Zimbabwe experiencing severe drought is projected to increase by 21 percent, coupled with a substantial increase in the number of days with a maximum temperature above 35°C and an increase in the length of dry spells.

140. **These conditions will increase the strain on rural communities, the majority of whom depend on rainfed crops which are highly vulnerable to climate change impacts and account for 80 percent of Zimbabwe's agricultural production (World Bank 2021).** Zimbabwe's Meteorological Services Department has already noted that warming trends since the 1970s have put stress on the agricultural sector.[16] Even the commercial agriculture sector, which is the country's largest employer, is likely to be negatively affected. Production of irrigated crops such as tobacco and cotton will also be affected, which will have a widescale impact on many households' ability to derive an income (World Bank 2021). Even under medium climate change projections, yields of all main crops except dry beans are expected to decline by the 2040s, including a 33 percent yield reduction for maize (World Bank 2019). Livestock production is also expected to be negatively affected, with income generated from cattle, goats, and sheep predicted to decline by 12 percent, 7 percent, and 14 percent, respectively. Overall, in the absence of effective adaption, the impacts of climate change on agriculture could cost a decline in Zimbabwe's GDP of over 2 percent (Benitez et al. 2018). These projected impacts highlight the great need for the adoption of CSA practices as an adaptation and mitigation strategy.

141. **Natural vegetation is also likely to change.** In Mazowe, mopane woodlands are likely to spread, largely at the expense of miombo woodlands (INDUFOR/AEMA and MEWC 2017). This will have repercussions for wood harvesting which is critical in the Mazowe Catchment owing to the high levels of fuelwood use for meeting energy needs. These consequences may be beneficial in some areas but would require further evaluation on the growth and harvesting rates of mopane wood.

142. **Climate change is expected to reduce groundwater recharge and surface runoff in the Mazowe Catchment.** Under a BAU (A2a) global emissions scenario, it is estimated that mean runoff in the

[16] The National Climate Policy of Zimbabwe (2016).

Mazowe Catchment will decrease by 15 percent by 2050 and groundwater recharge by 7 percent (Davis and Hirji 2014). These declines become much smaller under an ecologically aware (B2a) global emissions scenario (2 percent for surface runoff and 1 percent for groundwater recharge), highlighting the large impact of global actions on local climate change projections.

143. **Degradation of ecosystems in the study area is already compromising water security, food security, human health, and livelihoods.** Climate change puts pressure on ecosystems in the same direction. If the drivers of degradation are not addressed, then the population of the Mazowe Catchment could face catastrophic consequences such as famine under future climate conditions.

5.

Ecosystem Services, Beneficiaries and Value

5.1 Overview of concept, key services, and beneficiaries

144. **The ecosystem goods and services that are generated by the natural ecosystems of the Mazowe Catchment contribute to local livelihoods as well as to the economy.** The capacity of the area's ecosystems to supply these benefits is strongly linked to ecosystem characteristics and condition, as described in the previous chapter. This section quantifies and maps the ecosystem services provided within the Mazowe Catchment area in physical terms and estimates their approximate value to different groups of beneficiaries, within the limitations of a rapid desktop study.

5.1.1 Ecosystem services

145. **Ecosystem services are defined as "the benefits people obtain from ecosystems"[17] (Millennium Ecosystem Assessment 2003, 2005).** These benefits depend on the nature of ecosystems and their biodiversity. Ecosystem services are typically considered to include provisioning, regulating, and cultural services.

146. **Provisioning services are the harvestable resources supplied by ecosystems.** These include

- Wild foods and medicines;
- Raw materials;
- Ecosystem inputs to crop and livestock production; and
- Genetic resources.

147. **Regulating services are the functions that ecosystems and their biota perform that benefit people in surrounding or downstream areas or even distant areas.** These include

- Climate regulation;
- Flow regulation;

KEY POINTS

- Ecosystem services are broadly defined as the benefits people obtain from natural and man-modified ecosystems.
- They can be categorized into provisioning, regulating, and cultural services.
- Provisioning services include harvestable resources and land inputs to crop and livestock production.
- Regulating services are ecosystem functions that provide downstream benefits as inputs to economic production or cost savings. An example is sediment retention.
- Cultural services are the provision of opportunities for a range of experiences.
- This study focused on provisioning services (as completely as possible), carbon, flow regulation, soil/sediment retention, and tourism value.
- The beneficiaries of these services variously include local households, the tourism sector, water service providers, and society as a whole.

[17] An ecosystem is a community of living organisms in conjunction with non-living components of their environment, interacting as a system. The biotic and abiotic components are linked together through nutrient and energy flows. Ecosystems can be defined in space and range in size, for example, from ponds to a large rainforest.

- Sediment regulation;
- Water quality amelioration; and
- Pollination.

148. **Cultural services are the ecosystem attributes (for example, beauty and species diversity) that give rise to the 'use values' gained through any type of activity ranging from adventure sports to birdwatching, religious or cultural ceremonies, or just passive observation or the 'non-use values' gained from knowing that they exist and can be enjoyed by future generations.**

149. **A fourth category (supporting services) was also defined by the (Millennium Ecosystem Assessment 2003b) to encompass underlying ecosystem processes such as soil formation, nutrient cycling, and water cycling, but since these are internal to the provision of the other services, they are no longer included in more recent classifications of ecosystem services or in the System of Environmental Economics Accounting - Ecosystem Accounting methods (UN 2021).**

5.1.2 Selection of ecosystem services for analysis

150. **This study tackled selected services, based on data availability as well as their relative importance.** We focused on the provisioning services (as completely as possible but excluding medicinal plants for which there were insufficient data), carbon, flow regulation, soil/sediment retention, and tourism value.

5.1.3 Beneficiaries of ecosystem services

151. **The main beneficiaries of the selected ecosystem services in the catchment were identified as follows:**

- **Subsistence/small-scale farmers**, who benefit from harvesting wild resources and from ecosystem inputs to cultivated crops and livestock, and from linked regulating services such soil retention and crop pollination.
- **Commercial farmers and timber producers** benefit from land inputs to cultivated crops and tree plantations.
- **Water suppliers and users** benefit from the reduction of sediment and nutrient inputs into reservoirs, as well as from the regulation of the timing of surface flows. These save on both water storage and treatment costs.
- **The tourism sector and tourists** benefit from nature-based tourism opportunities. Tourist expenditure in the country is captured in the value of the tourism sector. Note that this study does not estimate the consumer surplus of tourists, most of which accrues to non-Zimbabweans.
- **Both Zimbabwean citizens** and **global society** benefit from the avoided climate change costs through retention of intact natural ecosystems. They also derive satisfaction from knowing about the existence of conserved biodiversity and wilderness areas. Zimbabwe shares in the global impacts of carbon emissions on climate change, the extent of its share of the costs being determined by global climate circulation and its relative vulnerability to climate change. Its share of the existence value of biodiversity is determined by relative ability to pay among other factors, but it is not valued here.

5.2 Provisioning services

5.2.1 Crop production

152. **The Mazowe Catchment contains some of the prime areas for crop production in Zimbabwe, particularly the wetter south and west of the catchment which fall within agroecological region II.** This is the optimal region for intensive production of maize, tobacco, and other key crops (World Bank 2021). The drier northeast of the catchment falls within agroecological regions III and IV, where conditions become increasingly marginal for rainfed crop production. Nevertheless, the area supports large numbers of smallholder farmers. Thus, much of the catchment is under commercial or small-scale production, with a mixture of food and cash crops being grown.

153. **Nature's inputs to crop production are complex and include the soil and the nutrient and moisture inputs.** As a proxy, the physical measure for the ecosystem service is the tonnage of crop production. Spatial variation in production of the 10 main crops

KEY POINTS

- The Mazowe Catchment is generally highly suitable for crop production. Some 254,000 tons of food and cash crops are produced on commercial farms and 353,000 tons on communal land. The value of this ecosystem service is estimated to be in the order of US$58 million per year.
- The study area has a higher density of cattle than for the country as a whole and average densities of goats and sheep, with total populations of about 840,000, 400,000, and 38,000, respectively. The value of land input to livestock production was estimated to be US$108 million per year.
- Households in the Mazowe Catchment are estimated to harvest over 2.2 million tons of wood, thatching grass, and wild foods annually, with a value of approximately US$106 million per year. Natural habitats have an average value of US$42 per ha per year. This does not include medicinal resources or bush meat.
- In general, provisioning service values are highest in the areas of high population density due to demand. In some areas, this will have compromised natural ecosystem capacity.

in the study area was estimated using the Integrated Valuation of Ecosystem Service Tradeoffs (InVEST) Crop Production model and production reported in Zimbabwe's Crop and Livestock Assessment Reports (see Appendix 5). The service was valued in terms of the gross margin of production.

5.2.1.1 Quantification of crop production

154. **The estimated production of 10 major food and cash crops in the Mazowe Catchment is shown in Table 2.** For most crops, the Mazowe Catchment, which covers about 10 percent of Zimbabwe's surface area, accounts for 20 percent or more of national production. This indicates its importance to agriculture in the country. The proportional contribution was particularly high for tobacco (36.6 percent) and beans (35.3 percent).

155. **Since communal and resettlement areas cover a larger proportion of the catchment than commercial farming areas, it is not surprising that production of most crops is higher here than in commercial farmland (Table 2).** However, beans and soya were an exception, with higher estimated

TABLE 2: ESTIMATED PRODUCTION OF 10 MAJOR FOOD AND CASH CROPS IN THE MAZOWE CATCHMENT

Crop	Total production (tons)	% of national production	Production commercial (tons)	Production communal (tons)
Maize	368,741	25.1	156,718	212,023
Sorghum	26,807	20.7	13,196	13,611
Millet	4,578	7.3	805	3,772
Ground and bambara nuts	40,702	26.7	15,205	25,497
Beans	6,215	35.3	3,163	3,052
Sweet potato	39,751	19.1	8,987	30,764
Tobacco	83,488	36.6	39,435	44,053
Cotton	19,233	15.4	6,710	12,523
Soya	14,579	24.5	8,880	5,699
Sunflower	2,522	25.2	630	1,892
All Crops	**606,616**	—	**253,729**	**352,887**

Source: Based on the Crop and Livestock Assessment reports (MoLAWFRR 2021) production in commercial farmland. Conversely, production of millet and sweet potato was estimated to be several times higher in communal and resettlement areas. This suggests sweet potato is largely grown as a subsistence crop. The higher output of millet is because these farming areas also tend to be in drier parts of the catchment.

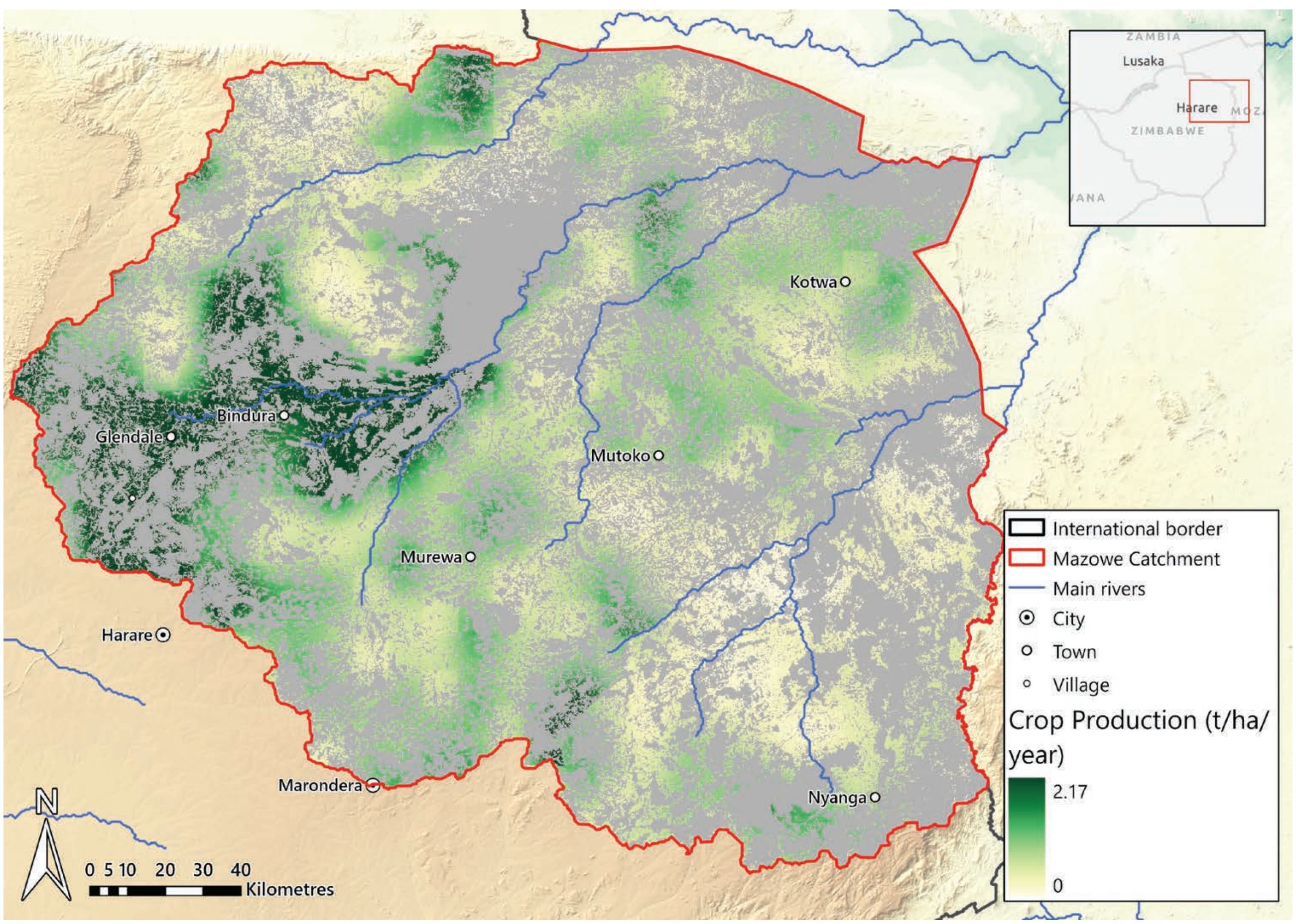
156. **The spatial variation in total crop production per hectare of all farmlands is shown in figure 18.** Note that these figures are lower than the yield of planted areas. Planted area cannot be differentiated from broader farmland in remote sensing products, which includes fallow and abandoned fields, hedgerows, and other landscape features which characterize small-scale farming areas in Zimbabwe. At the national scale, agriculture was estimated to cover 42 percent of land area in 2016 (World Bank 2021), whereas the total planted area for field crops in 2020/2021 (a good rainfall season) was just 3.5 million ha, or around 9 percent of the country (MoLAFWRR 2021).

157. **Total crop production is generally highest in the southwest of the catchment Figure 18, particularly in commercial farming areas.** This is not surprising as the southwest of the catchment has the best climatic conditions for agriculture, and indeed some of the most favorable farming conditions in the country. Production per hectare declines in the drier north and northeast of the catchment.

5.2.1.2 Value of land inputs to crop production

158. **In gross revenue terms, production of the 10 crops considered was estimated to be worth around US$454.6 million per year, with a gross margin of US$68.2 million per year (Table 3).** Maize and tobacco account for the bulk of this value. For maize,

FIGURE 18: ESTIMATED AGGREGATE PRODUCTION OF THE TEN MAJOR CROPS ACROSS THE MAZOWE CATCHMENT (GREY REPRESENTS NON-FARMLAND PIXELS)



Source: This study is based on the InVEST Crop Production Model and Crop and Livestock Assessment reports (MoLAWFRR 2020, 2021).

TABLE 3: ESTIMATED VALUE OF CROP PRODUCTION BASED ON GROSS REVENUE AND GROSS MARGIN, ASSUMING A 15 PERCENT PROFIT MARGIN

Crop	Producer price (US$/t)	Gross revenue commercial (US$ millions/year)	Gross revenue communal (US$ millions/year)	Gross margin commercial (US$ millions/year)	Gross margin communal (US$ millions/year)
Maize	341	53.4	72.3	8.0	10.8
Sorghum	341	4.5	4.6	0.7	0.7
Millet	341	0.3	1.3	0.0	0.2
Groundnuts and Bambara nuts	341	5.2	8.7	0.8	1.3
Beans	341	1.1	1.0	0.2	0.2
Sweet Potato	800	7.2	24.6	1.1	3.7
Tobacco	2,970	117.1	130.8	17.6	19.6
Cotton	455	3.0	5.7	0.5	0.9
Soya	780	6.9	4.4	1.0	0.7
Sunflower	935	0.6	1.8	0.1	0.3
All Crops	—	**199.3**	**255.3**	**29.9**	**38.3**

this reflects its areal dominance in the catchment, while the high contribution of tobacco to crop value is due to its much higher value per ton than any other crop.

5.2.2 Livestock production

159. **Livestock production is an important component of rural livelihoods in Zimbabwe.** Although conditions are favorable for crop production across much of the catchment, particularly the upper reaches, livestock remain an important part of mixed cropping systems. In addition to offtake for meat production, they are kept for a range of other reasons including to exploit crop-livestock interactions, provide a store of wealth, for draught power and *lobola* payments.

160. **Ecosystem inputs to livestock production include fodder production and natural water sources.** A suitable proxy physical measure of the service is the number of tropical livestock units (TLUs) supported. The spatial distribution of livestock in the landscape was modelled using the Food and Agriculture Organization (FAO) Gridded Livestock of the World (GLW3) dataset (derived from official government data; Wint and Robinson 2007), and data in the Crop and Livestock Assessment reports (MoLAWFRR, 2021) (see Appendix 5). The service was valued in terms of gross margin, as an approximation of the residual value attributed to the environment. For livestock in small-scale farming areas, this incorporated the value of manure, milk, draught power, and hides, all of which are particularly important components of the value of livestock to small-scale farmers.

5.2.2.1 Quantification of livestock production

161. **Communal and resettlement areas account for the bulk of livestock in the catchment, with the exception of sheep (Table 4).** In TLU terms, numbers are about 2.7 times higher in communal and resettlement areas than in commercial farming areas. Over 70 percent of cattle and goats are in communal and resettlement areas. The overall goat population is just under half the cattle population.

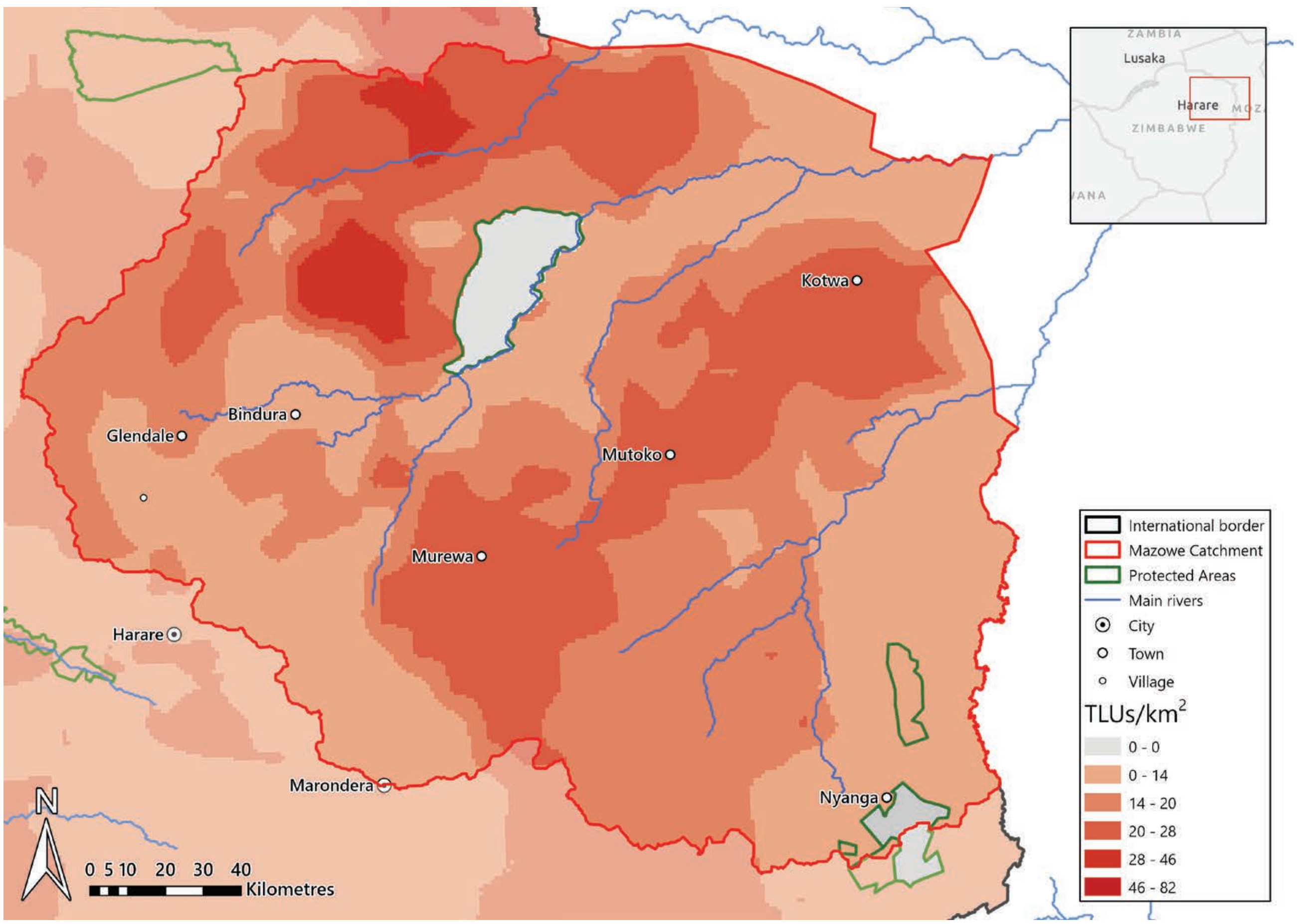
162. **Overall, the study area has a higher density of livestock (15.9 TLUs per km^2) than the national average (11.1 TLUs per km^2), and accounts for 14.6 percent of TLUs nationally and 15.1 percent, of the national cattle population.** Goat and sheep densities are similar to the national average.

163. **A map of livestock density per km^2 in TLU terms is shown in Figure 19.** This reflects the combined effects of land tenure, population density and rainfall.

TABLE 4: ESTIMATED POPULATIONS OF CATTLE, GOATS, AND SHEEP IN THE MAZOWE CATCHMENT AND THE AGGREGATED NUMBER OF TLUS

Livestock species	Livestock population commercial	Livestock population communal	Livestock combined	Percent of national population	Average density/km²	Average density nationally/km²
Cattle	231,185	609,613	840,798	15.1	21.0	14.2
Goats	98,501	302,527	401,028	10.4	10.0	9.8
Sheep	65,874	48,304	65,874	11.4	1.6	1.5
TLUs	173,436	461,812	635,249	14.6	15.9	11.1

FIGURE 19: MAP OF LIVESTOCK DENSITIES (EXPRESSED IN TLU TERMS) ACROSS THE MAZOWE CATCHMENT



Data source: Gridded livestock of the world (GLW3 - Buchhorn et al. 2020). Grey indicates the strictly protected areas of Umfurudzi Safari Area and Nyanga National Park where livestock grazing is not permitted.

Higher TLU densities are generally associated with communal areas due to the higher densities of households owning livestock, although there are exceptions such as Nyanga District in the southeast of the catchment which is noted for low livestock ownership. For example, Nyanga's District Risk Profile estimated that only 40 percent of households own livestock (GoZ and WFP 2017), significantly lower than most other rural districts. Parts of the district also have relatively low population densities, as do the dry communal areas north of Kotwa, contributing to low livestock densities in these areas. TLU densities were highest in the northwest of the catchment, where rural population densities are high while greater rainfall allows for higher stocking rates then in the drier northeast of the catchment.

5.2.2.2 Value of livestock production

164. **Due to much higher offtake levels in the commercial farming sector, sales revenue from livestock is more than double sales revenue from communal areas (Table 5).** Total livestock sales revenue in commercial farmland was estimated to be US$41.8 million per year, with cattle accounting for 92 percent of this value. In communal areas, the gross margin from livestock (that is, gross output minus variable costs) exceeds sales revenue, due to the inclusion of ploughing, hides and milk production in the estimate of total livestock output in communal areas. The total gross margin of livestock production in the catchment was estimated to be US$64.7 million per year, with cattle again accounting for the vast majority (94 percent) of this value.

5.2.3 Harvested wild resources

165. **Harvested wild resources are essential to rural livelihoods in the Mazowe Catchment, with the vast majority of households depending on firewood as their main source of energy (ZIMSTAT and UNICEF 2019).** Most rural households also obtain a range of other products from natural habitats, including wood and thatching grass for construction, wild fruits and vegetables, mushrooms, honey, medicinal plants, and other products.

166. **Harvested wild resources were modelled using the methods described in Turpie et al. (2020).** These estimate the use of natural resources based on the capacity of the landscape to supply different types of resources on the one hand and the spatial distribution of the human demand for a given resource on the other. A further factor considered is accessibility, with resources in protected areas assumed to be less available for harvesting (see Appendix 4).

5.2.3.1 Quantification of wild resource harvesting

167. **Wood is the dominant fuel source for most (94 percent) rural households in Zimbabwe (ZIMSTAT and UNICEF 2019).** The average wood usage across various studies consulted was around 4.5 tons per household per year (Campbell, Luckert, and Scoones 1997; Campbell, Vermeulen, and Lynam 1991; Mabugu and Chitiga 2002; McGregor 1991; Woittiez et al. 2013). According to census data, 22–38 percent of households across the

TABLE 5: ESTIMATED VALUE OF LIVESTOCK PRODUCTION, EXPRESSED IN TERMS OF SALES REVENUE AND GROSS MARGIN (US$ MILLION PER YEAR, LATTER INCLUDES THE VALUE OF PLOUGHING, MANURE, AND MILK PRODUCTION FOR COMMUNAL AREAS)

Livestock	Sales revenue (commercial) US$ millions/year	Sales revenue (communal) US$ millions/year	Sales revenue (combined) US$ millions/year	Gross margin (commercial) US$ millions/year	Gross margin (communal) US$ millions/year	Gross margin (combined) US$ millions/year
Cattle	27.7	10.7	38.4	20.80	40.2	61.0
Goats	1.4	1.3	3.4	0.80	2.5	3.3
Sheep	0.4	0.1	0.5	0.03	0.3	0.4
All livestock	**29.6**	**12.1**	**41.8**	**21.60**	**43.1**	**64.7**

provinces of the Mazowe Catchment use traditional wall materials (for example, pole and mud), while a further 36–43 percent of households have a mixture of modern and traditional structures (ZIMSTAT 2012). Average demand for construction wood was estimated to be around 1.5 tons per household per year (Campbell et al. 1991; McGregor 1991; Grundy et al. 1993; Woittiez et al. 2013). Some 43–56 percent of households in the study area have thatched houses (ZIMSTAT 2012), with annual demand from user households estimated to be 98 kg per year (Grundy et al. 2000; Twine et al. 2003). The next most harvested resources were estimated to be wild plant foods, followed by thatching grass, mushroom and honey. Note that this excludes medicinal resources, for which there was insufficient information available.

5.2.3.2 Value of wild resource harvesting

168. **The total value of the selected harvested wild resources (wood, thatching grass, wild plant foods, mushrooms, and honey) in the Mazowe Catchment was estimated to be US$105.7 million per year or an average value of US$42.06 per ha per year of natural habitat (Table 6).** Wood harvesting accounts for around half of this value. Wild plant foods were the next most valuable harvested resource, closely followed by mushrooms. Thatching grass and honey had relatively low total values. For thatching grass, this is the result of lower value per kg than most other resources, while for honey it reflects lower household consumption and participation in harvesting.

169. **Miombo woodland had the highest value of any habitat type (US$57.48 per ha per year; Table 7).** This is due partly to the location of miombo woodland areas in higher rainfall and generally more densely populated parts of the catchment, resulting in higher demand for resources and thus harvesting levels. Additionally, miombo woodland was estimated to have high stocks of certain natural resources. For example, wild plant food stocks per unit area are relatively high due to the presence and abundance of multiple prized fruit tree species, including muzhanje/mahobohobo (*Uapaca kirkiana*) and mobola plum (*Parinari curatellifolia*). Both species are harvested in large quantities by local communities for both consumption and informal sale (Chagumaira et al. 2016; Woittiez et al. 2013). Miombo woodland was also estimated to have high mushroom stocks, due to the abundance of tree genera (*Brachystegia, Jubelnardia,* and *Uapaca*) associated with ectomycorrhizal fungi. This results in a high abundance of edible fungi compared to other woodland types (Degreef et al. 2020; Mlambo and Maphosa 2021). In degraded form, the average value of resources harvested from miombo woodland declines to an estimated US$40.51 per ha per year.

170. **Plantation forest had a notably low value of harvested wild resources per hectare (US$9.78 per ha), underscoring the importance of indigenous forest and woodland habitats for resource harvesting.** Plantation forests do not support important resources such as thatching grass or indigenous edible plant foods. In addition, some of the plantation area falls within protected state forest areas, where livelihood activities are more restricted. Among natural habitat types, *Acacia-Terminalia* woodland and shrubland had relatively

TABLE 6: ESTIMATED QUANTITIES AND VALUES OF SUBSISTENCE HARVESTING OF SELECTED NATURAL RESOURCES IN THE MAZOWE CATCHMENT. PER HECTARE HARVESTING VALUES ARE BASED ON THE TOTAL AREA OF NATURAL HABITATS IN THE CATCHMENT, AS STOCKS OF HARVESTED RESOURCES WERE RESTRICTED TO NATURAL HABITATS ONLY

Resource	Total harvested (t/year)	Average harvesting (kg/ha/year)	Total value (US$ millions/year)	Average value (US$/ha/year)
Wood	2,125,385	845.7	53.1	21.14
Thatching grass	22,927	9.1	9.2	3.65
Plant foods	63,776	25.4	22.3	8.88
Mushrooms	14,383	5.7	17.3	6.87
Honey	1,548	0.6	3.8	1.52
All resources	**2,228,019**	**886.6**	**105.7**	**42.06**

TABLE 7: ESTIMATED QUANTITIES AND VALUES OF SUBSISTENCE HARVESTING OF SELECTED NATURAL RESOURCES IN THE MAZOWE CATCHMENT ACROSS DIFFERENT NATURAL HABITATS

Habitat	Area (ha)	Total value of resources (US$ millions/year)	Average value of resources (US$/ha/year)
Indigenous forest	9,878	0.34	34.64
Plantation forest	12,795	0.13	9.78
Degraded forest	1,423	0.03	19.74
Miombo woodland	1,279,090	73.52	57.48
Degraded Miombo woodland	113,285	9.18	40.51
Acacia-Terminalia woodland	448,086	4.59	20.34
Degraded Acacia woodland	11,501	0.11	9.94
Miombo shrubland	340,769	11.38	33.40
Degraded Miombo shrubland	22,131	4.95	24.62
Acacia-Terminalia shrubland	242,266	0.54	20.43
Degraded Acacia-Terminalia shrubland	4,183	0.05	11.35
Grassland	22,360	0.83	37.29
Degraded grassland	1,966	0.04	20.72
ALL	**2,513,022**	**105.70**	**42.06**

low harvested resource values per unit area. This is partly due to the location of these habitat types in drier, less densely populated parts of the catchment, as well as lower estimated stocks of certain resources compared to miombo woodland. Overall, the highest values of wild resource harvesting per unit area are generally associated with densely populated miombo woodland areas, such as the communal areas north of Harare (Figure 20). Natural resource stocks are generally more contiguous in the less densely populated northeast of the catchment, due to the larger blocks of natural habitat which remain here. However, harvesting values per unit area are generally lower here, due to lower household densities as well as the dominance of other vegetation types (for example, *Acacia-Terminalia* woodland) which have a lower abundance of most harvested resources than miombo woodland. The effect of protected areas is also reflected in the map, with low harvesting estimated for Nyanga National Park, Umfurudzi Safari Area, and state forest areas due to the assumption that resources are less available for harvesting here. However, WMAs were not assumed to influence the availability of resources, as they do not impose any specific restrictions on the use of wild resources.

5.3 Cultural services

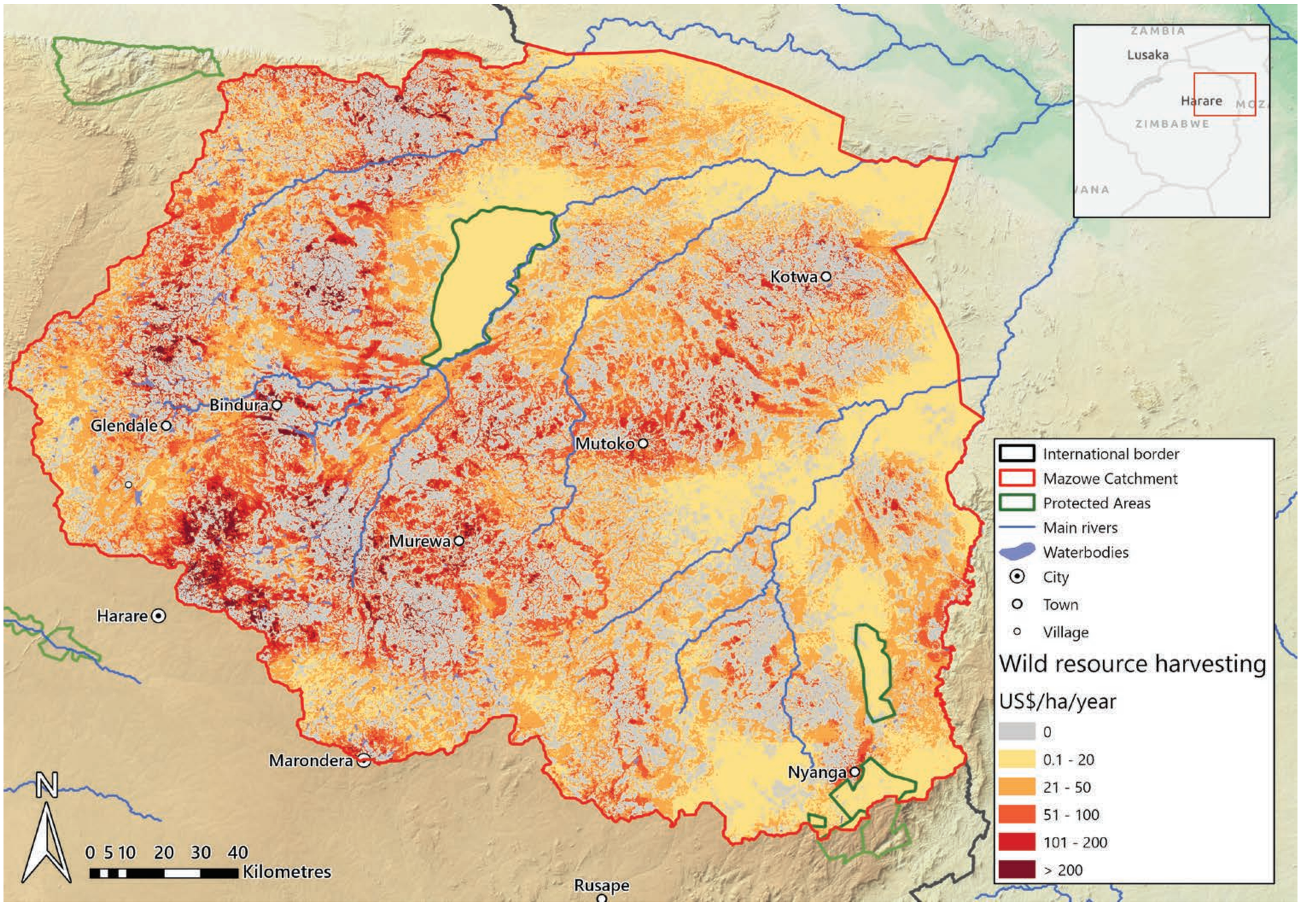
5.3.1 Nature-based tourism

171. **The Mazowe Catchment has few major tourist attractions, though it does include some notable nature-based tourism attractions such as the northern end of the Nyanga Mountains and the Umfurudzi Safari Area.** As in most areas where tourism is not well developed, there are few or no statistics available. However, big data which reveals tourism activity can allow for the estimation of how tourism value is spread across a landscape. National statistics were used to obtain information on tourism expenditure which was separated into attraction-based tourism and other forms of tourism. The InVEST Visitation model was then used to obtain a spatial disaggregation of tourism activity, based on geotagged photograph densities (See Appendix 4 for further details).

5.3.1.1 Value of attraction-based tourism

172. **In total, the value of attraction-based tourism across the catchment was estimated to be**

FIGURE 20: TOTAL VALUE OF SELECTED HARVESTED WILD RESOURCES (WOOD, THATCHING GRASS, WILD PLANT FOODS, MUSHROOMS AND HONEY ACROSS THE MAZOWE CATCHMENT)



Note: Grey areas with zero value reflect cultivated and built-up areas, since these land cover types lack harvestable wild resources.
Source: Based on Turpie et al. (2022).

KEY POINTS

- Tourism is not well developed in the Mazowe Catchment.
- In total, the value of attraction-based tourism across the rural parts of the catchment was estimated to be US$47 million in 2019 or 4.6 percent of the national attraction-based tourism value.
- Attraction-based tourism in natural areas specifically was estimated to have a value of US$36.2 million in 2019.
- Natural areas had significantly higher tourism value than areas dominated by cultivation.

US$76.5 million in 2019, or 8.2 percent of the national attraction-based tourism value. The estimated tourism value per unit area (US$1,811 per km^2) in the catchment is lower than the national average (US$2,246 per km^2), affirming that it is generally not a key region for tourism. Furthermore, much of this value is attributed to the outskirts of Harare. Excluding this peri-urban area, the tourism value of the rural area of Mazowe Catchment was estimated to be US$46.9 million in 2019 or an average of US$1,180 per km^2 of non-urban land.

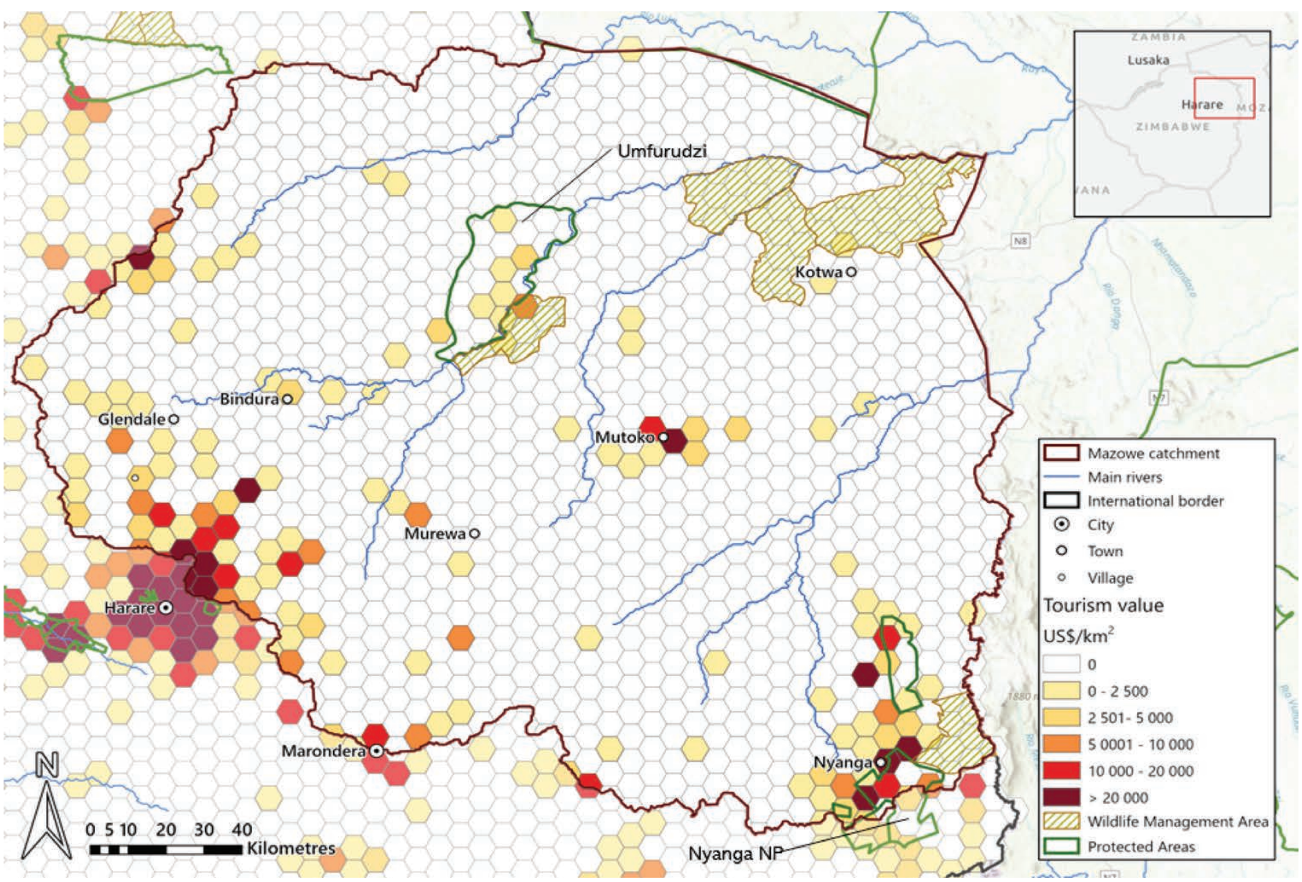
173. **The most notable areas of higher tourism value are associated with the outskirts of Harare in the southwest of the catchment and popular nearby**

natural attractions such as Domboshawa and Mazowe Dam (Figure 21). Other areas with notable clusters of photographs include around Nyanga in the southeast of the catchment, Mutoko in the center of the catchment, and, to a lesser extent, Umfurudzi Safari Area. Photographs are generally sparse in the north of the catchment, which has no notable tourist attractions. Using the total number of photo user days (PUDs) taken in grid cells where natural land cover categories were dominant, the value of nature-based tourism in the catchment was estimated to be US$36.2 million in 2019 or US$1,369 per km^2 of natural land cover. This relatively modest value again reflects the few major nature-based tourism attractions in the catchment. Nevertheless, natural areas still had significantly higher tourism value than cultivated areas. Attraction-based tourism in grid cells dominated by cultivation was valued at US$13.2 million or just US$851 per km^2. Thus, away from urban areas, the analysis suggests that natural areas are more attractive for tourism than more heavily transformed agricultural landscapes.

5.3.1.2 Visitor numbers to protected areas

174. **Available data on visitor numbers to parks within the Zimbabwe Parks and Wildlife Management Authority (ZPWMA) estate, derived from annual reports produced by the Zimbabwe Tourism Authority (ZTA), corroborate the modest estimates of nature-based tourism in the catchment.** Visitor number data for Umfurudzi Safari Area were provided only for 2007–2010, where annual visitors varied significantly from as low as 513 in 2010 to 7,005 in 2008, or an average of around 3,000 visitors per year. This is less than 1 percent of total visitor numbers to the whole ZPWMA estate over this period, highlighting that Umfurudzi is not a major tourist drawcard. Visitor numbers to Nyanga National Park are higher, averaging around 20,000 per year since 2010, or about 3.5 percent of all visitors to ZPWMA's protected area estate over this period, with a peak value of 26,408 visitors in 2018. In addition, much of Nyanga National Park is freely accessible, meaning visitor numbers are likely significantly higher in reality.

FIGURE 21: ESTIMATED TOURISM VALUE OF THE MAZOWE CATCHMENT IN 2019



Source: Based on this study.

However, some of Nyanga National Park's prime visitor attractions, such as Mount Nyangani and Mtarazi Falls, are not located within the smaller portion of the park which falls within the Mazowe Catchment. Nevertheless, a concentration of tourist activity was evident around Nyanga, including areas outside the boundaries of the national park which have high nature-based attraction tourism value due to their high scenic quality (*for example,* Troutbeck).

5.4 Regulating services

5.4.1 Carbon storage

175. **Ecosystems store carbon in their biomass and continuously add carbon to the soil.** The degradation of landscapes releases stored carbon into the atmosphere as CO_2, thereby contributing to global climate change. Conversely, retention of carbon in ecosystems helps to reduce CO_2 emissions.

176. **While much of the Mazowe Catchment has low biomass due to historical conversion of natural habitat to agriculture, settlement, mining and other uses, there are some notable areas of relatively dense woody natural habitats remaining, such as the Umfurudzi Safari Area and the sparsely populated rural areas in the northeast, which do store significant quantities of carbon.** Carbon biomass was mapped using datasets derived from remote sensing methods (Bouvet *et al.* 2018; Santoro *et al.* 2018) (See Appendix 5 for more details).

5.4.1.1 Quantification of carbon storage

177. **The total aboveground and belowground storage of carbon across the Mazowe Catchment was estimated to be 126.8 million tons, or 465.2 tCO_2e (Table 8).** This amounts to average storage of 31.7 tCO_2e per ha or 116.3 tCO_2e per ha. As the most extensive natural habitat type, miombo woodlands contain almost half of the carbon stored in the catchment. However, plantation and indigenous forest had higher values for carbon storage per hectare, reflecting the higher aboveground biomass (AGB) in these denser woody habitats. *Acacia-Terminalia* woodland also had notably high carbon storage per hectare, almost equal to indigenous forest. This is due in part to high estimated belowground biomass (BGB) across much of this habitat type. It also exhibits relatively high AGB, especially in comparison to miombo woodland. This is because *Acacia-Terminalia* woodland is situated in the less densely populated lower reaches of the catchment, where remaining natural areas are generally more intact and less degraded. This includes parts of Umfurudzi Safari Area and densely wooded hilly areas along the Mazowe River in the extreme northeast of the country.

178. **With the exception of bare areas, cultivation had the lowest carbon storage per hectare, about 3 times less than miombo woodland and 4.5 times less than indigenous forest and Acacia-Terminalia woodland (Table 8).** Carbon storage

KEY POINTS

- **Carbon storage.** In total, aboveground and belowground carbon storage across the Mazowe Catchment was estimated to be 126.8 million tons, or 465.2 tCO_2e. Retention of this carbon results in avoided climate change-related losses worth US$1.23 billion per year globally.
- **Flow regulation.** Through mediating infiltration, ecosystems can help reduce overall seasonal variation in flows, relative to the seasonal variation in rainfall. This potentially has an important bearing on the cost of supplying or obtaining water. Modelling of flows with and without vegetation cover did not generate a significant benefit for surface infrastructure. However, it was estimated that groundwater recharge would decline by 1263 Mm^3 under a bare ground scenario, with a replacement cost of US$84 million per year.
- **Sediment retention.** Vegetative cover prevents erosion by stabilizing soil and intercepting rainfall, thereby reducing its erosivity. It was estimated that landscapes across the Mazowe Catchment retain some 196.5 million tons per year of sediment (49.3 tons per ha per year), relative to a hypothetical landscape where all land cover is converted to bare ground. The value of the sediment retention service within dam catchment areas was estimated to be worth US$166 million per year.

TABLE 8: TOTAL ABOVEGROUND AND BELOWGROUND CARBON STORAGE ACROSS THE MAZOWE CATCHMENT

Land cover	Total carbon stored (million tons)	Mean carbon storage (tons/ha)	Total CO_2e (million tons)	Average tCO_2e/ha
Indigenous forest	0.61	61.7	2.24	226.5
Plantation forest	0.89	69.3	3.25	254.2
Degraded forest	0.05	38.5	0.20	141.3
Miombo woodland	54.46	42.6	199.86	156.3
Degraded Miombo woodland	2.77	24.4	10.16	89.7
Acacia-Terminalia woodland	27.84	61.7	102.16	226.3
Degraded Acacia-Terminalia woodland	0.46	40.0	1.69	147.0
Miombo shrubland	7.96	23.4	29.22	85.8
Degraded Miombo shrubland	0.35	16.0	1.30	58.7
Acacia-Terminalia shrubland	9.07	37.4	33.28	137.4
Degraded Acacia-Terminalia shrubland	0.13	30.8	0.47	113.1
Grassland	0.49	22.0	1.81	80.7
Degraded grassland	0.03	15.1	0.11	55.5
Cultivation	21.19	14.4	77.78	52.7
Sparsely vegetated	0.00	7.3	0.00	26.7
Built-up	0.45	48.0	1.66	176.1
ALL	**126.75**	**31.7**	**465.19**	**116.3**

per hectare was notably high in built-up areas which may be somewhat surprising. This can be attributed to the prevalence of large garden and street trees, particularly in suburban areas. Due to the 100 m resolution of the land cover, treed areas within towns are often lumped with hard infrastructure under the built-up land cover category.

179. **The spatial map of carbon biomass is shown in Figure 22.** Areas of low biomass throughout the study area are associated with cultivation, with the lowest values associated with densely cultivated communal areas in the south and west of the catchment. Highest carbon storage values are mostly found in the northeast where more extensive woody habitats remain. The Umfurudzi Safari Area is another area of notably high biomass in the northern central part of the catchment.

5.4.1.2 Value of carbon storage

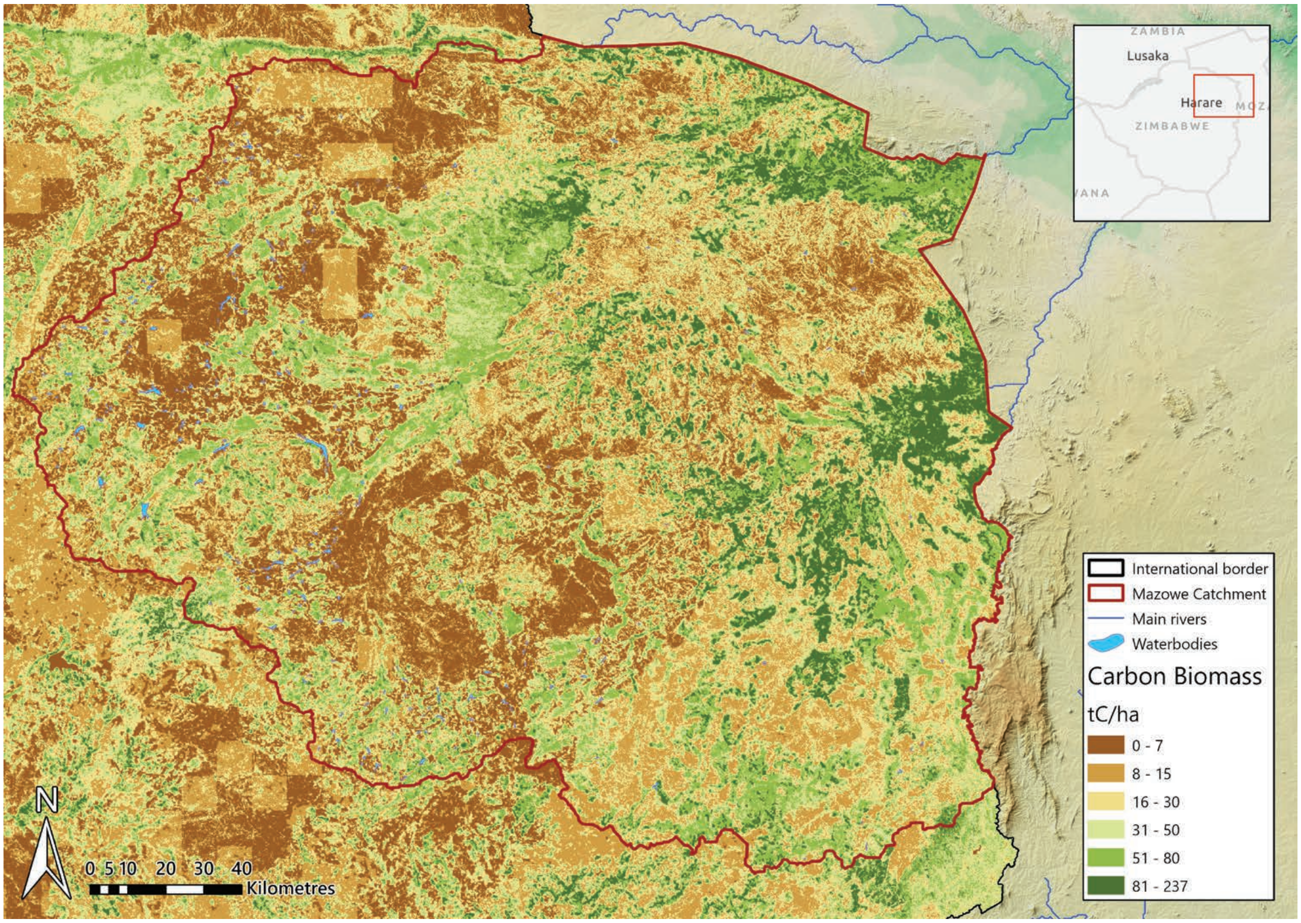
180. **The retention of ecosystem carbon can be valued in terms of the avoided costs of climate change and also in terms of potential income from the sale of carbon credits.** For comparability, these values, normally expressed in asset terms, were annualized.

181. **The avoided costs of climate change were based on the World Bank's median estimate of the social value of carbon for 2022 (US$62 per tCO_2e (World Bank 2017).** At the global level, the asset value of avoided economic losses through the retention of carbon stocks in the catchment was estimated to be US$26.7 billion, equivalent to an annual value of US$1.23 billion per year. The potential to generate income from carbon credits is explored in Chapter 6.

5.4.2 Flow regulation

182. **During rainfall events, some water soaks into the ground, while the balance runs off the surface (herein referred to as 'quickflow').** Some of the former is lost due to evaporation from the soil or evapotranspiration by plants. Of the remainder (herein referred to as the 'net infiltration'), some emerges at springs to join streams and rivers (termed

FIGURE 22: CARBON BIOMASS (ABOVE AND BELOW GROUND) ACROSS THE MAZOWE CATCHMENT



Source: Based on Bouvet et al. (2018) and Santoro et al. (2018):

'baseflows'), while some replenishes groundwater or aquifers (termed 'groundwater recharge').

183. **The balance between quickflow and infiltration varies considerably across the landscape and is mediated to some extent by ecosystems.** As well as retarding flood flows, vegetation cover facilitates the infiltration of rainfall into the ground, reducing the proportion of rainfall that runs off the surface during rainfall events. Depending on the evapotranspiration effects of the vegetation, this has an influence on the contribution of rainfall to groundwater and baseflows in the landscape.

184. **Through mediating infiltration, ecosystems can therefore help reduce overall seasonal variation in flows relative to the seasonal variation in rainfall.** This can affect the cost of surface or groundwater supply by water utilities and/or the cost of collecting water (for households not supplied by infrastructure). In general, the more variable the runoff, the larger the built storage capacity required to meet water demands during low flow seasons (for small dams) or drier years (for large dams, Guswa et al. 2017; Vogel et al. 1999, 2007). Small dams and run-of-river users are particularly sensitive to seasonal variation in flow. However, the extent to which ecosystems may play a role in smoothing surface flow variability and/or contributing to groundwater replenishment depends on a range of context-specific factors such as slope, geology, rainfall pattern, evaporation, evapotranspiration, groundwater depth, etc.

185. **Water supply systems are engineered to the way in which surface and groundwater flows vary across the landscape, as can be seen from the variation in how water is collected.** However, if land use or climate changes led to a decrease in infiltration, this can result in increased quickflow, leading to flooding, a reduction in dry season flows,

and/or the availability of groundwater and increased costs of storing and extracting water.

186. **Both surface water and groundwater sources are used in the Mazowe Catchment.** There are several small-to-moderate-size dams which supply irrigation schemes and bigger settlements. However, most rural households in the study area depend on groundwater. Excluding Harare, some 74–89 percent of households rely on boreholes and wells as their main water source and 3–9 percent rely on surface water (ZIMSTAT and UNICEF 2019). Groundwater is still a major source of water for irrigation, mining, and tourism (Davis and Hirji 2014).

187. **A rapid-level estimate of the effects of ecosystems on flow was made using the InVEST Seasonal Water Yield (SWY) tool.** This included the impacts of vegetation cover on quickflow, infiltration, and contribution to baseflow and groundwater recharge. Flows were first modelled under the current land cover. To obtain the contribution of ecosystems to flow regulation, current flows were then compared to those of a hypothetical bare ground landscape.

5.4.2.1 Ecosystem effects on flows

188. **It was estimated that total quickflow (surface runoff during or shortly after rainfall events) across the catchment is 3,132 Mm³ per year (78 mm per year).** Net infiltration amounts to some 3,575 Mm³ per year (89 mm per year; Table 9). Of this, an estimated 2,145 Mm³, goes to groundwater recharge, and 1,430 Mm³ is the baseflow contribution to streamflow. Thus, total streamflow (quickflow + baseflow) is estimated to be 4,562 Mm³. These estimates are in line with published values (see Appendix 5).

189. **Net infiltration is generally highest in natural land cover types with a lower density of trees (Table 9).** This reason also underlies the higher values for net

TABLE 9: AVERAGE QUICKFLOW AND NET INFILTRATION ACROSS DIFFERENT LAND COVER TYPES IN THE MAZOWE CATCHMENT

Land cover	Average quickflow (mm)	Average net infiltration (mm)	Net recharge (% of precipitation received)	% Difference from bare ground
Indigenous forest	16.0	−66.7	−7.0	−246.9
Plantation forest	162.9	−9.3	−0.8	−112.6
Degraded forest	29.3	171.3	18.1	169.2
Miombo woodland	38.0	124.0	15.0	276.1
Degraded Miombo woodland	79.4	185.9	22.5	321.8
Acacia-Terminalia woodland	28.1	34.9	5.1	104.8
Degraded Acacia-Terminalia woodland	56.5	79.0	11.7	321.6
Miombo shrubland	64.5	167.9	21.2	347.0
Degraded Miombo shrubland	103.1	238.4	30.1	359.5
Acacia-Terminalia shrubland	48.9	105.6	15.8	398.8
Degraded Acacia-Terminalia shrubland	77.8	141.4	21.1	488.2
Grassland	176.9	254.9	29.5	424.7
Degraded Grassland	220.4	274.6	31.8	438.4
Cultivation	125.0	47.0	6.0	1.4
Sparsely vegetated	290.4	49.1	5.9	−16.2
Built-up	601.8	−10.8	−1.3	−103.7
ALL	**76.1**	**90.0**	**11.5**	**143.1**

recharge in degraded land cover classes relative to their undegraded equivalents. This is in line with the meta-analysis of groundwater recharge studies conducted by Owuor et al. (2016), which found that groundwater recharge rates usually decline when bare or degraded areas are restored.

190. **Most natural land cover types have higher net infiltration rates than cultivated areas, as the greater vegetation cover reduces quickflow, allowing more time for infiltration to occur.** However, forest and Acacia-Terminalia woodland had lower values for net recharge than cultivation, due to the higher evapotranspiration losses associated with these denser vegetation types. Indigenous and plantation forests in fact had negative values for average net recharge, meaning that on each 30 m forest cell, more water is lost to evapotranspiration that the amount that is left over on the cell after the immediate loss of a portion of rainfall to runoff. This indicates that forested areas use surplus groundwater and subsurface flow coming down from upslope areas (that is, the upslope subsidy) to meet a portion of their water requirements.

191. **The average quickflow in the different natural land cover types reflects the combined effects of vegetation cover and rainfall.** The highest values were associated with built-up and sparsely vegetated areas (Table 9), which have hard surfaces and/or little vegetation to slow runoff. Indigenous forest had the lowest value, as it is the densest land cover type. In contrast, plantation forest had a high mean quickflow value due to its sparse understory coupled with its location in high rainfall parts of the catchment.

192. **Cultivated areas also had relatively high quickflow values relative to most wooded land cover types due to sparse vegetation cover.** Acacia-Terminalia woodland had the lowest per hectare quickflow value, due to both dense vegetation cover which intercepts and slows runoff and its location in the drier lower reaches of the catchment.

193. **The highest net infiltration rates are found in the high rainfall Eastern Highlands, especially under more open land cover types (relative to forest) such as grassland and miombo woodland.** The recharge rate is also relatively high in the relatively wet south and west of the catchment. Conversely, it is lowest in the northeast of the catchment reflecting lower rainfall and, in some cases, high evapotranspiration due to high tree cover. Throughout the catchment, areas where net infiltration is less than 0 mm reflect areas where evapotranspiration loss exceeds the infiltration capacity.

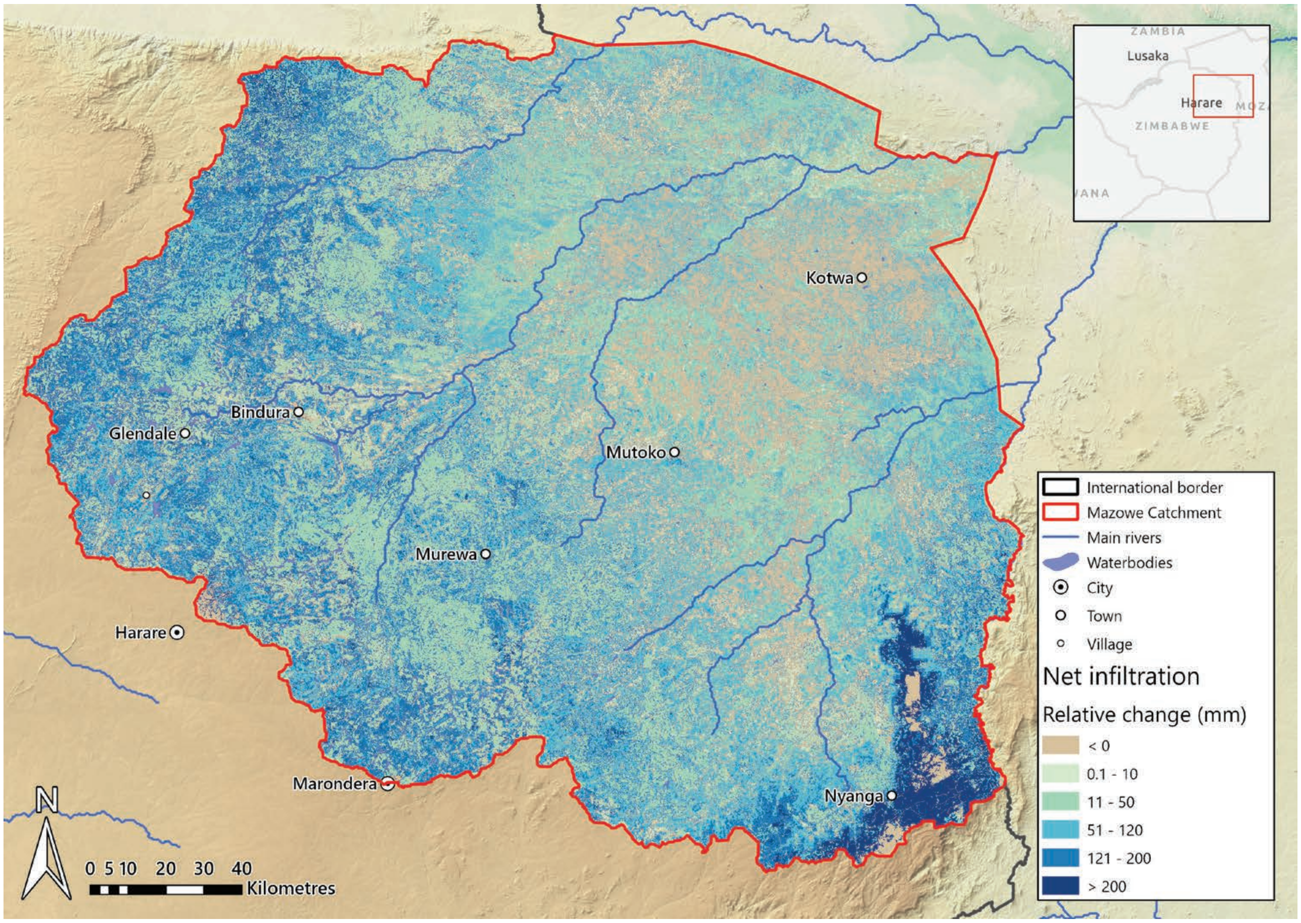
5.4.2.2 Ecosystem contribution to groundwater recharge and baseflow

194. **Overall, it was estimated that net infiltration under the current land cover (3,576 Mm^3 per year) is 2.4 times greater than if the catchment was bare of vegetation (1,470 Mm^3 per year; Table 9).** Groundwater recharge and baseflow were estimated to be 1,263 Mm^3 and 842 Mm^3. higher than under bare land cover. This is because quickflow runoff increases drastically at the expense of infiltration when there is no vegetation cover to intercept and slow runoff.

195. **Natural habitats with a lower density of woody vegetation (shrubland and grassland) had the highest recharge capacity, with vegetation cover increasing infiltration by at least 6 times relative to bare ground in these habitats (Table 9).** This is due to their ability to slow runoff as well as their lower evapotranspiration losses relative to denser habitats. Conversely, forest has a lower net infiltration than bare ground, in line with findings of experimental studies (Owuor et al. 2016). This is due to high rates of evapotranspiration associated with trees. Cultivated areas also have lower net infiltration than bare ground due to crop water consumption.

196. **The difference in net infiltration that can be attributed to ecosystems is shown in Figure 23.** This map represents the ecosystem service of water capture by vegetation. Overall, this map shows that there is significantly higher infiltration under the current land than would be the case for a bare landscape. Areas where net infiltration would be higher if existing cover were converted to bare ground are shown in brown. Examples include some of the forested areas around Nyanga, due to the high evapotranspiration of forest vegetation noted earlier. There are also some areas in the northeast of the catchment where recharge would be increased if current cover was converted to bare ground. This is because evapotranspiration losses from habitats such as woodland and cultivation account for a higher proportion of the overall water balance equation in these drier areas.

FIGURE 23: DIFFERENCE IN NET INFILTRATION BETWEEN CURRENT LAND COVER AND BARE GROUND



Note: Darker blue areas indicate a higher value for current land cover. Brown values (that is, <0) indicate areas where net infiltration would be higher if current cover was converted to bare ground. *Source:* Original calculations from this study.

5.4.2.3 Value of the flow regulation service

197. **The groundwater recharge mediated by ecosystems was valued in terms of the avoided additional expense that would have to be incurred to meet current demands under a no-ecosystem (bare-ground) scenario.** It was assumed that the percentage decrease in net infiltration would have a similar impact on the combined yield from existing borehole and well infrastructure in each catchment, and the deficit would be made up through investment in surface water infrastructure. Based on an assumed storage-yield ratio of 2, an estimated construction cost of US$1.88 per m^3 (based on data from eight dam projects in Zimbabwe), and a 15 percent cost of capital, the value of the service for water supply was valued at US$84 million per year. Note that this does not include the value of maintaining groundwater-dependent ecosystems such as wetlands.

198. **The value of regulating surface water flows was also explored.** Patterns of quickflow and net infiltration within dam catchment areas were examined. Quickflow is strongly linked to rainfall and drops to virtually zero from May to September. Reduced vegetation increases the difference between wet and dry season flows. The sequential mass curve procedure was used to estimate reservoir capacity requirement for a series of arbitrary yield ratios for the dam catchment areas under the current and bare ground scenarios. However, the loss of vegetative cover could not be shown to lead to a larger dam capacity requirement. In fact, because of the large increase in quickflow, the required dam capacity (for all else equal) was smaller under bare ground. The important caveat here is that, because this study was trying to isolate the flow regulation effect, this does not consider the impact of higher erosion and sedimentation, which can severely reduce reservoir

capacity. It was concluded that sediment retention is the more important hydrological service in terms of surface water resources to support existing dams within the catchment. Similarly, in terms of flow regulation as a whole, the mediation of groundwater recharge appears to be the more important ecosystem service than sustaining dry season flows. This is in line with the non-perennial nature of most rivers in the region, which suggests that baseflow does not make a large contribution to sustaining dry season flows (NUST 2019)

5.4.3 Erosion control and sediment retention

199. **Soil erosion has been a serious concern in Zimbabwe for some time (Whitlow 1988).** High soil erosion rates reduce topsoil depth as well as reducing soil water content, soil organic carbon and removing nutrients (Roose 2008). This imposes costs on farmers, who must increase fertilizer application to replace lost nutrients. In extreme cases, soils may become too shallow to support crop growth (Whitlow 1988). In addition to affecting agricultural productivity, the export of eroded soil to watercourses results in siltation, which can affect river flows and reduce the storage capacity of reservoirs.

200. **Vegetative cover prevents erosion by stabilizing soil and intercepting rainfall, thereby reducing its erosivity.** Vegetated areas, especially wetlands, may also capture the sediments that are eroded from upstream agricultural and degraded lands and transported in surface flows, preventing them from entering streams and rivers (Blumenfeld *et al.*, 2009). Thus, vegetation protects downstream areas from the impacts of sedimentation, which can include impacts on water storage capacity, hydropower generation and navigability of rivers (Pimentel *et al.* 2008). While some level of sedimentation of reservoirs is expected under natural conditions, and planned for, elevated catchment erosion either incurs dredging costs or shortens the projected lifespan of reservoirs and related infrastructure. The reduction of natural vegetation cover, whether through building roads and settlements, mining, resource harvesting, grazing, agriculture, or burning, results in elevated levels of erosion and subsequent increases in sediment loads carried downstream. Globally, anthropogenic sedimentation accounts for about 37percent of the annual costs of reservoirs (Basson 2009). In urban contexts, elevated sediment loads also have to be removed from sewerage systems, storm water drainage systems, and harbors.

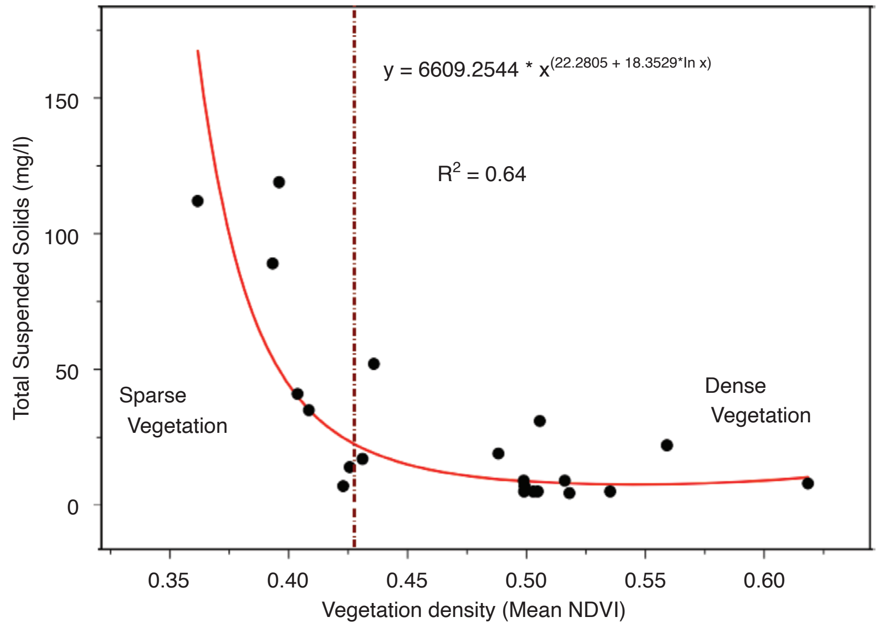
201. **Soil loss and the sedimentation of rivers and reservoirs is a serious issue in Zimbabwe, including in the Mazowe Catchment (Makwara and Gamira 2012; Tundu, Tumbare, and Onema 2018).** For example, there has been a 39 percent reduction in capacity of Chimhanda Dam (Tundu, Tumbare, and Onema 2018) and a 67 percent loss in storage capacity for Chesa Causeway Dam (Godwin et al. 2011). These smaller, low-capacity dams in communal areas are particularly prone to high siltation rates (Whitlow 1988). It has been estimated that such dams have an effective lifespan of just 15 years before being filled with sediment (Magadza 1984). Murwira et al. (2014) found a strong negative relationship between the degree of vegetative cover and the suspended sediment loads of rivers in the Mazowe Catchment (Figure 24).

202. **In this study, soil erosion and sedimentation rates were modelled using the InVEST Sediment Delivery Ratio (SDR) model to estimate the amount of erosion and how much is exported to watercourses as sediment (See Appendix 5).** In this study, we focus on the value of sediment retention by ecosystems for water supply from reservoirs, recognizing the serious issues caused by reservoir sedimentation discussed above. The sediment retention service was quantified by comparing sediment export from the current landscape to one where all land cover is converted to bare ground and the service valued is based on the cost of dredging dams to recover lost storage.

5.4.3.1 Current erosion and sediment export

203. **Total erosion across the Mazowe Catchment was estimated to be around 127.9 million tons per year, or an average of 32.0 tons per ha per year.** This estimate is comparable with Tundu, Tumbare, and Onema (2018), who estimated soil loss across the catchment ranged from 36 tons per ha per year to 65 tons per ha per year between 2000 and 2014. Tolerable soil loss rates vary significantly, but generally range from 1 to 12 tons per ha per year,

FIGURE 24: RELATIONSHIP BETWEEN VEGETATION DENSITY (AS INDICATED BY NDVI) AND THE CONCENTRATION OF SUSPENDED SOLIDS IN RIVERS IN THE MAZOWE CATCHMENT



Source: Murwira et al. 2014.

or around 10 tons per ha per year for agricultural soils (Roose 1996). Modelled erosion rates thus significantly exceeded tolerance limits over much of the catchment, particularly in small-scale farming areas (69.2 tons per ha per year), as well as degraded natural land cover types (*for example,* 30.3 tons per ha per year in degraded miombo woodland, 83.5 tons per ha per year in degraded grassland). These high erosion rates are in line with previous works. For example, Whitlow (1988) reported soil erosion rates in communal farmland to be 50 tons per ha per year and 75 tons per ha per year in communal rangelands. These high rates of soil erosion on farmland impose costs on farmers who must replace lost nutrients with fertilizers, while in extreme cases, soils may become too shallow to support crop growth (Whitlow 1988).

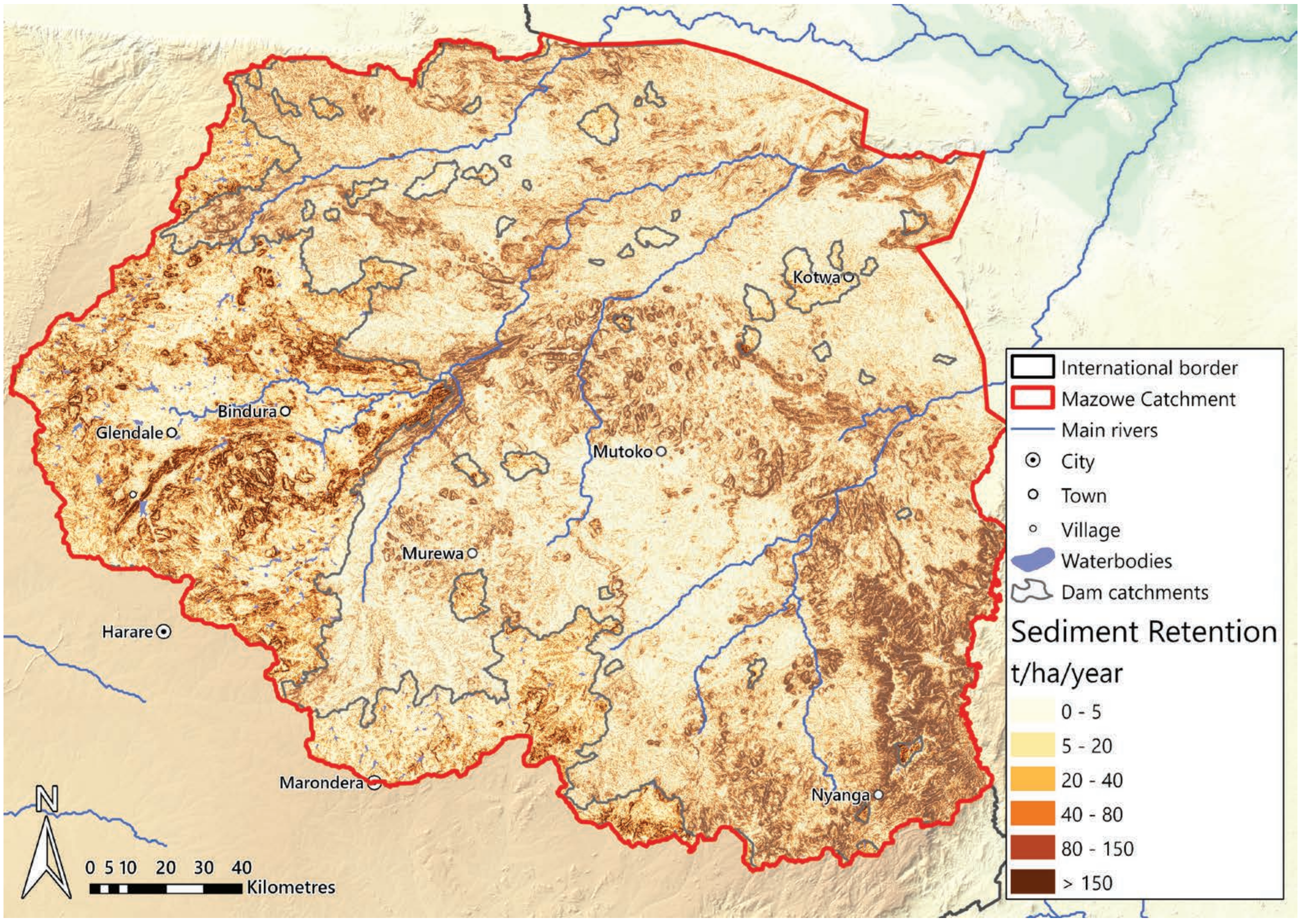
204. **Of the soil eroded in the study area, around 11.6 million tons per year were estimated to be exported to watercourses as sediment, with the remainder being deposited across the landscape before it reaches streams or reservoirs.** This gives an average sediment export rate of 2.9 tons per ha per year. This is somewhat lower than the 6.0 tons per ha per year estimated by Tundu, Tumbare, and Onema (2018). However, comparison with measured sedimentation rates did not suggest that the final modelling results underestimated sediment export in the relevant catchments.

5.4.3.2 Sediment retention

205. **It was estimated that landscapes across the Mazowe Catchment retain some 196.5 million tons per year of sediment (49.3 tons per ha per year), relative to a hypothetical landscape where all land cover is converted to bare ground (Figure 25).** Topography is a major factor determining the potential for sediment export, with the highest values for sediment retention associated with hilly areas under natural land cover.

206. **In the catchment areas of dams, total sediment export was estimated to be 2.75 million tons per year (2.59 tons per ha per year), while retention by the landscape was estimated to be 43.7 million tons per year (41.1 tons per ha per year) (Table 10).** These figures highlight that sediment export form natural land cover types is much lower than for cutlivated areas, with the latter being the major contributor to sedimentation in the catchment. For example, sediment export from miombo woodland, the dominant natural land cover in the catchment, is around 16 times lower per hectare than sediment

FIGURE 25: SEDIMENT RETENTION ACROSS THE MAZOWE CATCHMENT RELATIVE TO A LANDSCAPE WHERE ALL COVER HAS BEEN CONVERTED TO BARE GROUND



Source: Calculations from this study. Sediment retained outside of dam catchments has been slightly greyed out.

export from cultivated areas. Sediment retention realtive to a bare landscape is also drastically higher for natural land cover types than for cultivation (Table 10), highlighting the higher value of the sediment retention service provided by natural land cover types. This reflects both the greater erosion control provided by natural land cover and that the remaining natural habitats tend to be located in steeper areas which are less suited to farming. This results in even greater erosion reduction relative to natural land cover in flat areas.

5.4.3.3 Value of sediment retention

207. **Based on the cost of dam dredging, the value of the sediment retention service within dam catchment areas was estimated to be worth US$166.3 million per year, or US$158.0 per ha.** Sediment retention by miombo woodland accounts for the majority of the sediment retention value in the landscape, reflecting its areal extent as well as the general location of miombo woodland in higher rainfall areas that are more prone to erosion.

5.5 Summary of ecosystem values and their beneficiaries

208. **The ecosystem services of the Mazowe Catchment benefit a range of stakeholders (Table 11).** The way in which these benefits are distributed among the different stakeholders is determined by the use of the landscape, the resulting balance between natural and transformed land cover types, and the condition of those land cover types.

TABLE 10: ESTIMATED SEDIMENT EXPORT AND SEDIMENT RETENTION ACROSS DIFFERENT LAND COVER TYPES WITHIN DAM CATCHMENT AREAS OF THE STUDY REGION, AND THE ESTIMATED VALUE OF THE SERVICE

Land cover	Sediment export (t/ha/year)	Sediment retention (t/ha/year)	Sediment retention value (US$ million/year)
Indigenous forest	0.06	88.0	1.0
Plantation forest	0.04	40.1	0.3
Degraded forest	0.74	114.3	0.4
Miombo woodland	0.32	88.4	88.4
Degraded Miombo woodland	1.72	53.3	23.1
Acacia-Terminalia woodland	0.12	64.2	1.4
Degraded Acacia-Terminalia woodland	1.25	27.7	0.1
Miombo shrubland	1.91	69.3	12.7
Degraded Miombo shrubland	5.67	50.5	2.3
Acacia-Terminalia shrubland	0.50	37.3	0.6
Degraded Acacia-Terminalia shrubland	2.68	14.9	0.0
Grassland	1.75	47.4	2.1
Degraded grassland	5.24	22.4	0.2
Cultivation	5.25	29.1	32.9
Sparsely vegetated	1.01	14.6	0.0
Built-up	5.45	37.1	0.8
ALL	**2.23**	**41.1**	**166.3**

TABLE 11: SUMMARY OF THE CURRENT VALUES OF SELECTED ECOSYSTEM SERVICES ASSESSED IN THIS STUDY, IN US$ MILLIONS PER YEAR

Types of services	Explanation	Value to whom	Value per year (US$, millions)
Cultivated production	Production value net of human inputs	Communal farmers	38.0
		Commercial farmers	30.2
Livestock production	Production value net of human inputs	Communal farmers	43.1
		Commercial farmers	21.6
Wild resources	Value of wild harvested foods, fuel, and raw materials net of human inputs	Rural households	105.7
Sediment regulation	Cost savings due to vegetation capacity to hold soil in place or trap eroded soils before entering streams	Water utilities and private dam owners	166.3
Flow regulation (contribution to baseflows and groundwater)	Cost savings in water resources infrastructure due to facilitation of recharge by vegetation	Water utilities and/or direct water users	83.9
Tourism	Net income generated as a result of tourism to natural attractions	Tourism sector	42.9
Carbon retention	Avoided climate-change damages as a result of avoided CO_2 emissions from ecosystem degradation	Zimbabwe	30.0
		Rest of world	1,230.0

209. **Rural households, who make up most of the population, enjoy the greatest aggregate benefits from ecosystems.** These include agriculture and livestock production, worth an estimated US$43 and US$38 million per year, respectively, and at least US$106 million per year from the use of natural resources provided by ecosystems. Commercial farmers derive over US$50 million per year in benefits from the Mazowe Catchment, in addition to plantation forestry (not estimated).

210. **In addition, all the inhabitants of the catchment area benefit from the opportunities for recreational, cultural, or spiritual fulfilment offered by the area's natural assets.** Rural landscapes of the Mazowe Catchment area also make a small contribution to the tourism sector, in the range of US$43 million per year. This value is linked to the extent of road infrastructure and tourism facilities as well as attractive scenery and wildlife.

211. **The water sector is also a major beneficiary.** In this study, it was estimated that sediment retention by ecosystems generates cost savings of US$166 million per year from avoided dam sedimentation risk alone. Further benefits may be obtained where water is treated for use. While the regulation of surface flows was not found to be a major factor, it is estimated that groundwater recharge saves costs in the region of US$84 million per year.

212. **Finally, there are global benefits from the retention of carbon in the landscape, which helps avoid further climate change damages, potentially worth billions of dollars.**

213. **Table 12 shows that natural ecosystems provide a broader range and higher value of ecosystem services compared to croplands per hectare.** Croplands often involve intensive agricultural practices, such as monocultures, intense tillage, and the use of synthetic fertilizers and pesticides, which can have negative environmental impacts. However, well-managed agricultural systems through CSA can incorporate some ecosystem services, such as soil conservation practices or agroforestry systems that provide habitat for wildlife. Global carbon benefits account for the highest per hectare ecosystem service value for both natural ecosystem and cropland ($408 and $147 respectively). Total ecosystem service values per hectare provided by natural ecosystem increases from $168 to $576 with the consideration of global carbon benefits. For cropland the total ecosystem service value per hectare is $84, but increases to $231 with the consideration of carbon sequestration in agricultural soils.

TABLE 12: SUMMARY OF BASELINE ECOSYSTEM SERVICES VALUE (US$ PER HA)

	Crop production	Livestock production	Wild resource harvesting	Sediment retention	Groundwater	Carbon (LB)	Carbon (GB)	Tourism	Total value excluding GB	Total value including GB
Natural ecosystem	0.0	25.7	42.1	52.8	33.9	0.1	408.4	13.7	168.3	576.5
Cropland	51.6	0.0	0.0	23.8	0.3	0.1	147.0	8.5	84.3	231.2

6.

Enhancing the Asset Value of the Mazowe Landscape: A Scenario Analysis

6.1 Overview

214. **The previous chapter of the report quantified and valued key ecosystem services provided by landscapes of the Mazowe Catchment in their current state.** As noted over the course of the report, the full ecosystem service potential of the study area is not being realized due to environmental degradation.

215. **This chapter evaluates potential landscape interventions to restore, maintain, or enhance the flow of ecosystem services from natural and cultivated lands within the study area.** It starts by identifying potentially suitable interventions for the various socioecological contexts of the study area and estimating the impact that these could have on ecosystem conditions and agricultural productivity.

216. **The potential outcomes in terms of the supply of ecosystem services are compared with a business-as-usual scenario in a high-level cost-benefit analysis to determine the potential ROI.** The analysis is also performed at the sub-catchment scale, to highlight priority sub-catchments and guide a phased investment approach.

6.2 Potential management actions

217. **Management actions to maintain soil, vegetation cover, biodiversity, and agricultural productivity are mutually supportive and include (a) supporting, regulating, and/or incentivizing CSA practices which increase the productivity of land and reduce rates of land conversion, soil loss, and water consumption; (b) limiting the use of grazing and wild resources to sustainable levels, to maintain their productivity as well as other services; and (c) restoring and protecting key natural areas**

KEY POINTS

- A range of agricultural and natural habitat restoration interventions are proposed for the study area: CSA, restoration of riparian buffers that have been lost to cultivation, the passive restoration of degraded natural habitats, management of grazing and resource harvesting pressures, and the improvement of community conservation areas.
- CSA could increase crop production from small-scale farmland by US$32.8 million per year.
- Full restoration of riparian buffers and degraded natural habitats could increase the value of wild resource harvesting by US$3.54 million per year.
- The recovery of riparian buffers and degraded natural habitats and increased sequestration of soil carbon through conservation tillage could generate carbon credits worth at least US$13.5 million per year.
- Collectively, the three interventions could result in an increase in groundwater recharge worth around US$11.8 million per year and avoided reservoir sedimentation costs of US$10.2 million per year.
- A high-level estimation of costs and benefits of the proposed interventions over a 25-year time horizon suggests that implementing the proposed interventions across the whole study area could generate a return of US$1.70 for every dollar spent.
- Six sub-catchments had an ROI of 2 or greater. This suggests interventions will be most cost-effective in these sub-catchments.

important for biodiversity and ecosystem services (Figure 26).

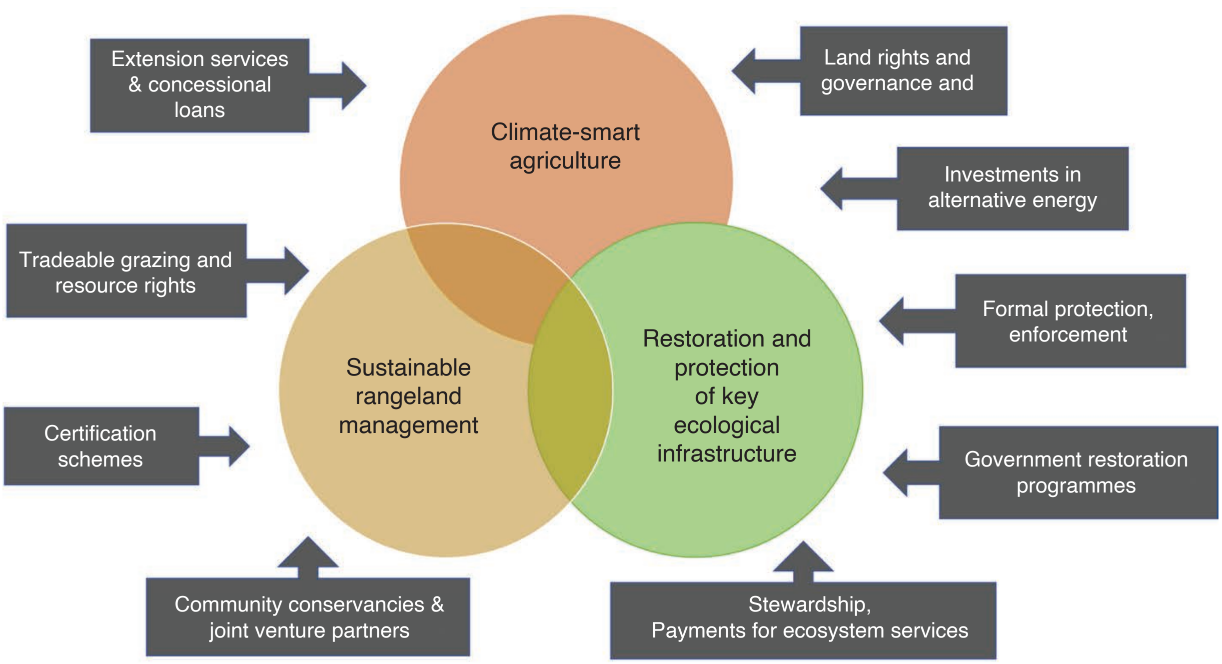
218. **These will act synergistically toward deriving diverse benefits from the area's ecological capital.** CSA practices increase productivity, thus reducing the pressure to convert natural areas to farmland and reducing dependence on grazing and harvested resources. If such practices are applied well, the rate of loss of natural ecosystems within the catchment could be reduced. The recovery of rangelands will ensure the provision of benefits into the longer term, including during times of economic shocks or climate stress. The restoration of natural areas will help sustain water quality and water yields critical for household livelihoods, as well as provide alternative income opportunities, such as from biodiversity, carbon, and hydrological services, some of which could be reinvested in land and resource management.

219. **The choice of policy measures or interventions to achieve these ecosystem management changes depends on how critical the outcome is, the relative costs and benefits to the actors versus the rest of society, and who the beneficiaries are.** Some examples are given in Figure 26. Because CSA measures are generally a win-win solution, they may only need financial and technical inputs in the start-up phase. On the other hand, curbing the unsustainable use of rangelands, trees, and wild resources and encouraging practices to allow their recovery requires stronger and ongoing regulation and/or incentives (such as payments for ecosystem services) and supporting measures such as the planting of woodlots and/or investment in alternative or more efficient energy sources. Provision of secure land tenure and resource rights, for example, through conservancy establishment, could be a powerful incentive for the sustainable management of natural resources as well as a lever of private sector conservation funding. Current understanding of the potential for these three areas of intervention are discussed in more detail below.

6.2.1 Climate-smart agriculture

220. **Earlier discussions highlighted the severe threat posed to agriculture under future climate change (Benitez et al. 2018; World Bank 2019, 2021) as well as the serious concerns with erosion, particularly in communal areas (Godwin et al. 2011; Makwara and Gamira 2012; Tundu, Tumbare, and Onema 2018; Whitlow 1988).** The adoption of CSA has the potential to address both low productivity and land

FIGURE 26: THE THREE BROAD INTERVENTIONS TO ACHIEVE SUSTAINABLE USE OF THE MAZOWE CATCHMENT AREA THAT DERIVES MAXIMAL BENEFIT FROM ITS ECOLOGICAL CAPITAL AND THE VARIOUS MEASURES THAT CAN BE USED TO ACHIEVE THEM



degradation. Indeed, a Climate Smart Agriculture Investment Plan (CSAIP) has already been prepared for Zimbabwe (World Bank 2019).

221. **CSA encompasses a wide range of practices, including conservation agriculture (CA) (which reduces soil and water losses), agroforestry, improved livestock fodder production, rainwater harvesting, and soil conservation infrastructure.** CSA practices improve land productivity and could reduce the rate of loss of natural ecosystem areas to cultivation (Marongwe et al. 2011).

6.2.1.1 Conservation agriculture

222. **CA is premised on three main principles: minimum mechanical soil disturbance, improved maintenance of ground cover using organic matter, and diversification of crop species to move away from monocultures (Kassam et al. 2009; Marongwe et al. 2011).** These practices have the potential to bring multiple benefits to both farmers and ecosystems at large. Conservation tillage (for example, ridge tillage, tine tillage[18]) is estimated to reduce erosion by 65 percent and no tillage by 75 percent, relative to conventional ploughing (Panagos et al. 2015; Stone and Hilborn 2001). Mulching is estimated to reduce evaporation from the soil by 15–24 percent (World Bank 2019) while contributing to further reductions in erosion (Kassam et al. 2009; Panagos et al. 2015). All of this contributes to higher germination rates and reduced moisture stress and improves resilience in the face of increased temperatures and rainfall variability under climate change (Marongwe et al. 2011; World Bank 2019). Soil fertility may be enhanced by intercropping or rotation with legumes and/or agroforestry species, while the precise application of fertilizer reduces input costs and nutrient pollution (Marongwe et al. 2011; Twomlow et al. 2008). Recommended strategies for the Mazowe Catchment include intercropping or rotation of maize with crops such as soybeans, cowpeas, or green beans to both enhance soil fertility and increase nutritional diversity. Collectively, these factors have generated considerable yield increases, ranging from around 30 percent to as high as 200 percent across different regions of the country (Marongwe et al. 2011; Twomlow et al. 2008; ZCATF 2009). In addition to production and water saving benefits, it has been estimated that conservation tillage increases the uptake of soil carbon by 0.18 tCO_2e/year, thus increasing the value of carbon stored by the landscape (World Bank 2019)

223. **Zimbabwe officially promotes CA practices through the *Pfumvudza/Intwasa* programme.** The implementation of CA on 360,000 ha of cropland and 1.1 million ha of degraded arable land also forms part of the country's LDN targets. In the 2020/2021 season, around 200,000 ha of maize was planted under the *Pfumvudza/Intwasa* programme (MoLAWFRR 2021). Average yields were 5.3 tons per ha, nearly five times higher than the national average of 1.2 tons per ha (MoLAWFRR 2021). Within 16 project districts, average maize yields in *Pfumvudza* plots (4.19 tons per ha) were almost twice as high as those from non-*Pfumvudza* plots (2.27 tons per ha) (IAPRI and FAO 2021). This is a more realistic comparison, as it effectively controls for selection bias in the location of the program within the country. However, it should be noted that a key component of the *Pfumvudza* concept is the use of small plot sizes (around 600 m^2). Small fields are generally more productive per unit area than larger fields (see Ali and Deininger 2015; Larson et al. 2014). When comparing small fields only, *Pfumvudza* plots have a yield benefit of just 9 percent over similarly sized non-*Pfumvudza* plots. Nevertheless, the analysis used just one year of data from areas which received relatively good rainfall and greater relative benefits would be expected in drier areas (IAPRI and FAO 2021). Also, benefits are likely to increase over time (Twomlow et al. 2008; ZCATF 2009).

224. **Barriers to adopting CA include higher labor requirement, and competition with livestock for crop residues (Twomlow et al. 2008; ZCATF 2009).** Labor demands could be addressed through the use of low-cost seeding equipment (Marongwe et al. 2011). Support for purchasing such equipment could thus be key to increasing adoption of CA. To address competition over crop residues, farmers could consider using other sources of mulch such as grass or kitchen compost (ZCATF 2009). Ultimately, increased production under CA could yield more crop residue for both mulching and livestock.

[18] Ridge tillage involves creation of raised planting beds (ridges), while tine tillage involves working only the top 5–7 cm of soil

6.2.1.2 Adjusting crop choices

225. **In addition to rotation and intercropping as part of CA, switching to more drought-resistant crops like sorghum has also been suggested to maintain or improve agricultural production (World Bank 2019).** However, sorghum is generally lower yielding. According to the National Crop and Livestock Assessment Reports, the average sorghum yield across the constituent provinces of the Mazowe Catchment is around 0.47 tons per ha, compared to 0.99 tons per ha for maize (MoLAWFRR 2020, 2021).[19] In this study, an analysis was undertaken to investigate whether switching to sorghum would yield production gains in the Mazowe Catchment (see Appendix 6). Future suitability ratio layers were generated for maize and sorghum by dividing current suitability by future suitability, using the layers produced for the CSAIP (World Bank 2019). In all sub-catchments, future combined production of maize and sorghum was lower under the crop switching scenario than predicted future production if the current maize/sorghum mix remains unchanged. This is because projected maize yields in the study area remain higher than sorghum even under climate change. Thus, the final intervention scenario did not include any production gains due to crop switching. Nevertheless, it is acknowledged that switching to sorghum may be beneficial for increasing drought resistance among small-scale farmers in drier parts of the catchment. Switching from sorghum to maize is likely to be more beneficial in the south and west of the country, where future suitability for maize declines more drastically than in the Mazowe Catchment (see Appendix 6).

6.2.1.3 Agroforestry

226. **Agroforestry involves integrating woody perennial species with crops and/or livestock to take advantage of a range of benefits and services (Liniger et al. 2011).** Forms of agroforestry are already traditionally practiced by small-scale farmers in Zimbabwe, including the retention of indigenous fruit trees and planting of fruit trees in and around rural home gardens (Campbell, Luckert, and Scoones 1997; Maroyi 2009). Agroforestry has also been identified as a key strategy for improving the agricultural sector by the Zimbabwean government (GoZ 2013).

227. **Agroforestry can increase the absorptive capacity of soil, reducing runoff evaporation, improving soil fertility and nutrient cycling, and providing leaf litter for mulching and fodder and shade for livestock (Liniger et al. 2011; World Bank 2019).** This could be beneficial in the hot and dry northern regions of the catchment. For example, agroforestry has been shown to reduce soil evaporation after rainfall by 15–24 percent and increase soil wetness by 9–18 percent (Siriri et al. 2013). Other benefits include the provision of wood and other non-timber forest products such as fruit, which can be used to diversify diets and income sources, particularly during drought and other challenging times (Liniger et al. 2011; World Bank 2019).

6.2.1.4 Improved livestock fodder production

228. **Intercropping of cereal crops with fodder crops and/or shrubs has the potential to improve soil fertility and reduce fertilizer costs (Marongwe et al. 2011) while providing an improved source of food for livestock.** The CSAIP recommended the introduction of velvet beans as an additional food source for cattle as one of the most promising cost-effective measures for improving the sustainability and productivity of communal cattle (World Bank 2019). This could help reduce grazing pressures on natural habitats but only if it is accompanied by measures to discourage an increase in stocking rates as a result of the availability of supplementary food. Since fodder crops provide a more nutritious food source than natural forage, especially in the dry season, this could improve livestock production and meat quality (World Bank 2019). It could also reduce the need for dry season burning to stimulate grass growth (World Bank 2019).

6.2.1.5 Soil and water conservation and harvesting

229. **The majority of smallholder farmers in Zimbabwe depend on rainfed agriculture, putting them at high risk of crop failure, especially under climate change (World Bank 2019, 2021).** Measures to improve conservation and harvesting of water are thus a key part of CSA. CA practices like mulching can already result in notable gains in crop water efficiency

[19] These estimates are based on the reported yields for the three most recent rainy seasons captured in the National Crop and Livestock Assessment Reports.

(Marongwe et al. 2011; World Bank 2019). In addition, availability of water for irrigation could more than double the yields for many crops, particularly in the country's drier agro-ecological regions (World Bank 2019). Small-scale water harvesting technologies like rain barrels or community ponds are cost-effective ways of achieving this compared with large-scale irrigation infrastructure (World Bank 2019).

230. **Enhanced soil and water conservation structures in fields could also lead to further water savings.** Contour ridging and hedgerows are already prevalent in communal farmland in the study area (Whitlow 1988; Zikhali 2010). However, old contour ridges are often neglected or ridges not dug at all on new farmland, partly due to the persistent association of contour ridges with forced labor under colonialism, where the practice was made compulsory (Makwara and Gamira 2012; Whitlow 1988). Low-cost techniques, such as adding sisal or vetiver grass to contour ridges/hedgerows, in combination with improved contour ridge maintenance, could be effective. This will lead to improved soil and water conservation (Makwara and Gamira 2012; ZCATF 2009).

6.2.2 Sustainable rangeland and resource management

231. **There are extensive areas of the catchment where natural vegetation persists in a degraded state and its ecosystem service value is reduced.** This includes areas which have been partially cleared for cultivation, abandoned fields, areas thinned out for fuelwood harvesting, and areas where livestock overgrazing has reduced woody and/or herbaceous biomass. Pressure on these areas needs to be reduced to allow them to recover their productivity and then managed sustainably. This could make a significant contribution to Zimbabwe's LDN commitment to reforest 6.4 million ha of deforested land (GoZ 2017) as well as improve the resilience of the area to climate change.

232. **Woodland structure and biomass in abandoned fallows and areas affected by fuelwood harvesting can fully recover over 20–30 years, through passive restoration alone (Kalaba et al. 2013; Williams et al. 2008).** This is because the main regeneration strategy of miombo species is through coppice regrowth and root suckers, meaning vegetation can recover passively where sufficient stumps and root stock remain (Strang 1974). Passive recovery can be brought about through adoption of sustainable rangeland management and the sustainable harvesting of resources, particularly wood.

233. **In communal lands, access to grazing and firewood is relatively unrestricted.** Sustainable practices would require active management on the basis of regular assessments of resource status and following best practice guidelines (Liniger and Studer 2019). This would entail reducing livestock numbers and using rational grazing, reducing burning practices, and reducing the rate of harvesting of woody resources in rangeland areas. Initially, these pressures would need to be greatly reduced until forage and woody stocks recover to maximally productive levels.

6.2.3 Protection of key ecological infrastructure

234. **As shown in Chapter 5, the value of ecosystem services varies across the landscape.** Areas that are of particular importance in terms of regulating services are recognized as 'ecological infrastructure' since they often complement or save on grey infrastructure in economic production. These tend to include[20]

- *Higher-rainfall areas*, where healthy vegetation cover is important for mediating rainfall infiltration;
- *Steeper areas,* where natural vegetation cover is important for preventing erosion;
- *Riparian areas*, where natural vegetation cover is particularly important for preventing anthropogenically generated sediments and nutrients from entering river systems; and
- *Wetlands*, which contribute to flood attenuation as well as sediment trapping and nutrient uptake.

[20] Note that areas important for carbon sequestration and storage are not typically referred to as ecological infrastructure. Ecological infrastructure is more commonly associated with hydrologically linked services. In the study area, all the interventions address the restoration and retention of carbon in the landscape, and the potential for this is an important driver for rangeland conservation through PES.

6.2.3.1 High-rainfall areas

235. **High-rainfall areas are often protected as water catchment areas.** In the study area, some protection is afforded by the Nyanga National Park, but much of the higher rainfall areas is already heavily transformed.

6.2.3.2 Vegetation on steep slopes

236. **Steeper areas tend to be less transformed by agriculture but are increasingly becoming affected by woody vegetation removal.** Landowners need to be educated on this, and areas on steep slopes may need to be protected through legislation.

6.2.3.3 Riparian buffers

237. **Riparian vegetation plays an important role in trapping sediment in runoff and reducing channel erosion (Márquez et al. 2017; Tanaka et al. 2016; Wenger 1999) and also retains a significant proportion of the nutrient runoff from agricultural landscapes (Anbumozhi, Radhakrishnan, and Yamaji 2005).** Indeed, studies have shown that a riparian buffer width of 30 m is sufficient to trap sediments under most circumstances (Wenger 1999).

238. **Riparian buffers also have notable biodiversity benefits.** They help maintain aquatic habitats by regulating stream temperature and providing inputs to woody debris and other organic matter beneficial to aquatic organisms (Wenger 1999). They can also help serve as movement corridors for terrestrial wildlife, thus enhancing landscape connectivity.

239. **In theory, cultivation within 30 m of streams is prohibited in Zimbabwe under the Stream Bank Protection Act of 1952, though this prohibition is commonly ignored (Dube et al. 2018; Zinhiva, Murwendo, and Rusinga 2017;).** Satellite imagery reveals that this is the case in the study area too, with riparian buffer areas in parts of the catchment reduced to less than 30 m or removed altogether (see Figure 27 for an example).

240. **Where riparian buffers have been degraded by deforestation, livestock watering, and cultivation, they can be allowed to recover slowly through protection, or recovery can be enhanced through assisted natural regeneration (ANR).** ANR seeks to accelerate natural successional processes through removing or reducing barriers to regeneration, such as controlling weeds and/or invasive species, protecting

FIGURE 27: AN EXAMPLE OF A HEAVILY CULTIVATED RIPARIAN AREA ALONG THE MAZOWE RIVER NEAR GLENDALE, WITH MINIMAL RIPARIAN VEGETATION REMAINING

Source: Google Earth imagery.

from livestock and fire, and other measures (Shono, Cadaweng, and Durst 2007).

241. **Restoration of degraded ecological infrastructure would also contribute to the country's ambitious LDN target of reforesting 6.4 million ha of deforested land (GoZ 2017).**

6.2.3.4 Wetlands

242. **Wetlands are particularly valuable elements of the landscape.** Their actual roles vary considerably, based on how they are formed and how they function. In general, they are highly productive and have high value in terms of provisioning services, ranging from harvesting of foods and raw materials to a source of dry-season grazing. These same characteristics often make them important refugia for biodiversity. Because of their vegetation and storage capacity, wetlands also play a major role in attenuating flows (quickflow) through the landscape. Their capacity to slow water flows, combined with their high productivity, gives them a high capacity for removing anthropogenic sediments and nutrients before they enter rivers. The characteristics of wetlands that enable them to deliver these services also make them highly vulnerable to degradation and loss through overgrazing and cultivation. When this leads to development of erosion gullies and consequent desiccation, the degradation is particularly difficult to reverse.

6.3 Potential measures to bring about sustainable practices

243. **Achieving the recovery and sustainable use of rangeland areas would require motivating communities to establish respected systems of governance that can control the use of resources to the benefit of the community as a whole.** From an individual perspective, this would come at an opportunity cost, at least in the short term. Interventions to achieve sustainable resources management therefore need to (a) generate benefits greater than those opportunity costs, (b) address the demand for those resources, or preferably both. Addressing demand will help reduce opportunity costs. These are discussed further below.

6.3.1 Providing positive incentives

244. **Creating the incentive for communities to control their own use (option a above) could be achieved through a combination of the provision of secure property rights[21] and reliable stock assessments and management advice and could be further incentivized through PES schemes and/or provisions to set up communal conservancies to generate income from wildlife-based joint venture partners.** Secure property rights (whether communal or individual) and ecosystem monitoring are both prerequisites for the successful establishment of both PES schemes and joint venture business arrangements.

6.3.1.1 Payments for ecosystem services

245. **PES schemes involve making payments to ecosystem owners/managers in return for the delivery of ecosystem services or a proxy management regime.** The payments are conditional on service delivery, and the metrics and rewards for delivery are clear and transparent.

246. **Participation is voluntary.** Communities are ideally invited to organize themselves and bid to become part of the scheme through persuasive marketing rather than being coerced to participate. Payment terms are negotiated and need to exceed the costs incurred by the service providers, to be viable. These costs could include reduced livestock benefits and reduced access to harvested resources as well as the protection of the designated area from use by others. It could also include labor time in ANR and desisting from expansion of fields into unploughed areas.

6.3.1.2 Riparian stewardship/PES

247. **Protecting riparian areas can be difficult because of their linear nature.** However, engaging communities

[21] Note that, in the context of rangelands, by assigning secure property rights we do not mean subdividing or fencing common grazing areas. Large contiguous grazing areas are increasingly necessary in the face of climate change, as they provide opportunity to move in response to local conditions. Rather it means that access and use of rangeland areas is limited and controlled, as opposed to uncontrolled open access.

to do this under a stewardship program can provide a practical solution. While it is untested in rural areas, there is successful precedent for such a program in urban or peri-urban areas—the Mlalakua River Restoration Project in Dar es Salaam and the Sihlanzimvelo Stream Cleaning Project in Durban. In these programs, sections of rivers or streams are maintained by cooperatives which are responsible for removing alien vegetation, rubble, and any solid waste blocking the free flow of water down the stream or river. They are also responsible for maintaining the grass and other vegetation along the banks of the waterway. Both projects were initiated with donor funding (EUR 400,000 in Dar es Salaam and US$3 million in Durban). The programs have provided employment for hundreds of people. It would not be difficult to adapt the idea for rural riparian areas.

6.3.1.3 Communal wildlife conservancies and joint venture partnerships

248. **Another option that will help recover and maintain healthy rangelands is to switch to wildlife-based land use.** This is potentially feasible where sizeable tracts of the landscape remain untransformed and where agriculture is marginal. As noted in Zimbabwe's Biodiversity Economy report (Turpie et al. 2022), there is potential to expand the development of wildlife-based land uses outside state protected areas, particularly in communal areas and private land, and potentially in state-owned fast-track resettlement areas, through a new community conservancy model similar to Namibia's community-based natural resources management (CBNRM) program. The main barriers to this are land tenure, lack of rights over wildlife, and start-up costs, particularly since wildlife has largely been depleted in these areas. While CAMPFIRE has gone some way toward increasing community involvement and benefits from conservation, this has been limited by the program's institutional setup under the rural district councils. Allowing communities to form true community-owned conservancies would increase the attractiveness of wildlife-based land use. Community conservancies would provide opportunities for joint-venture enterprises and agreements to be made directly between private investors and communities. Community conservancies would also contribute to biodiversity conservation and maintaining of wildlife populations in the catchment as a whole.

249. **Current opportunities for expanding wildlife-based land uses in the Mazowe Catchment are relatively limited due to the highly transformed nature of most of the catchment, particularly in communal areas.** Currently, wildlife-based land uses in communal land are mainly in the far northeast of the catchment, where sizeable areas of natural habitat remain in an area of rugged mountainous terrain which supports populations of elephant and other wildlife (Amon 2011; Muchapondwa, Carlsson, and Köhlin 2008). Due to topography and climatic conditions, this is also one of the most marginal parts of the catchment for agriculture. The selected area encompasses the existing Nyatana Game Reserve[22] and adjoining WMAs of Karamba, Chimukoko, and Mukota A. Nyatana is around 75,000 ha and is jointly managed by the three CAMPFIRE districts of Mudzi, Rushinga, and Uzumba-Maramba-Pfungwe. Elephant trophy hunting has been important in the past, through joint venture partnerships between the Nyatana Joint Management Trust and private safari operators (Amon 2011). However, there is little up-to-date information on the status of this area, though there are indications that it is experiencing degradation by poaching, deforestation, mining, and other activities.[23] A news article from 2021 also stated no hunting partner was currently operating in the area.[24]

250. **Given that its current tourism potential is not being realized, there are opportunities to improve and expand community conservation areas and associated tourism activities in the northeast of the catchment.** Satellite imagery, land cover, and aboveground carbon biomass suggests that there is also an area with potential for conservation extending beyond the boundaries of Nyatana Game Reserve. Wildlife tourism could be a particularly valuable alternative livelihood strategy here, given that this is the driest and hottest part of the Mazowe Catchment with conditions poorly suited to rainfed

[22] Unfortunately, Nyatana Game Reserve is not included in the World Database on Protected Areas (WDPA) layer of protected areas in Zimbabwe (UNEP-WCMC 2022). A rough map of its boundaries is shown in Amon (2011).
[23] https://allafrica.com/stories/201509100267.html.
[24] https://www.herald.co.zw/jumbo-attacks-on-the-rise/.

agriculture. However, significant investments in tourist infrastructure such as roads and lodges, improved protection of the area, marketing, and other measures would be needed to create an attractive tourism product. These investments would provide opportunities for employment of community members as game scouts, guides, or lodge staff.

6.3.2 Managing resource demands

251. **Demand for scarce resources can be addressed in several ways, usually through regulation and/or pricing, or the introduction of cheaper or better alternatives.** For grazing, this can be achieved through grazing taxes or fees or tradeable grazing rights.[25] For firewood, this can be achieved by introducing cooking technologies that require less firewood or by introducing alternative energy sources. Production of charcoal is illegal in Zimbabwe and can also be controlled through enforcement of the law. These options are discussed in more detail below.

6.3.2.1 Grazing taxes and rights

252. **Taxes and charges are among the most effective instruments for reducing environmental damages.** While they are also useful for raising revenues, they are understandably unpopular and tend to be used only where it can be shown that they do not have retrogressive effects. Taxes, for example, can be justified to reduce carbon emissions, which pose serious threats to humanity. Charges can be justified where these are used to pay for the management of communal areas.

253. **Tradeable grazing rights can further strengthen the control of grazing pressure within a communally managed grazing system.** This is a cap-and-trade arrangement, where the number of grazing permits is capped according to grazing capacity and production objectives (traditional wealth systems under open access tend to be at full capacity, commercial production systems focusing on income typically optimized at half capacity). Permits are freely tradeable.

6.3.2.2 Replacing traditional functions

254. **Many households keep cattle to fulfil one or more roles such as a form of banking (converting cattle to cash when required) or payment (for example, for bride price) or to provide draught power, manure, and milk and for status.** While small herds will likely remain important to most farmers because of their integral relationship to crop farming, herd size might be reduced in the presence of easier access to cash or banking and cheaper credit.

6.3.2.3 Improved cookstoves

255. **Improved cookstoves can reduce fuelwood consumption through more efficient combustion, with fuel savings of up to 60 percent improvement over the traditional three stone stove (Urmee and Gyamfi 2014).** Reductions in carbon and particulate matter emissions also mean improved cookstoves can bring significant health benefits (Ezzati, Mbinda, and Kammen 2000). However, the success of this strategy is varied (Honkalaskar, Bhandarkar, and Sohoni 2013; Jeuland and Pattanayak 2012). Adoption of improved cookstoves in Zimbabwe remains limited, with many programs having collapsed soon after the termination of donor funding (Makonese, Chikowore, and Annegarn 2011). Barriers to sustained adoption include the costs of the stoves, inappropriate technologies, and lack of community training and participation in stove design (Roden et al. 2009; Urmee and Gyamfi 2014). Designs need to include consideration of cultural preferences, convenience, and versatility relative to traditional cooking methods (Makonese, Chikowore, and Annegarn 2011). If these issues can be addressed, there is potential for meaningful adoption of improved cookstove technology, as demonstrated by the relative success of the well-designed *Tsotso* stove in Zimbabwe in the 1980s (Makonese, Chikowore, and Annegarn 2011; Urmee and Gyamfi 2014). More recently, the United Nations Children's Fund (UNICEF) reported that *Tsotso* stoves were rolled out to almost 4000 households in Hurungwe, reducing fuelwood consumption by up to 39 percent.[26]

[25] Growing feed has been suggested as an option but is likely to have rebound effects (supporting more rather than fewer livestock).
[26] https://blogs.unicef.org/blog/improved-cookstoves-cut-illness-not-trees/.

6.3.2.4 Alternative energy - biogas digesters

256. **Biogas digesters have also been introduced in Zimbabwe as an alternative energy source, with potential to make a significant contribution to reducing household fuelwood use (Kaifa and Parawira 2019; Mshandete and Parawira 2009).** The government has established a National Biomass Programme in partnership with donors and nongovernmental organizations and embarked on the construction of biogas digesters at rural schools and hospitals through the Rural Electrification Agency, including a commercial biogas plant in Kotwa in the northeast of the Mazowe Catchment.[27] Cow dung is used in around 90 percent of plants in Zimbabwe, with the remainder using human sewage or pig manure (Kaifa and Parawira 2019). While there could be some competition with the need for manure in agriculture, the leftover digestate can itself be used as a fertilizer (Kaifa and Parawira 2019).

257. **However, adoption of biogas digesters remains low, due in large part to the costs of installing biogas digesters and insufficient awareness of the technology.** Furthermore, poor design, insufficient fuel stock, poor maintenance, and other challenges hinder the long-term success of installed digesters. For example, one Zimbabwean study found that only 11 percent of surveyed biomass digesters were still functional (Kajau and Madyira 2019). In this study, appropriately designed, low-cost improved cookstoves are recommended as a more realistic intervention for widespread household adoption, as costs and technical expertise requirements are much lower than for biogas digesters.

6.4 Scenario analysis

6.4.1 *Business as usual*

258. **In the scenario analysis, a full-scale intervention scenario is compared with a BAU scenario.** The impact of a BAU trajectory on ecosystem service values was modelled by the extrapolation of the natural habitat degradation trends (as measured by NDVI) that were estimated in the assessment of ecological trends in the Mazowe Catchment. This projection was performed for a 25-year period, to match the period over which restoration costs and benefits were modelled. In projecting future degradation, it was thus assumed that future rates of degradation would be comparable to the annual rate of degradation observed between 2001 and 2018 through the NDVI trend analysis.

6.4.2 *Full-scale intervention scenario*

259. **The sustainable land use scenario involved modeling the effects of a range of interventions to improve land and resource management practices in the study area (Table 13).** Based on the rationale

TABLE 13: SUMMARY OF PROPOSED LANDSCAPE MANAGEMENT INTERVENTIONS AND THEIR RELATIVE EXTENTS AND COSTS

Sustainable land uses	Potential extent	Supporting interventions	Initial cost (US$)	Ongoing costs (US$/year)
CSA practices	550,527 ha, 175,000 households (50%)	Assistance with setup, long-term extension services	120/hh	20/hh
Sustainable rangeland management	735,586 ha	PES services	10/ha	Average 18.8/ha
	515,000 households	Rollout of subsidized efficient stove technologies linked to PES scheme	15/hh	—
Community conservancies	53,000 ha	Community conservancy development, capacity building, and joint ventures	1.50/ha	0.40/ha
Riparian buffers	9,166 km	Stewardship payments/monitoring and enforcement	1,200/km	180/km

Note: hh = Household.

[27] https://rea.co.zw/biogas_energy/.

provided in the previous sections, the assumptions for the scenario are outlined below.

6.4.2.1 Climate-smart agriculture

260. **CSA is supported in communal lands and resettlement areas, through provision of extension services, equipment, and supplementary labor.** These areas generally have more serious land degradation and soil erosion issues and lower crop yields than commercial farmland. It was assumed that 50 percent of farmers would adopt CSA practices, and that their crop yields would increase by 50 percent based on the yield gains reported elsewhere (IAPRI and FAO 2021; Marongwe et al. 2011; World Bank 2019; ZCATF 2009).

261. **Establishment costs for CSA include the costs of extension and training of communal farmers, additional costs of equipment and inputs required for CSA (for example, planting equipment to reduce labor burdens), and labor and input costs associated with upgrading erosion control structures or small-scale water harvesting infrastructure.** Based on the literature, particularly the investment volumes noted in the Zimbabwe CSAIP, establishment costs in the first year were estimated to be US$120 per household (Dallimer et al. 2018;; World Bank 2019). Once they are established and with suitable equipment, most of the CSA practices should be largely self-sustaining. Additionally, practices like CA can often become less labor-intensive than conventional practices with the right equipment (Liniger et al. 2011; ZCATF 2009). Hence, maintenance costs are limited to the additional labor associated with the improved maintenance of soil erosion control structures, management of water harvesting infrastructure, and ongoing extension support, as well as some incentives for farmers to not expand their fields. Ongoing costs for CSA were thus estimated to be US$20 per household.

6.4.2.2 Recovery and sustainable use of rangelands and harvested resources

262. **Degraded habitats throughout the catchment are restored to a more natural and productive state through improved rangeland management and resource harvesting controls.** This is incentivized through provision of support for the formation of community conservancies and through the implementation of a payments for ecosystem services scheme.

263. **The cost of setting up such a scheme was estimated at US$10 per ha (Bond et al. 2010).** Assuming that delivery of the objectives is achieved, the annual payment was estimated to be in the region of US$18.8 per ha. The precise level of payment at the sub-catchment level varied, based on the current levels of wood extraction and values of agriculture.

6.4.2.3 Conservancies

264. **Opportunities for community conservation development were identified in the northeast of the catchment, where conditions for agriculture are marginal and suitable natural habitat and wildlife populations remain.** The initial costs of improving and expanding community conservation initiatives in this area would include the transaction costs needed to designate specific areas of the catchment as community conservation areas through public participation processes and negotiation. This is estimated to be around US$1.50 per ha (based on Wise et al. 2012). The communities are assumed to cover the costs of management out of the revenues (rent and royalty) received from joint-venture partners. Nevertheless, ongoing support would be required, which based on figures from Namibia, could amount to some US$0.4 per ha per year (MEFT/NASCO 2021).

6.4.2.4 Riparian buffers

265. **The legal protection of the 30 m riparian buffer zone is enforced along all streams and rivers throughout the study area.** This involves the cessation of existing cultivation and mining activities within these areas. Degraded and cultivated areas are allowed to regenerate to riparian woodland vegetation.

266. **It was assumed that some riparian buffer areas would recover passively once cultivation was stopped while others would require ANR, depending on the amount of natural vegetation remaining.** It was estimated that a mix of passive restoration and ANR would have an establishment

cost of around US$200 per ha in the first year or US$1,200 per km of river (Brancalion et al. 2019; Dugan 2011). Costs would gradually decline over the next two years to reach a long-term maintenance cost of US$30 per ha per year or US$180 per km of river. This is based largely on the estimated costs of monitoring and enforcement to ensure riparian buffers are being left to recover, drawing on estimates of the cost of guarding and patrolling nature reserves (Chardonnet 2019; Frazee et al. 2003; James, Green, and Paine 1999).

6.4.3 Impacts on ecosystem services

6.4.3.1 Crop production

267. **About 94,000 ha of cultivation was converted to natural vegetation through the restoration of riparian buffers, representing 6.9 percent of the current extent of cultivation in the study area.** Despite this, overall crop production with implementation of CSA was estimated to increase by 7.2 percent (Table 14). Crop production in communal and resettlement areas, where the interventions were focused, was estimated to increase by 17.9 percent. Overall, it was predicted that the value of crop production in the study area would increase by US$21.2 million, with production from communal and resettlement areas specifically increasing by US$32.8 million per year.

268. **The highest increases in production are associated with sub-catchments with large areas of farmland within communal and resettlement areas, particularly the Ruya sub-catchment (#4) in the far north of the study area and the Nyadiri sub-catchment (#7), which includes heavily cultivated communal areas around Mutoko (Figure 28).**

6.4.3.2 Harvested wild resources

269. **Changes in the use of harvested wild resources with full restoration of the study area were generally estimated to be fairly modest.** Due to the way harvested resource use is modelled, increased use in the restored scenario would only occur in areas where current demand exceeds supply in the BAU scenario. By increasing natural resource stocks through restoration of habitats, the supply constraint in some of these areas can be overcome in the restored scenario.

270. **Overall, the value of the five harvested resources considered (wood, thatching grass, wild plant foods, mushrooms, and honey) was estimated to increase by US$3.54 million per year in a fully restored catchment, with a total value of US$107.6 million per year compared to the BAU value of US$104.0 million per year.** Changes in the total value of wild resource harvesting at the sub-catchment level are shown in Figure 29. The greatest changes in value (dark green) are associated with the Upper Mazowe (#17) and Nyangui sub-catchments (#15), both located in the southwest of the study area. Restoration of both these sub-catchments increases natural resource stocks significantly relative to BAU. They also have large rural populations and thus high demand for resources.

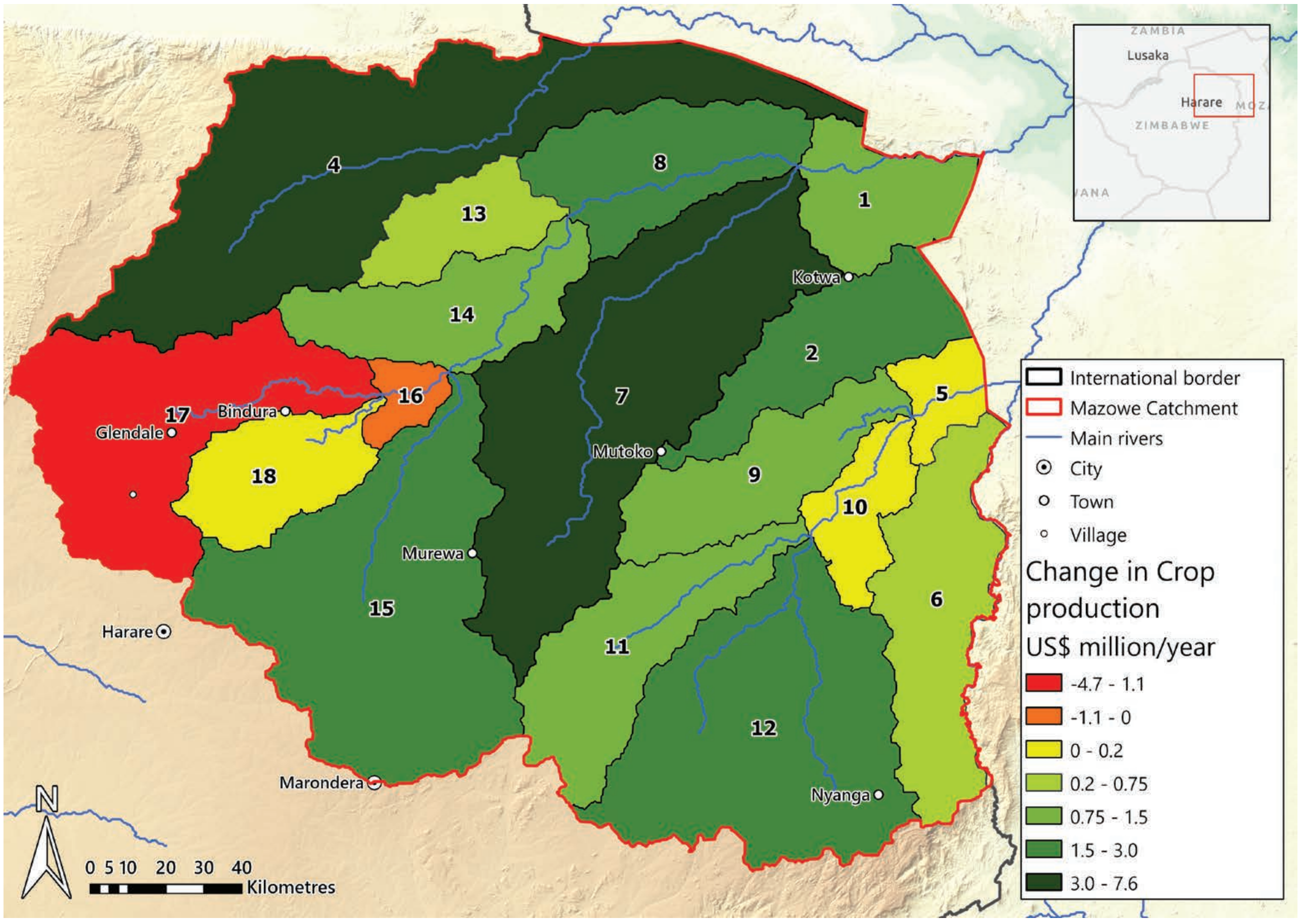
6.4.3.3 Carbon storage

271. **Carbon storage in the restored scenario is increased by the restoration of degraded natural habitats and conversion of cultivation in riparian zones to riparian woodland, as well as a smaller addition from the increased uptake of soil carbon by areas under conservation tillage.** It was estimated that full restoration would increase carbon storage by

TABLE 14: CROP PRODUCTION WITH FULL RESTORATION OF THE STUDY AREA AND CHANGES RELATIVE TO THE BASELINE SITUATION

Farming type	Production (t)	Change in production (t)	% change	Production change (US$ million/year)
Communal/resettlement	411,361	58,473	17.9	32.8
Commercial	239,094	−14,365	−7.2	−11.6
All	**650,454**	**43,838**	**7.2**	**21.2**

FIGURE 28: CHANGES IN THE GROSS MARGIN OF CROP PRODUCTION AT THE SUB-CATCHMENT LEVEL WITH FULL RESTORATION OF THE STUDY AREA (SUB-CATCHMENTS NUMBERED ON MAP)

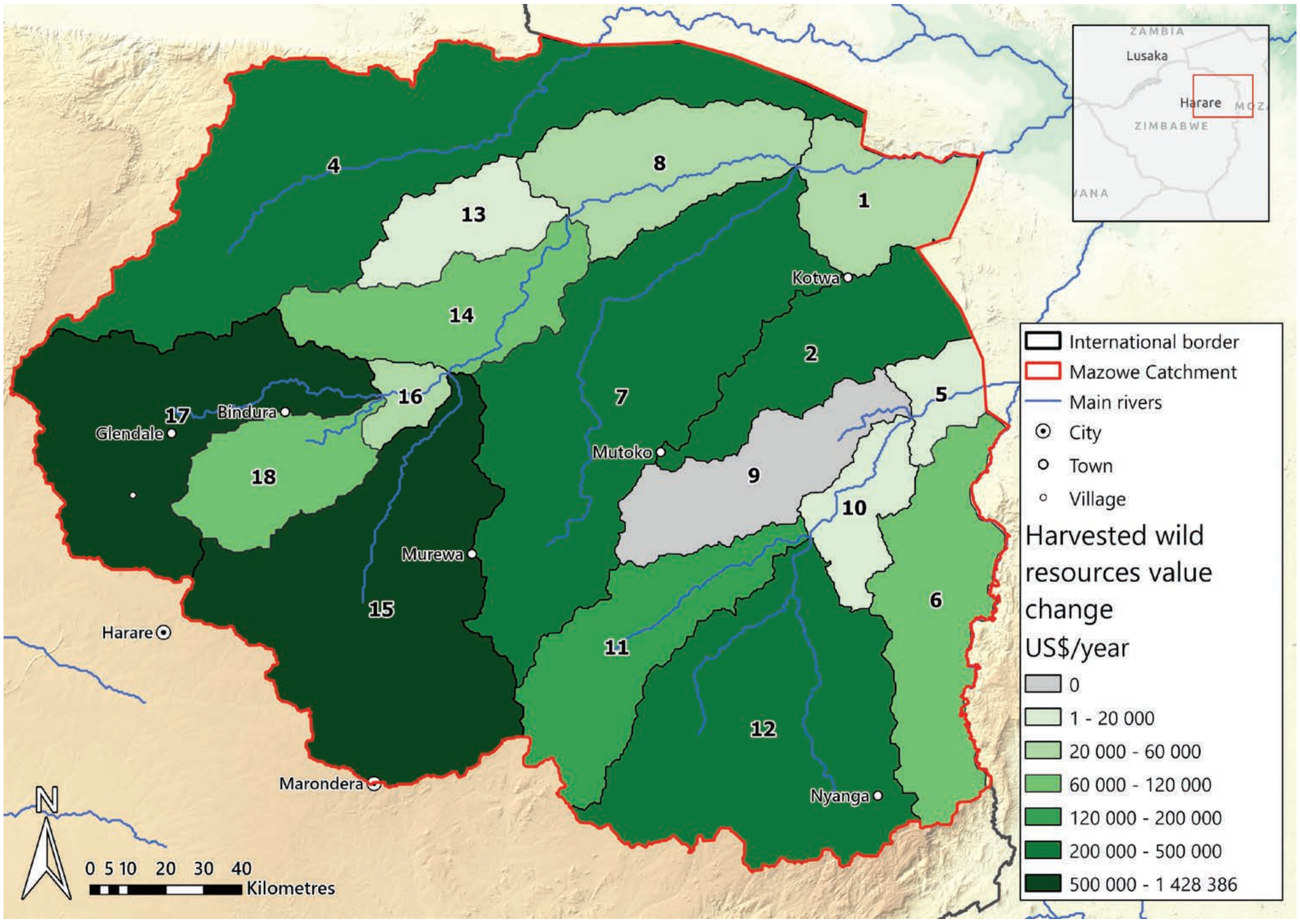


Source: Original calculations from this study.

16 percent relative to a BAU scenario. The current value of avoided climate-change related losses for the world rises to US$1.46 billion per year, a US$225 million increase from the baseline landscape. By 2047 (in 25 years), the value of avoided climate-change related losses would increase to US$2.58 billion per year, based on the values projected by World Bank (2017). Using a relatively low estimate of US$4.5 per tCO_2e (Ecosystem Marketplace 2021), full restoration of the study area could generate a total of US$325.5 million in carbon credits for Zimbabwe at current prices. Given that studies have shown full recovery of biomass in miombo ecosystems takes around 25 years (Kalaba et al. 2013; Williams et al. 2008), the annual value of carbon credits generated by the recovery of natural vegetation in the study area would be around US$13.5 million per year. If it is assumed that all households living within 1 km of restored areas are potential beneficiaries of carbon credit sales, then annual benefits per household could be around US$25 per year. Notably, the value that could be generated through carbon credit sales would increase significantly with likely future increases in carbon credit pricing.

272. **The total change in carbon storage with full restoration of the study area is shown at the sub-catchment level in Figure 30.** This reflects the area of degraded habitat being restored within each sub-catchment, as well as the area of riparian cultivation being converted to riparian buffers. The largest changes are in the Ruya sub-catchment (#4) in the far north of the study area and the Upper Mazowe sub-catchment (#17) in the southwest.

FIGURE 29: CHANGES IN THE ANNUAL VALUE OF WILD RESOURCE HARVESTING AT THE SUB-CATCHMENT LEVEL WITH FULL RESTORATION OF THE STUDY AREA, RELATIVE TO BAU (SUB-CATCHMENTS NUMBERED ON MAP)



Source: Original calculations from this study.

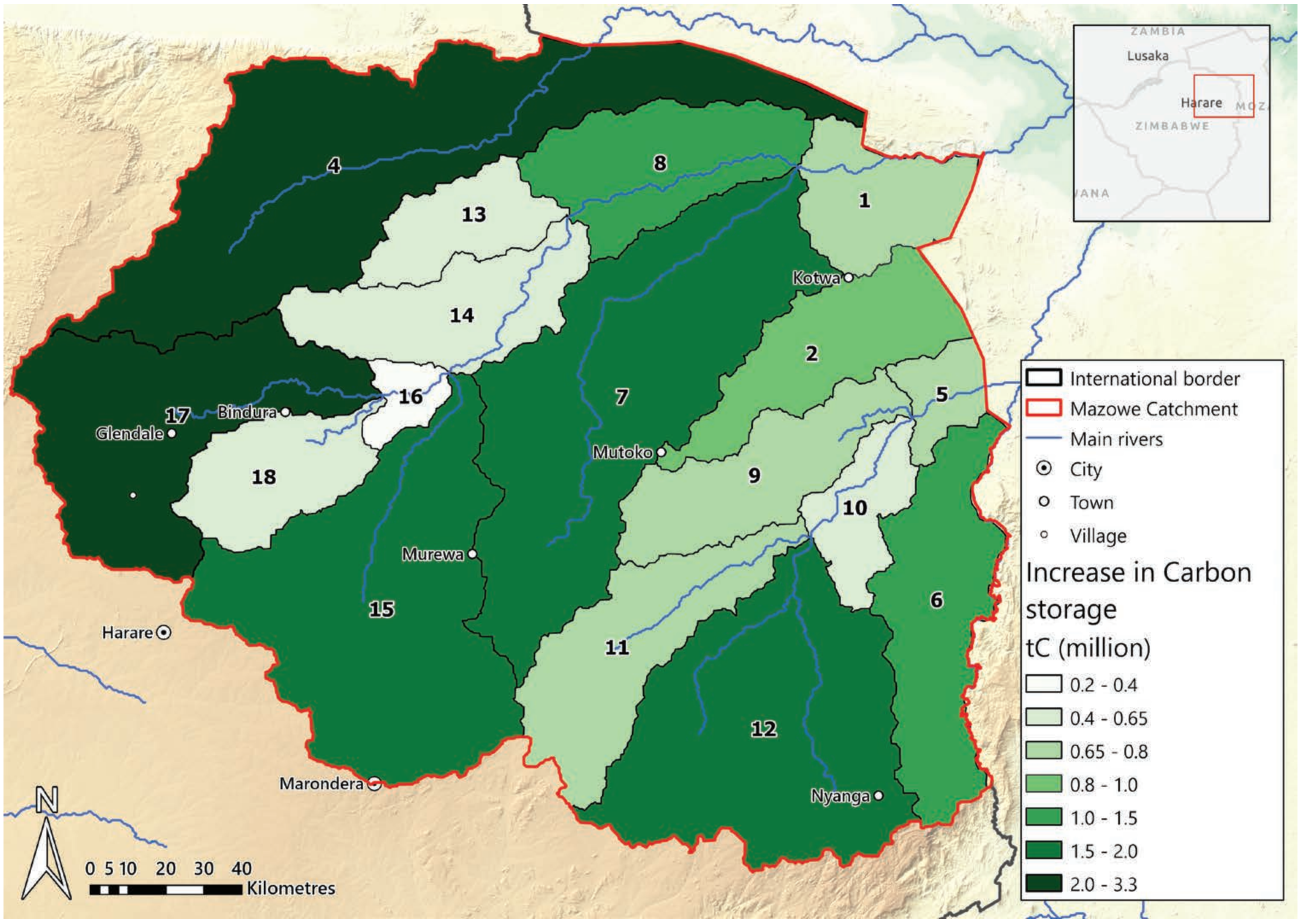
6.4.3.4 Flow regulation

273. **Groundwater recharge is predicted to increase by 99.2 Mm³ per year or 4.5 percent relative to the BAU scenario.** CSA interventions significantly reduce runoff and evapotranspiration from cultivated areas while increasing infiltration, as found elsewhere (Marongwe et al. 2011; Nyamadzawo et al. 2012; World Bank 2019). This makes a large contribution to the overall increase in net recharge at catchment scale. In contrast, the restoration of degraded habitats decreases net recharge in some cases, due to the increased evapotranspiration losses. These differences are evident in the results summarized by sub-catchments (Figure 31). The largest increases in recharge are seen in Nyangui sub-catchment (#15) near Murewa, Nyadiri sub-catchment (#7) near Mutoko, and Upper Rwenya sub-catchment (#12) northwest of Nyanga, all of which are characterized by dense communal farmland.

6.4.3.5 Erosion control and sediment retention

274. **Erosion would be reduced by 47.8 percent relative to BAU (from 34.1 to 17.8 tons per ha per year) and sediment export by 63.2 percent (from 3.1 to 1.1 tons per ha per year).** CSA interventions on farmland in communal and resettlement areas roughly halve erosion in these areas, with mean erosion declining from 69.2 to 36.8 tons per ha per year. The latter still exceeds the suggested soil erosion tolerance rates of 1–12 tons per ha per year (Roose 1996), suggesting that 50 percent adoption of CSA is not sufficient for totally addressing soil erosion issues from communal farmland.

FIGURE 30: INCREASE IN TOTAL CARBON STORAGE AT THE SUB-CATCHMENT LEVEL WITH FULL RESTORATION OF THE STUDY AREA, RELATIVE TO BAU (SUB-CATCHMENTS NUMBERED ON MAP)



Source: Original calculations from this study.

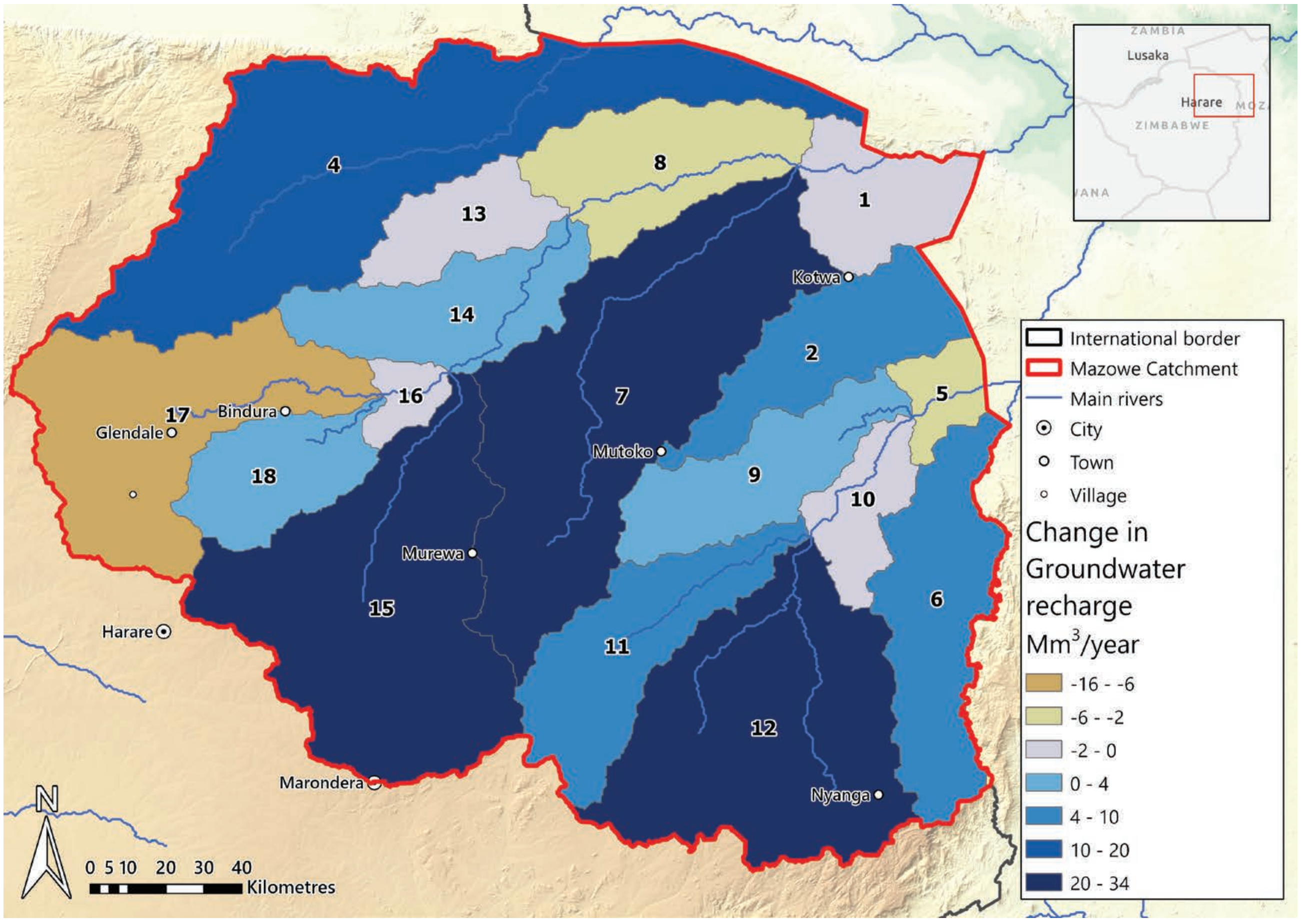
275. **In dam catchment areas, total sediment export is reduced by 61.7 percent, or 2.04 million tons relative to BAU.** This has an estimated cost saving of US$10.2 million per year. Notably, the reduction in sediment export from small-scale farmland accounts for over half of the overall sediment reduction in dam catchment areas. The overall reduction in sediment export to dams at the sub-catchment level is shown in Figure 32.

276. **The spatial patterns shown are closely tied to the number of dams in each sub-catchment, with avoided sediment export generally higher in the west of the study area.** The sub-catchments with the highest reduction in sediment export fall within the Upper-Mazowe around Glendale and Bindura (#17 and #18) as well as the Nyangui sub-catchment (#15). The southwest of the Mazowe Catchment has a high density of dams due to its location in a prime farming area, resulting in large reductions in sediment export to waterbodies with restoration of degraded natural habitats, conversion of riparian cultivation to woodland, and/or improved erosion control on small-scale farmland.

6.4.3.6 Tourism

277. **As noted earlier, opportunities for expanding nature-based tourism in the Mazowe Catchment seem fairly limited.** The main area where opportunities for growth were identified is in the far northeast of the catchment, where there is an opportunity to enhance and expand the Nyatana Game Reserve, which is currently not fulfilling its tourism potential. The potential value that could be generated with improvement of tourism facilities in this area was calculated from averaging the

FIGURE 31: CHANGES IN GROUNDWATER RECHARGE AT SUB-CATCHMENT SCALE WITH FULL RESTORATION OF THE STUDY AREA, RELATIVE TO BAU (SUB-CATCHMENTS NUMBERED ON MAP)



Source: Original calculations from this study.

tourism value per hectare of the well-established Umfurudzi Safari Area and the Muzarabani Wildnerness Area located just west of the Mazowe Catchment. The latter was selected as its rugged terrain is comparable to the proposed focal area in the northeast of the catchment.

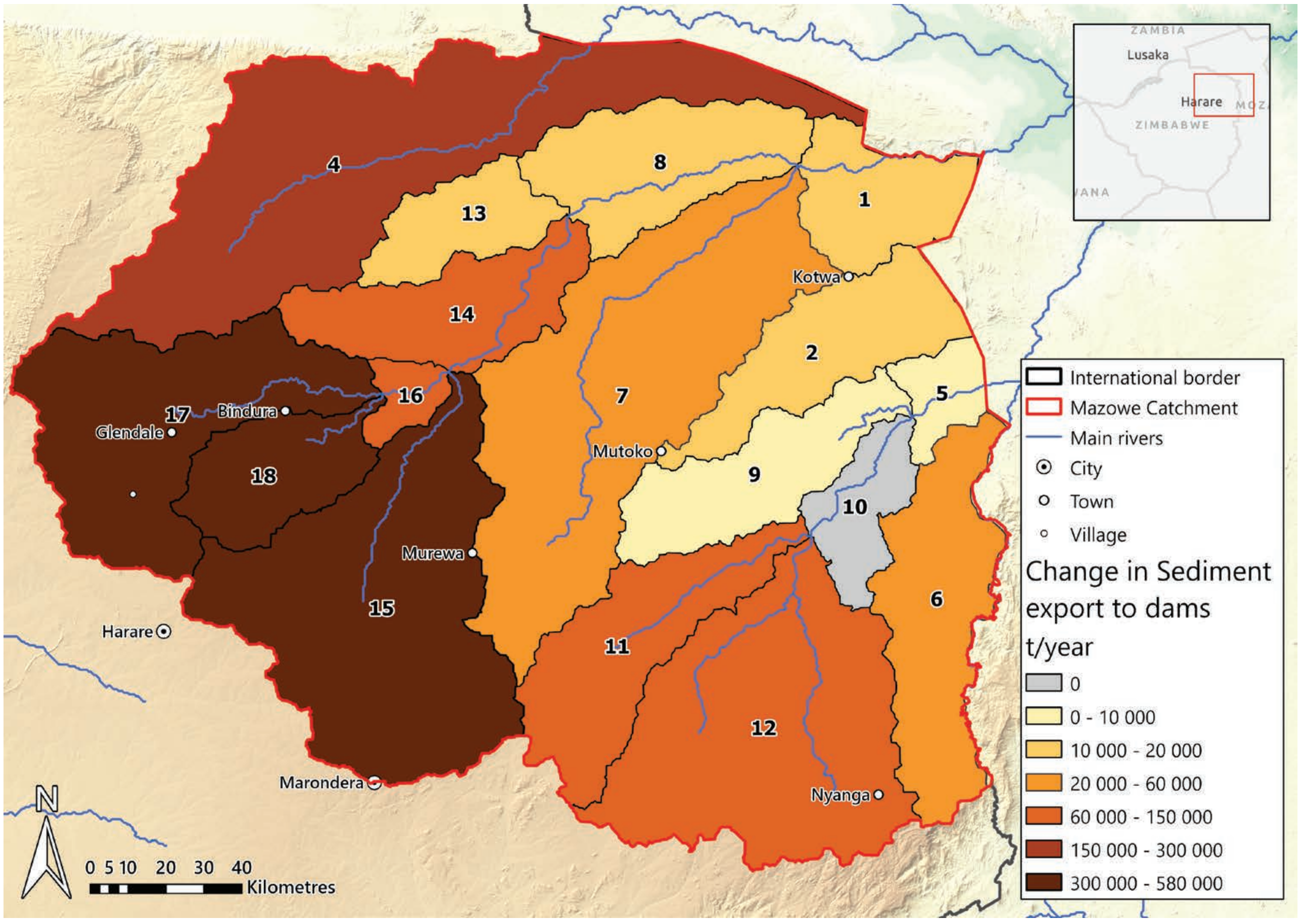
278. **Extrapolating from the tourism value per unit area of comparable areas, it was estimated that improvement and expansion of community conservation areas in the northeast of the catchment could generate around US$0.5–1 million per year of additional tourism value.** While this value is relatively modest, it could make a meaningful contribution to diversifying livelihoods in this area, as it encompasses the hottest and driest regions of the catchment where most conditions for rainfed agriculture are particularly marginal (agroecological region IV).

6.4.4 Cost-benefit analysis

279. **A high-level cost-benefit analysis was conducted to evaluate the potential of the proposed interventions to generate positive ROI in the form of enhanced ecosystem service delivery.** The analysis was performed at the sub-catchment level.

280. **Costs and benefits were converted to present value using a time horizon of 25 years and a social rate of discount of 4.56 percent.** Costs were assigned to the proposed interventions based on estimates from the literature for comparable interventions in Zimbabwe and the broader region where local estimates were scarce. These included both one-off establishment costs and ongoing maintenance costs. Benefits were assumed to be realized gradually over time for most of the services assessed. Crop production benefits from CSA began

FIGURE 32: AVOIDED SEDIMENT EXPORT TO DAMS AT THE SUB-CATCHMENT LEVEL WITH FULL RESTORATION OF THE STUDY AREA, RELATIVE TO THE BASELINE LANDSCAPE



Source: Original calculations from this study.

in year 2, plateauing from year 5 to 25 based on the assumption that it would take 5 years for the full benefit to be realized. For carbon and harvested resources, a linear increase in benefits was assumed, with benefits starting in year 2 and reaching their maximum value by year 25, based on studies of miombo woodland recovery after disturbance (Kalaba et al. 2013; Williams et al. 2008). The benefits of the hydrological regulating services (groundwater recharge and soil erosion control) were modelled using an initial sharper increase up to year 5, reflecting the spread of CSA. Hydrological benefits increased more gradually thereafter to reach their maximum value by year 20, due to the slower recovery of natural habitats.

281. **The results of the cost-benefit analysis demonstrate that well-implemented restoration and conservation interventions could produce benefits that outweigh their costs over the Mazowe Catchment as a whole (Table 15 and 16).** The NPV over 25 years is estimated to be US$288 million, with an ROI of 1.7. In other words, a US$1 investment in the interventions could generate US$1.70 of benefits. ROI exceeds 1 in all but 2 of 18 sub-catchments, reaching up to 3 (Table 15, Figure 33). Notably, six sub-catchments have an ROI of 2 or above, suggesting interventions would be most cost-effective in these parts of the study area.

282. **At the whole Mazowe catchment level, restoration of degraded habitats is estimated to cost $200.5 million over a 25-year period, whereas CSA implementation will cost $168.2 million.** Installation of riparian buffers will cost $41 million, while establishment of conservancy will cost $0.4 million. Changes in land management following adoption of CSA is estimated to generate the

TABLE 15: PRESENT VALUE (PV) COSTS AND BENEFITS AND ROI OF THE LANDSCAPE INTERVENTIONS FOR EACH SUB-CATCHMENT AND FOR MAZOWE CATCHMENT AS A WHOLE (US$, MILLIONS, 25 YEARS, 4.56 PERCENT)

Sub-catchment	Total PV costs (US$, millions)	Total PV benefits (US$, millions)	NPV (US$, millions)	ROI
1	10.6	23.9	13.3	2.3
2	27.1	56.0	28.9	2.1
4	77.2	118.1	40.9	1.5
5	2.8	8.2	5.5	3.0
6	13.8	24.4	10.6	1.8
7	64.6	154.6	90.0	2.4
8	21.7	31.9	10.3	1.5
9	15.1	22.5	7.4	1.5
10	5.4	8.6	3.2	1.6
11	15.9	31.5	15.6	2.0
12	35.3	55.0	19.7	1.6
13	6.2	11.1	4.9	1.8
14	13.3	23.1	9.8	1.7
15	47.2	117.7	70.5	2.5
16	4.1	−6.4	−10.5	−1.6
17	44.8	−2.4	−47.3	−0.1
18	17.0	32.0	15.1	1.9
Mazowe Catchment	**422.0**	**709.9**	**287.9**	**1.7**

largest ecosystem services benefits for the whole Mazowe catchment ($258.7 million), followed by revenue from carbon credits ($191.9 million), water recharge ($125 million), avoided sedimentation ($107.8 million). while tourism development yields the lowest benefit of $5.2 million (Appendix 7).

283. **At the subcatchment level, investment costs are primarily driven by the size of subcatchments, the extent of land degradation of the subcatchments, land cover types, and the type of sustainable land management investment relevant for a given subcatchment.** The cost of restoring degraded natural habitats range from $1.7 million for subcatchment 5 to $38.9 million for subcatchment 4, while the cost of implementing conservation agriculture ranges from $0.5 million for subcatchment 16 to $32.5 million for subcatchment 7 (Nyadire) noted for a preponderance of subsistence farmers growing maize, sunflower, millet, groundnuts, and vegetables. The cost of installing riparian buffers varies from $0.1 million for subcatchment 5 to $6.9 million for subcatchment 7.

284. **At the subcatchment level, ecosystem services benefits are primarily driven by positive changes in land resources management following CSA adoption, availability of water resources, presence of intact forests and wetlands, and presence of high biodiversity within the ecosystem.** These drivers are reflected in the location of the largest ecosystem services benefits: for CSA adoption, subcatchment 7 ($95 million); avoided dam costs, subcatchment 15 ($43.6 million); carbon revenues, subcatchment 4 ($32 million); harvested

TABLE 16: PRESENT VALUE OF COSTS AND BENEFITS OF LANDSCAPE INTERVENTIONS IN MAZOWE

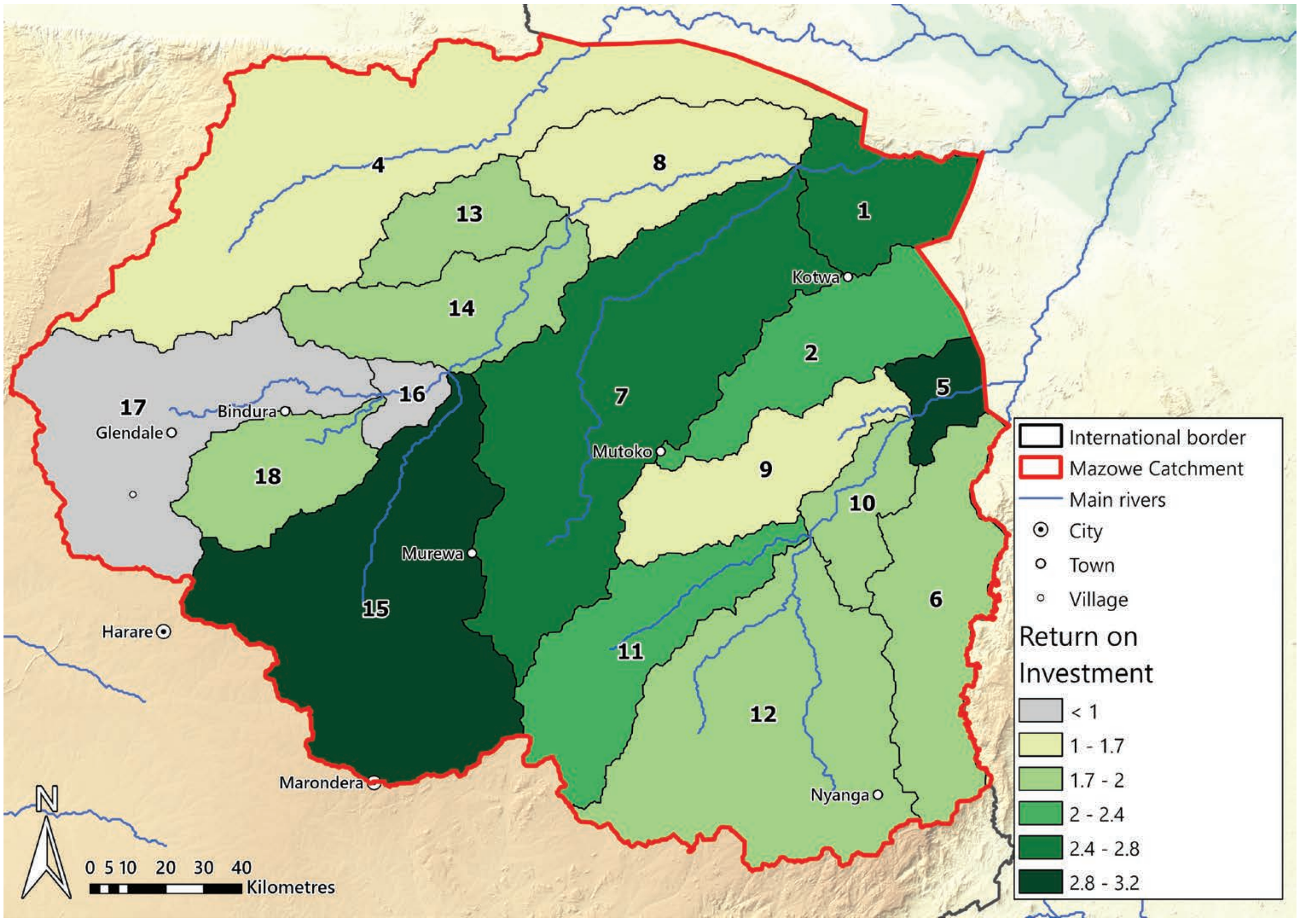
	$ million
Costs	**422.0**
Restore degraded natural habitats	200.5
Establish conservancies	0.8
Implement climate-smart agriculture (50% adoption)	179.7
Install riparian buffers	41.0
Benefits	**709.9**
Avoided dredging (sediment)	107.8
Avoided dam costs (change in recharge)	125.0
Gains in wild harvested resources	21.1
Changes in agricultural production	258.7
Revenue from carbon credits	191.9
Tourism gains	5.2
Net present value	287.9
B:C ratio / ROI	**1.7**
ROI for farmland interventions	**1.44**
ROI for natural land interventions	**1.86**

Duration is 25 years at 4.56% SDR.

wildlife resources, subcatchment 15 ($8.5 million); and tourism, subcatchment 1 ($4.3 million). Crop production results in losses in subcatchments 16 and 17, a phenomenon driven by overall losses in crop production due to the conversion of sizeable areas of high-yielding commercial farmland to riparian buffers.

285. **The negative ROI for cropland in subcatchments 16 and 17 is driven by overall losses in crop production due to the conversion of sizeable areas of high-yielding commercial farmland to riparian buffers.** The proposed interventions to improve agricultural production focused on lower-yielding communal and resettlement farmland areas, rather than commercial farmland. In all other subcatchments, these higher crop yields from communal and resettlement land resulted in an overall increase in crop production, despite the loss in farmland area within riparian buffer zones. This was not the case in subcatchments 16 and 17 because the extent and relative contribution of communal and resettlement areas to overall production here is small. As a result, any increases in production from communal and resettlement areas in these subcatchments was not enough to compensate for the losses in production resulting from the loss of higher-yielding commercial farmland along rivers. This is reflected in the negative ROIs for the two subcatchments. On the other hand, other subcatchments have positive ROIs ranging from 1.5 for subcatchment 8 to 3.1 for subcatchment 5.

FIGURE 33: ROI PER SUB-CATCHMENT WITH IMPLEMENTATION OF THE PROPOSED LANDSCAPE INTERVENTIONS (NUMBERS CORRESPOND WITH SUB-CATCHMENT NUMBERS USED IN TABLE 15)



Conclusions and Recommendations

286. **This study has shown that degradation in the Mazowe Catchment is increasing and that this will undermine not only biodiversity but the well-being of its inhabitants and of Zimbabweans in general.** It is clear that the environmental issues in the catchment need to be addressed. The study has also identified the priority areas for intervention. However, there are several information gaps that also need to be addressed in moving forward. Bearing this in mind, as well as the fact that similar issues are threatening livelihoods and the economy across the country, the overall recommendations from this study are as follows.

1) **Support the upscaling of CSA interventions in the Mazowe Catchment without delay since these have already been demonstrated to be effective.** There is an urgent need to implement Zimbabwe's CSAIP which aims to strengthen the country's agriculture sector's resilience to climate change. Priority investments recommended by the CSAIP include on-farm investments in improved crops, fertilizers, irrigation, and animal management to increase farmer production and build resilience; off-farm investments in storage, processing, marketing, and research & development to increase the agricultural value chain's productivity and efficiency; and cross-cutting investments in land reform and water management to help the country realize its full agricultural potential. These investments should be backed up by strengthening the policy and regulatory environment for CSA and building the capacity of extension agents, farmers and other stakeholders through training and resources they need to adopt climate-smart practices. Grain loss account for about 25–30% of their crop due to high moisture, pest damage, fungal or bacterial infections, and rodent damage. Integrated Pest Management (IPM), an approach that utilizes various pest control methods, including biological, cultural, physical, and chemical controls, to manage pest populations effectively and economically, is crucial for ensuring the success of Climate Smart Agriculture (CSA) interventions in Zimbabwe. By implementing IPM, farmers, can effectively manage pests while minimizing risks to the environment and human health, promoting ecological balance, and ensuring the long-term productivity and sustainability of agricultural landscapes.

2) **Enforce riparian protection.** Government should act to enforce the already-existing laws prohibiting use of the riparian zone. Riparian protection is critical to landscape health and to the persistence of biodiversity across the landscape. To enforce riparian protection, first there is a need to develop a riparian restoration plan to identify areas that needs ANR, those that can recover naturally, as well as the threats and drivers of degradation. A riparian restoration plan could also inform REDD financing opportunities. Second, develop the riparian zone as a resource to conserve biodiversity and increase tangible benefits to farmers. Third, there is a need to work with farmers and communities to develop local-level solutions and ownership. As farming is a key driver of riparian loss, it is important to consider how riparian zones could be part of the overall farm management. This should include protection from instream mining activities as well as from agriculture and wood harvesting in the riparian zone.

3) **Enable conservancy establishment.** Zimbabwe has a comparative advantage in terms of its wildlife heritage and parts of the study area (as well as many other areas in Zimbabwe) still hold the potential for wildlife-based land use. The government needs to amend its policies and legislation to support the establishment of communal conservancies with land and resource rights that allow for commercially viable joint venture conservation-based business arrangements. Increasing environmental management problems such as land-degradation, forest fires, water pollution and wildlife poaching suggest considerable scope for further decentralization within the new devolution thrust of the new constitution, to improve resource allocation and decision-making making at lower levels of Government

to strengthen stakeholder and community participation in natural resources management in Zimbabwe.

4) **Undertake strategic environmental assessments to inform proactive planning.** Proper spatial planning is required to accommodate conflicting activities such as agriculture, mining, wildlife-based land uses, and the provision of ecosystem services to society as a whole. It is recommended that the government undertake detailed strategic environmental assessments for these different activities, to plan where they should and should not be allowed to take place.

5) **Improve and enforce environmental safeguards.** Some of the threats to the study area, such as mining, are difficult to address because of a combination of easy access, the promise of quick returns, and the lack of enforcement of environmental standards that would make the operations more costly. Such activities need to be closely regulated and need to involve the use of appropriately specified performance bonds that will fully cover the restoration of environmental damages. The internalization of these costs could go a long way toward addressing the environmental problems in the study area. Environmental safeguards should be set in place for all types of development.

6) **Invest in Sustainable Forestry Management (SFM) across the Landscape: The high rate of deforestation observed in this study requires investment in sustainable forest management to maintain the health and integrity of forest ecosystems, conserve biodiversity, mitigate climate change, and provide livelihoods for communities that depend on forests.** Investing in sustainable forest management will also help conserve ecosystem services, provide social and community benefits, and align development efforts with the growing trend of green investments and impact investing for a green economy. A complex array of anthropogenic and climate-change related drivers have led to severe land degradation in Mazowe Catchment. Land degradation manifests in large scale deforestation of previously dense woodland and wooded grasslands, loss of other groundcover, reduced agricultural productivity, as well as soil erosion, sedimentation, and pollution of water bodies. Sustainable forestry management is a key component of sustainable landscape management to address land degradation and restore ecosystem health in the catchment. Key investments for consideration in this regard include reforestation and afforestation of severely degraded land, conversion, and passive reforestation of marginal agricultural land into silvo-pastoral systems for adapted livestock species or community conservancies, encouraging private investments in commercial forestry for all socioeconomic category of farmers down to smallholder commercial woodlots thereby enhancing household income diversification and resilience. Other SFM investments include the strengthening of value chains for timber and non-timber forestry products as well as the commercial promotion of efficient cook-stoves.

7) **Design and pilot two schemes for payments for ecosystem services (PES).** The analysis has generated first-order evidence to support the design and implementation of two pilot schemes for payment for ecosystem services (PES) based on appropriate global examples. One scheme will be based on sustainable landscape management to reduce land degradation and soil erosion on catchments of water-supply dams for urban settlements in Mazowe Catchment. Candidate urban settlements include Bindura, Murewa and Mutoko. These local authorities care about and could logically be willing to pay appropriate sums of money for incentivising sustainable land management practices in upstream catchments to regularize and guarantee portable water-supply as well as reduced siltation in feeder dams. The quality and regularity of bulk water supply is important for reducing the cost and efficient functioning of water-treatment and pumping equipment, in turn to guarantee public health of urban residents. On the other hand, private investment in sustainable watershed management by distributed actors in the landscape is fraught with and discouraged by significant external costs and benefits. A well-designed pilot scheme for sustainable watershed management in a focused catchment is one key investment and nature-based solution to consider for securing sustainable urban water supply.

   Another pilot PES scheme could be built on a sustainable landscape management scheme to verifiably generate and sell carbon credits through carbon funds. The path to sustainable development in Zimbabwe lies in the effective management of its natural resources, particularly its forests and agricultural lands. With forests being a source of livelihood for 1.5 million people and agriculture accounting for the largest share (50 percent) of employment in the country, adopting sustainable practices has the potential to not only conserve resources, but also boost the economy and uplift the living standards of smallholder farming households. By promoting sustainable agriculture and reducing deforestation, the country can break the cycle of poverty, create jobs, and contribute to a more inclusive and resilient future. In addition, sustainable landscape management will enable the country to tap into the potential of carbon finance and generate and trade emission reductions in the carbon markets. A carefully selected catchment could include hard investments and governance arrangements to generate and sell carbon credits from an integrated combination of climate-smart agriculture, sustainable forestry management, biodiversity conservation and sustainable landscape management. Initial conditions on existent land-uses will determine the form and portfolio of carbon-generating activities.

287. **The private sector has a critical role to play in biodiversity conservation and sustainable landscape management in Zimbabwe by i) financing projects that contribute to the conservation, restoration, and sustainable use of landscape; and ii) directing financial flows away from projects with negative impacts on biodiversity and ecosystem services.** However, government holds the key to harnessing the power of the sector to mobilize the needed private finance at scale to protect nature. Government can support the integration of biodiversity criteria in private sector decision making by adopting natural capital accounting and making relevant data available as public good. Second, environmental fiscal policy reforms that value natural capital can provide incentives for the private sector to co-invest in the sustainable use of natural resources and contribute toward net domestic resource mobilization. Third, government can drive the green transition by promoting policies such as greening the supply chain to drive changes in corporate behavior. Encouraging the certification of products or enhancing the commercial and entrepreneurship skills of producers could serve for example as an incentive to reduce deforestation while increase revenues at the same time. Efforts to protect the landscapes should also prioritize gender equality to deliver a more sustainable future. Integrating gender equity into policies and practices in sustainable landscape management will address entrenched and systemic traditions and practices, which have significant implications for how women access and contribute to improvements to landscape management and commodity value chains. Lastly, there is a need for multi-sectoral, people centered approach to natural resources management by ensuring the integration of natural capital consideration into planning, budgeting, implementation, and decision-making at the national and local levels will help build resilience.

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Appendix 1. Selection of the Focal Landscape: Detailed Methods and Results

Methodology

Overview and selected indicators

The analysis proceeded along the following steps:

1. **Identify indicators of the provision of ecosystem services considered in this study.** Ecosystem services included food provision (crops and livestock production), erosion control, water, carbon storage, and ecotourism potential. Indicators were selected for rapid assessment based on data availability, their relevance to the ecosystem services in question, and whether they could be applied consistently at a national scale. Selected indicators are given in table 17. For sediment retention and water yield, InVEST models (Sharp et al. 2020a) were applied to derive pixel-level estimates of these parameters, based on detailed input data on topography, soils, land cover and management, and climate.
2. **Identify relevant indicators on the beneficiaries of ecosystem services,** where appropriate. Beneficiary proxies were selected that represent the potential demand on an ecosystem services, and data were selected using the same criteria as for ecosystem service indicators (availability, relevance, consistency for application at a national scale; Table 17). Croplands, grazing lands, and dams were considered to be the beneficiaries of erosion control. People and dams were considered to be the beneficiaries of water provision. Croplands and livestock were considered to be the beneficiaries of biomass produced on the landscape (resulting in food for people). For carbon and ecotourism, no beneficiary indicators were used. In the case of carbon, the beneficiaries are global, and in the case of ecotourism we were limited by the lack of spatially disaggregated data on visitation at a national scale. Note that the ability of beneficiaries to take advantage of the provision of ecosystem services is based on many local factors, such as dependence, access to the service and/or service providing area, and access to alternatives. Such factors were not considered in this rapid screening; therefore, the results should be interpreted as *potential*, rather than as *realized*, demand.
3. **Perform an assessment of trends in land and water degradation over the last 20 years**. Indicators included vegetation productivity (NPP), evapotranspiration, soil moisture, baseflow, and surface runoff (table 18). For each indicator, a linear regression was applied to the values over a 20-year period to determine the slope of the trend.
4. **Summarize indicators of services, beneficiaries, and land and water degradation** at the watershed scale. For each service, the indicator(s) were aggregated to the watershed level, and then a binary variable was assigned indicating which watershed/service pair fell into the top 25 percent of values (top quartile) or the top 50 percent of values (values above the median). For degradation indicators, the slope of the pixel-level trends was averaged to arrive at the watershed-level trend, and the same binary variable was assigned. The final land and water degradation indicator is the total number of sub-indicators for that watershed that fall into the top 50 percent of values. For the service and beneficiary indicators, it is the total number of services/beneficiaries that fall into the top 25 percent or 50 percent of values for that watershed.

Summary of InVEST models for sediment and water

Water flows

Watersheds capture and store water, thereby contributing to the quantity of water available and the seasonal flow of water. The so-called 'albedo' effect refers to the process

TABLE 17: INDICATORS UTILIZED FOR PROVISION OF ECOSYSTEM SERVICES AND THE BENEFICIARIES OF SERVICES

Ecosystem service	Indicator of service provision	Method or source	Beneficiary indicator	Beneficiary data source
Erosion control	Soil retained by vegetation (ton/ha)	InVEST SDR model (Sharp et al. 2020a)	Croplands	Copernicus 2019 100 m land use land Cover data (Gilbert et al. 2018) 'Cropland' class
			Grazing lands	Gridded livestock of the world (GLW3 - Buchhorn et al. 2020), areas with >1,000 animals/km^2
			Percent of area contributing to dam(s)	Global Reservoir and Dam Database (GRanD) v1.3 (Lehner et al. 2011) GlObal geOreferenced Database of Dams (GOOD2) Dams Dataset (Mulligan, van Soesbergen, and Sáenz, 2020)
Water regulation	Annual water yield (mm)	InVEST SWY model (Sharp et al. 2020a)	Population	Population density, 2020 (Bondarenko et al. 2020)
			Water yield contributing to reservoirs	Same as 'dams' above
Food production	Mean annual biomass production in croplands	MOD17A3HGF.006 MODIS/Terra Net Primary Production V006, 500 m (Running and Zhao 2019)	Population	Population density, 2020 (Bondarenko et al. 2020)
	Mean annual biomass production in grazing lands		Number of grazing animals	GLW3 (Gilbert et al. 2018), sum of animals/watershed
Ecotourism	Percent of area in protected status	WDPA (IUCN and UNEP-WCMC 2016)		
Carbon storage	Total aboveground and belowground carbon	NASA ORNL Global Aboveground and Belowground Biomass Carbon Density, 300 m (Spawn and Gibbs 2020)		

TABLE 18: METRICS UTILIZED AS LAND AND WATER DEGRADATION INDICATORS

Indicator	Data source	Method
Net primary productivity	MOD17A2H MODIS/Terra Gross Primary Productivity V006, 500 m (Spawn and Gibbs 2020)	20-year trend analysis, using linear regression to derive slope of trend for each parameter
Surface runoff ('quickflow')	Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS) (McNally et al. 2017)	
Baseflow		
Evapotranspiration		
Soil moisture		

by which vegetation increases evaporation of water from the earth's surface to cause increased cloud formation and rainfall (Myers 1997). Through this effect, ecosystems dominated by vegetation, such as forest ecosystems, play a significant role in determining rainfall patterns at a regional scale. Vegetation also acts as a 'sponge', soaking up and storing water when abundant and releasing it slowly during the dry periods. This system of water regulation reduces the impacts of flood and drought on downstream communities (Myers 1997).

In this study, we used the InVEST SWY model (Sharp et al. 2020) to look at water flows as a function of landscape characteristics and land cover and management. The model estimates the amount of water produced by a watershed that arrives in streams over the course of a year. The two primary outputs of the model are quickflow and baseflow—quickflow represents the amount of precipitation that runs off of the land directly, during and soon after a rain event, and baseflow is the amount of precipitation that enters streams more gradually through subsurface flow, including during the dry season. Data inputs to the SWY model include rainfall, potential evapotranspiration, topography, soil, and land cover.

To understand which areas of the landscape are contributing more or less water to streams over the course of the year, we combined the quickflow and baseflow results from the model to produce a total annual water flow map, given in cubic meters per year. Total annual mean water flows were summed by watershed, to provide input to the water ecosystem services map for the national screening.

Erosion and sediment retention

Soil erosion is the movement or displacement of the upper layer of soil, and it is a naturally occurring process that affects all landforms. Certain human activities greatly enhance this process and contribute to a significant soil loss. This matters significantly because topsoil contains the highest amount of organic matter and is best suited for agricultural activities. In the last 150 years, as much as half of the world's topsoil has been lost.

However, the effects of soil erosion go far beyond the loss of fertile land and include increased pollution and sedimentation in streams and rivers. As a result, these waterways are prone to clogging, which causes declines in fish and other species. Furthermore, degraded land can often hold less water, which can worsen flooding (RUVIVAL 2018). Soil erosion in terrestrial ecosystems is therefore a global environmental problem, and it significantly affects environmental quality and social economy. Ecosystems such as forests, wetlands, and mangroves help stabilize soils, reducing erosion. The vegetative cover shelters soil from the force of rain by intercepting rainfall while roots help maintain the soil structure (Myers 1997). By protecting soil from wind and water erosion, terrestrial ecosystems supply human beings with soil erosion control service, one of the fundamental ecosystem services that ensure human welfare (Fu et al. 2011).

The InVEST SDR model (Sharp et al. 2020) was used in this study to evaluate erosion rates and overland sediment transport. The SDR model highlights areas where higher levels of erosion are occurring, highlights areas providing the service of retaining some of that erosion, and quantifies the amount of sediment that arrives in streams and reservoirs. The model is based on an implementation of the Revised Universal Soil Loss Equation (RUSLE1; Renard et al. 1997) for the calculation of annual soil loss and a sediment delivery function on the hydrological connectivity of each pixel in the landscape.

The SDR model requires input datasets of biophysical parameters for the calculation of erosion dynamics, sediment export, and retention across the landscape. For the erosion component, data on land cover, rainfall erosivity energy (EI30), soil texture erodibility, length-slope derived from topography, soil cover fraction by vegetation, and assumptions regarding soil conservation practices are required. For the transport of sediment and retention on the landscape, a hydrologically corrected DEM is required.

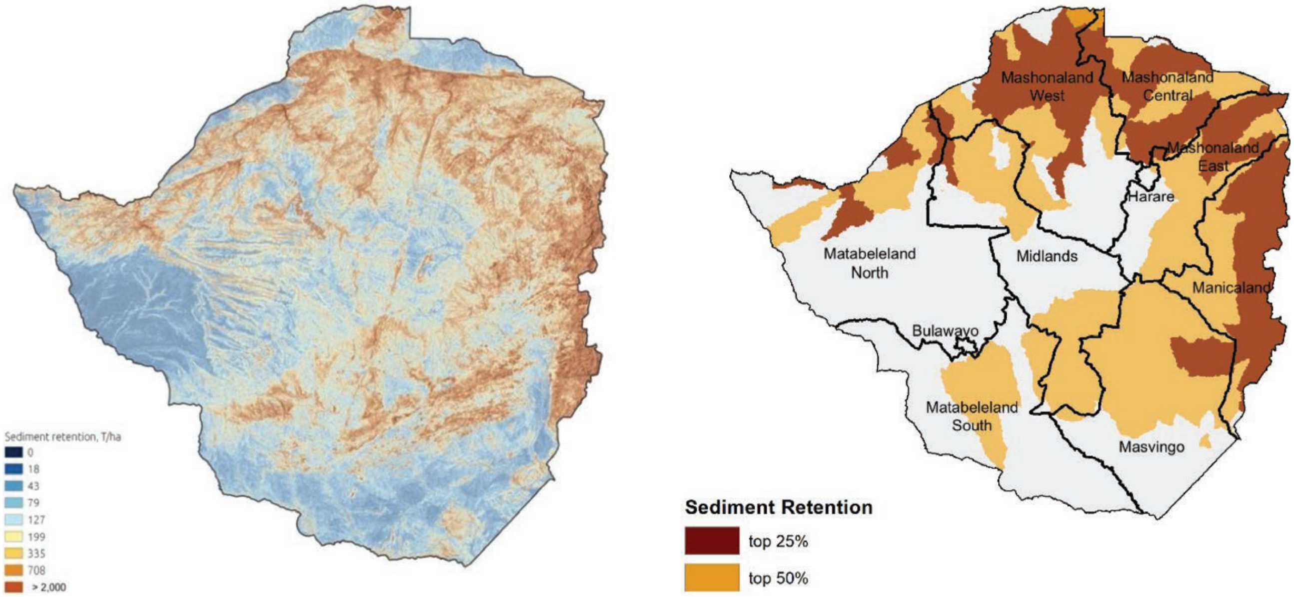
For assessing the national-scale assessment of the erosion control service, the soil retention model was used. This output represents the amount of sediment (tons per year) that would otherwise be eroded but is currently retained by the landscape, preventing it from entering streams and potentially affecting downstream users.

Detailed results

Ecosystem services

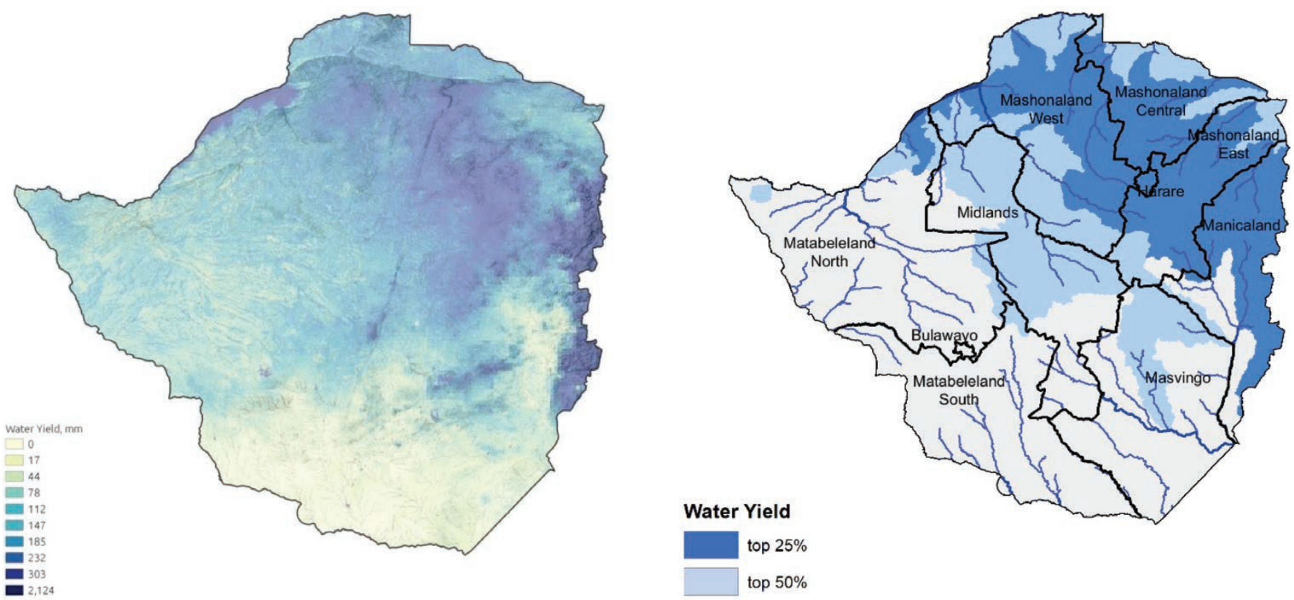
The following figures present the detailed results for soil retention (Figure 34), water yield (Figure 35), carbon storage (Figure 36), and primary productivity (Figure 37), as well as the location of protected areas (Figure 38).

FIGURE 34: SOIL RETENTION BY VEGETATION (LEFT) AND THE TOP WATERSHEDS FOR PROVIDING SEDIMENT RETENTION SERVICE IN THE CURRENT LANDSCAPE (RIGHT)



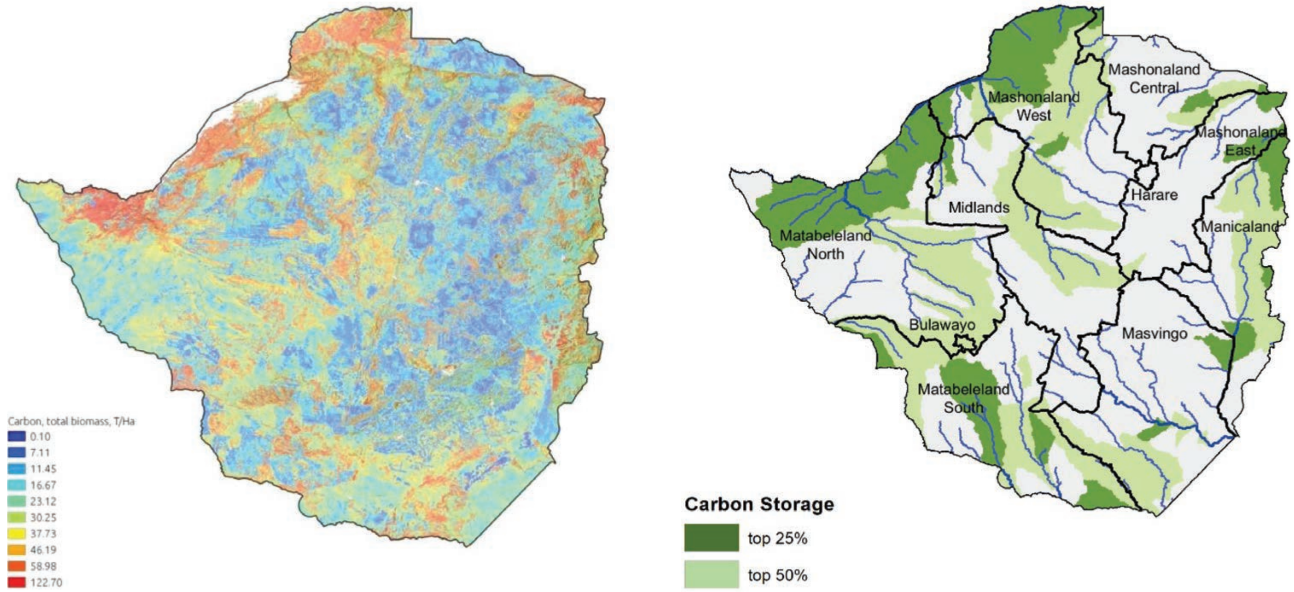
Source: This study, calculated from data sources given in Table 16.

FIGURE 35: WATER YIELD (LEFT) AND THE TOP WATERSHEDS FOR PROVIDING WATER FLOW ECOSYSTEM SERVICE IN THE CURRENT LANDSCAPE (RIGHT)



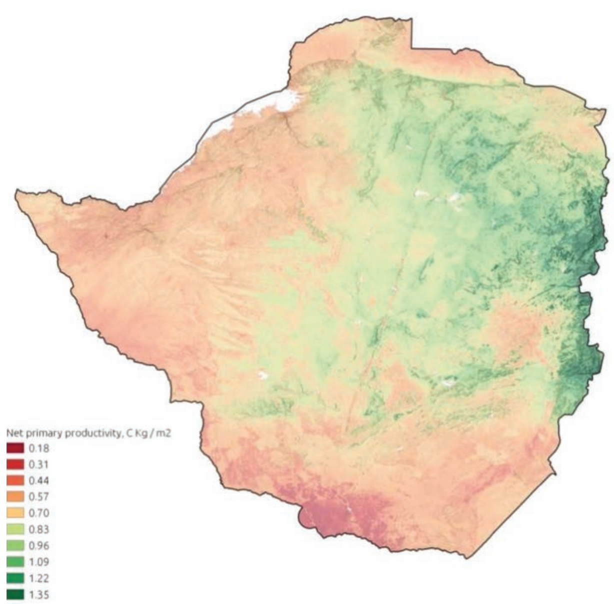
Source: This study, modelled from data sources given in Table 16.

FIGURE 36: TOTAL ABOVEGROUND AND BELOWGROUND CARBON STORAGE IN THE CURRENT LANDSCAPE (LEFT), AND THE TOP WATERSHEDS IN TERMS OF STORING CARBON (RIGHT)



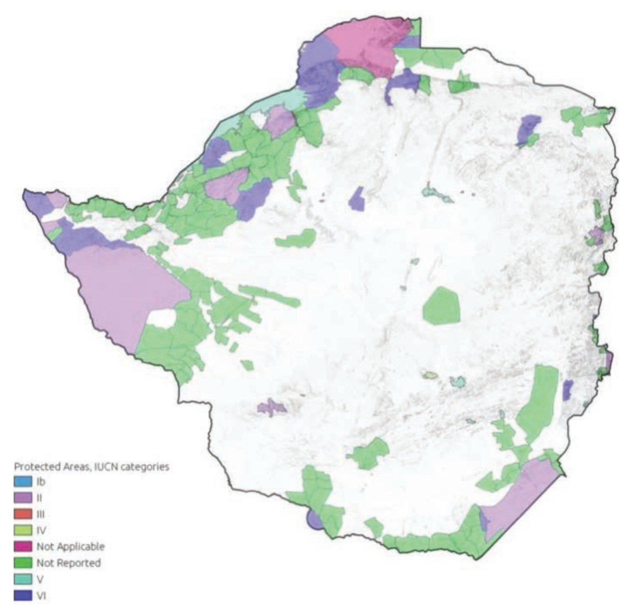
Source: NASA ORNL Biomass Carbon Density.

FIGURE 37: NPP (BIOMASS), USED AS A PROXY FOR CROP AND LIVESTOCK PRODUCTIVITY



Source: MODIS/Terra Net Primary Production V006.

FIGURE 38: PROTECTED AREAS, USED AS A PROXY FOR ECOSYSTEM SERVICES RELATING TO ECOTOURISM

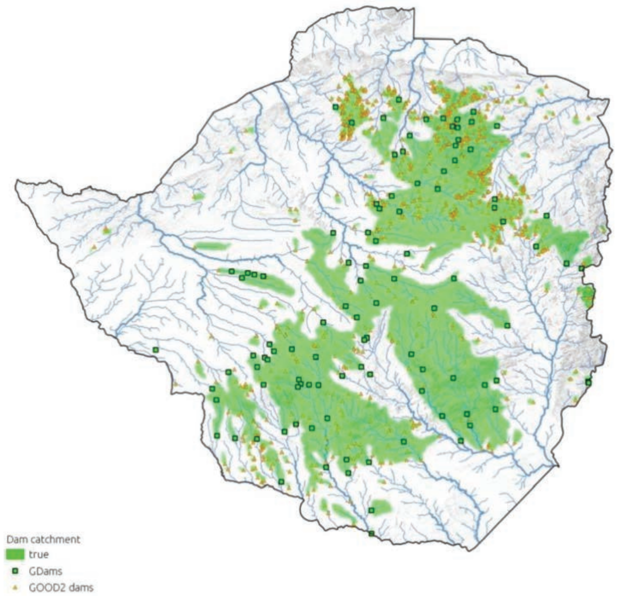


Source: IUCN WDPA.

Beneficiaries of ecosystem services

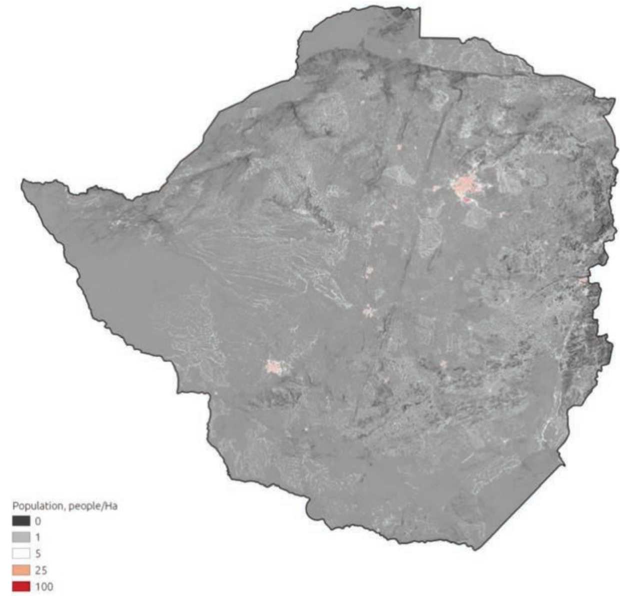
Figures 39 to 41 show the location of dam catchment areas and spatial spread of human populations and grazing animals.

FIGURE 39: DAMS AND THEIR CATCHMENT AREAS, CONSIDERED AS BENEFICIARIES FOR SEDIMENT RETENTION AND WATER FLOW ECOSYSTEM SERVICES



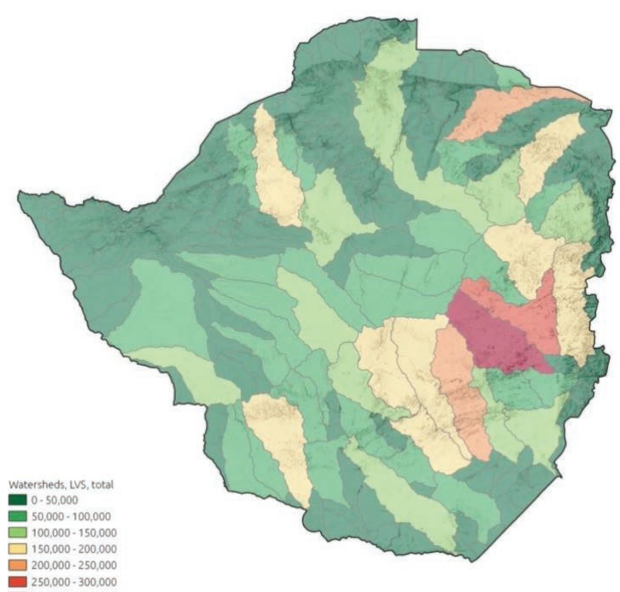
Source: GRanD and GOOD2 Dams datasets.

FIGURE 40: POPULATION, CONSIDERED AS DIRECT BENEFICIARIES OF CROP PRODUCTION AND WATER REGULATION SERVICES



Source: Worldpop 2020.

FIGURE 41: NUMBER OF GRAZING ANIMALS PER WATERSHED, CONSIDERED AS BENEFICIARIES OF BIOMASS PRODUCTION IN LIVESTOCK GRAZING AREAS



Source: GLW3.

Appendix 2. Rural Livelihood Zones in Mazowe Catchment

TABLE 19: DESCRIPTION OF THE FOUR MAIN RURAL LIVELIHOOD ZONES THAT OCCUR WITHIN THE STUDY AREA

Zone	Description
Central and Northern Semi-Intensive Farming	Dominated by maize and small grain crops for both food requirements and as cash crops. Poorer households depend on multiple sources of income including sale of handcrafts, petty trading (fish sales and beer brewing), and artisanal mining. An important income source is remittances from relatives. Livestock sales are not common but are a source of income for some middle-income households. The main chronic hazards are malaria, crop pests, and human and animal disease. Fluctuating markets for agricultural produce also place a strain on commercial farmers. Drought (roughly every 1–3 years out of 10), land degradation, deforestation, and wildfires are the main periodic natural hazards to livelihoods. Conflicts around water accessibility in dry years and water quality (reduced by siltation) have also been noted.
Highveld Prime Communal	Both food and cash crops, dominated by maize production. Wide variety of other crops grown. Favorable rainfall but soils not particularly arable. Own food production is important. Livestock and grazing are limited due to densely populated areas and crops. Sales of harvested resources are common by poorer households. Following the FTLRP, there was significant outflow of labor to urban areas resulting in a decline in commercial crop production. An important source of cash is remittances. Illegal artisanal mining is common among households unable to sell cash crop produce. Stock and crop theft is the main chronic threat. Low market prices are also a key chronic threat. Besides animal diseases and crop pests as periodic threats, degradation, especially in the form of deforestation for tobacco curing, is also a key issue. Uncontrolled veld fires are a major threat.
Highveld Prime Cereal and Cash Crop Resettlement	Mostly agricultural resettlement land that changed hands following FTLRP, mostly food secure but food production has declined. Many farmers have abandoned farms to work in urban areas, leaving farms to caretakers. Key crops are maize, soya, tobacco, and groundnuts, often supplemented by livestock production. Production of crops and livestock is either for subsistence or commercial output with substantial differences in income and food security between these groups. Following redistribution of land, many commercial farmworkers lost both their livelihoods and homes or job security. This has resulted in similar income earned by resettlement and subsistence farmers. Remittances and food aid have been important for the poorest residents. Crop pests and hailstorms are key chronic hazards. Land degradation is also widespread, particularly through harvesting of firewood for tobacco curing, as is increased abundance of invasive species such as *Spropobulus*, which spreads in overgrazed rangelands. Animal diseases are the main periodic hazard while wildfires and theft from farms (of stock, crops, and equipment) are also periodic threats.

TABLE 19: (Continued)

Zone	Description
Greater Mudzi Communal	Extensive rainfed maize crops as well as smaller areas of small grain crops, cotton, and groundnuts. Incomes supplemented by cotton production, animal husbandry, and increasingly through artisanal gold panning along rivers in the dry season. Poorer households rely on a more diverse range of food and income sources as compared to more well-off farmers who can satisfy most of their food requirements from their own crops. Livestock sales (particularly cattle and goats) to agents (predominantly from Harare) are relatively important for supplementing income in this zone, especially in low rainfall years. Fishing is also an important income and food supplement. There is some outmigration of workers to work on potato farms further south in the Nyanga district on a seasonal basis. Fairly significant food aid has been received over the last few decades. The fluctuating price of cotton is regarded as a chronic hazard. This makes it difficult for farmers to plan and devote land to cotton crops, which would reduce the availability of land for food crops. Malaria and landmines (nearer the Mozambique border) are chronic threats. Droughts occur roughly every 3 years. Inaccessibility of the area creates challenges for market access. Several animal diseases are periodic threats while human-animal conflict is an issue around the WMAs and protected areas.

Source: Based on GoZ and WFP 2017; ZimVAC 2011.

Appendix 3. Land Cover Accounts

TABLE 20: CHANGES IN EXTENT IN LAND COVER CLASSES BETWEEN 1992 AND 2018 IN MAZOWE CATCHMENT

	Forest	Dense woodland	Open woodland	Shrubland	Wooded grassland	Herbaceous vegetation	Grassland	Natural-dominant mosaic with crops	Crop-dominant mosaic with natural areas	Cultivated (irrigated)	Cultivated (rainfed)	Bare ground	Urban/ built-up	Waterbodies	Wetland	No data	Total
1992 extent (km²)	**45**	**9,458**	**176**	**5,032**	**448**	**10,38**	**777**	**160**	**239**	**< 1**	**12,299**	**297**	**34**	**95**	**22**	**37**	**39,857**
Additions to stock (km²)	0	822	63	702	5	760	107	28	75	0	931	16	30	1	3	2	**3,544**
Reductions in stock (km²)	0	2,048	26	537	407	163	71	90	14	0	166	20	0	0	2	1	**3,544**
Net change in stock (km²)	**0**	**−1,226**	**37**	**165**	**−402**	**597**	**35**	**−62**	**61**	**0**	**765**	**−4**	**30**	**1**	**1**	**1**	
Net change as percent of opening	**0**	**−13**	**21**	**3**	**−90**	**6**	**5**	**−39**	**25**	**—**	**6**	**−1**	**87**	**1**	**4**	**3**	
Unchanged (km²)	45	7,410	150	4,495	41	10,575	706	70	225	0	12,134	277	34	95	20	36	
Unchanged as percent of opening (km²)	100	78	85	89	9	98	91	44	94	100	99	93	100	100	89	99	
Turnover (additions + reductions) (km²)	0	2,869	88	1,239	412	923	178	118	89	0	1,097	35	30	1	6	2	
Turnover as percent of opening	1	30	50	25	92	9	23	74	37	200	9	12	88	1	26	6	
2018 extent (km²)	**45**	**8,232**	**213**	**5,196**	**46**	**11,335**	**813**	**98**	**300**	**< 1**	**13,065**	**293**	**64**	**95**	**23**	**38**	**39,857**

Note: Values are rounded to the nearest integer.

TABLE 21: LAND COVER CHANGE MATRIX FOR MAZOWE CATCHMENT SHOWING LAND COVER CHANGE PATHWAYS BETWEEN 1992 AND 2018

Land cover 1992 / Land cover 2018	Forest	Dense woodland	Open woodland	Shrubland	Wooded grassland	Herbaceous vegetation	Grassland	Natural-dominant mosaic (with crops)	Crop-dominant mosaic (with natural areas)	Cultivated (irrigated)	Cultivated (rainfed)	Bare ground	Urban/ built-up	Waterbodies	Wetland	No data	Total reductions	Total area 2018
Forest	*45*	—	—	0	—	—	—	—	—	—	—	—	—	—	—	—	*0*	45
Dense woodland	—	*7,410*	27	683	3	526	102	26	71	—	580	9	15	1	3	0	*2,048*	9,458
Open woodland	—	4	*150*	1	—	9	—	—	0	—	8	—	3	—	—	—	*26*	176
Shrubland	—	388	5	*4,495*	1	71	5	2	3	—	54	6	3	—	—	0	*537*	5,032
Wooded grassland	—	2	1	—	*41*	136	—	—	1	0	267	—	0	—	—	0	*407*	448
Herbaceous vegetation	—	137	14	10	0	*10,575*	—	—	—	—	—	0	1	—	—	0	*163*	10,738
Grassland	—	39	1	0	—	9	*706*	—	—	—	21	—	1	—	—	0	*71*	777
Natural-dominant mosaic (with crops)	0	86	0	2	—	0	—	*70*	0	—	—	—	1	—	—	—	*90*	160
Crop-dominant mosaic (with natural areas)	0	13	0	—	—	—	—	—	*225*	—	—	—	1	—	—	—	*14*	239
Cultivated (irrigated)	—	—	—	—	—	—	—	—	—	*0*	—	—	—	—	—	—	*0*	0
Cultivated (rainfed)	—	141	15	4	1	1	—	—	—	—	*12,134*	0	3	0	—	0	*166*	12,299
Bare ground	—	9	0	0	—	8	—	—	—	—	2	*277*	1	—	—	—	*20*	297
Urban/ built-up	—	—	—	—	—	—	—	—	—	—	—	—	*34*	—	—	0	*0*	34
Waterbodies	—	—	—	—	—	—	—	—	—	—	—	—	—	*95*	—	—	*0*	95
Wetland	—	2	—	—	—	—	—	—	—	—	—	—	—	—	*20*	—	*2*	22
No data	—	0	—	—	—	0	0	—	—	—	—	—	—	—	—	*36*	*1*	37
Total additions	*0*	*822*	*63*	*702*	*5*	*760*	*107*	*28*	*75*	*0*	*931*	*16*	*30*	*1*	*3*	*2*		
Total area 2018 (km²)	**45**	**8,232**	**213**	**5,196**	**46**	**11,335**	**813**	**98**	**300**	**0**	**13,065**	**293**	**64**	**95**	**23**	**38**		**39,857**

Note: Cells with zero indicate a change of less than 0.5 km^2 while dashes indicate no change between the respective classes.

Appendix 4. Assessment of Land Degradation

Satellite data can reveal changes in primary productivity, which can be indicative of land degradation. Primary productivity refers to the rate at which energy is converted to organic substances by vegetation in croplands, pastoral areas, and natural ecosystems. It is, however, difficult and costly to estimate at large scales, requiring surrogate indexes such as NDVI.

NDVI is a simple quantification of vegetation vigor or greenness, often used as an indicator of vegetation health. NDVI data are generated globally and made available on a biweekly basis, making it well suited to analyzing changes in land productivity over time.

Using the Trends.Earth software plugin (Conservation International 2018), degradation metrics were derived for the Mazowe Catchment. The plugin allows for making calculations to derive the UN Sustainable Development Goal (SDG) Indicator 15.3.1, which aims, by 2030, to "combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world." As part of calculating SDG 15.3.1, three sub-indicators are calculated: productivity, land cover, and soil carbon. The productivity sub-indicator is useful for deriving general degradation impacts and uses three measures of NDVI change: trajectory, performance, and state. Trajectory indicates the rate of change of NPP between 2000 and 2015 using NDVI.

A positive significant trend in NDVI indicates potential improvement while a negative significant trend points to potential degradation of land and ecosystems (Conservation International 2018). It is important to note that crop areas will potentially result in false indication of land or ecosystem improvement where they in fact do not allow for the provision of as many ecosystem services as that in a natural or near-natural state.

Appendix 5. Methods for Quantifying and Valuing Ecosystem Services

Harvested wild resources

A natural habitats layer, generated through combining land cover (Buchhorn et al. 2020) and World Wide Fund for Nature (WWF) ecoregions layers (Olson et al. 2001), formed the basis for mapping the supply of natural resources. Each habitat was assigned a stock estimate per unit area for the different wild resources considered, based on remotely sensed woody biomass data for woody resources (Bouvet et al. 2018; Santoro et al. 2018), and stock estimates derived from literature studies for other resources (Campbell 1987; Campbell, Luckert, and Scoones 1997; Degreef et al. 2020; Frost 1996; Garcia et al. 2013; Jaffé et al. 2010; Mlambo and Maphosa 2021; Ngadze et al. 2017; Ngulube, Hall, and Maghembe 1996; Poilecot and Gaidet 2011; Pritchard et al. 2018). The demand for natural resources was estimated based on household density, the proportion of households using a particular resource, and the average consumption per user household. Population density was obtained from the WorldPop 100 m constrained population density map (www.worldpop.org). Information on household usage of particular natural resources was derived from literature studies and the most recent intercensal survey (ZIMSTAT 2017). The latter provides figures for the proportion of households using wood as a cooking fuel and the proportion of traditional dwelling types (that is, those using thatch for roofing and wooden poles in their walls) at the provincial level. Household use of all other modelled resources was obtained from literature studies (Campbell et al. 1991, 1997; Chagumaira et al. 2016; Dowo, Kativu, and de Garine-Wichatitsky 2018; Grundy et al. 1993, 2000; Kupurai, Kugedera, and Sakadzo 2021; Mabugu and Chitiga 2002; Mahlatini et al. 2020; Mashapa et al. 2021; McGregor 1991; Mudekwe 2007; Shackleton and Shackleton 2004; Twine et al. 2003; Woittiez et al. 2013).

Once resource demand, stocks, and accessibility had been mapped, the quantities of resources harvested were calculated from the minimum of the estimated demand and the estimated available stocks of resources within a specified distance of the demand source. To estimate and map harvesting at a high resolution, the running mean method developed by Turpie et al. (2020) in KwaZulu-Natal, South Africa was used.

Ecosystem inputs to crop production

Crop production was modelled using the InVEST Crop Production model, with correction factors applied based on production from Zimbabwe's Crop and Livestock Assessment reports (MoLAWFRR 2020, 2021). Production was modelled for six food crops/food crop groupings (maize, sorghum, millet, ground and bambara nuts, beans, and sweet potatoes) and four cash crops (tobacco, cotton, soya, and sunflower). The InVEST Crop Production model was used to estimate production of each crop per hectare of cultivated land (as per the land cover layer), thus generating an estimate of the spatial variability in production based on Monfreda, Ramankutty, and Foley (2008), which is the input dataset for the InVEST model. The modelled production was then summed at a provincial level and compared with mean production at the provincial level between 2019 and 2021, as per the Crop and Livestock Assessment reports. Correction factors were then applied to the InVEST crop production maps to ensure alignment with modelled and reported production at the provincial level and the InVEST model data were updated to reflect recent production levels.

Crop production was valued using the most recent producer prices derived from the Grain Marketing Board, Tobacco Industry and Marketing Board, and Cotton Company. None of these sources provide a producer price for sweet potato. However, an estimate was sourced from a recent article published by the Alliance for Science, which reported a price of US$800 per ton for sweet potato production in Zimbabwe.[28] Prices were converted from Z$ to US$ using

[28] https://allianceforscience.cornell.edu/blog/2021/11/sweet-potato-farmers-profit-from-climatic-protection/.

the mean of the interbank and official exchange rates according to the Reserve Bank of Zimbabwe as of mid-May 2022. To arrive at a more realistic estimate of the value of crop production, gross revenue was converted to gross margin. While gross margin is likely to vary significantly across the catchment, both spatially and from year to year, a gross margin of 15 percent was assumed for this study. This is because the government aimed to ensure farmers realize at least a 15 percent profit margin when it set these producer prices.[29]

Ecosystem inputs to livestock production

The quantification of livestock production employed a similar approach to crop production. In this case, correction factors from Zimbabwe's Crop and Livestock Assessment reports were applied to the FAO GLW3 dataset (Wint and Robinson 2007). The analysis focused on cattle, goats, and sheep, which are the major free ranging livestock in Zimbabwe (particularly cattle and goats). The 10 km^2 resolution FAO data were first downscaled to give livestock density per km^2 and then summed at the provincial level. This was again compared with livestock numbers reported in the Crop and Livestock Assessment reports, allowing for correction factors to be calculated and applied to the FAO data. Livestock numbers were also expressed and mapped in terms of TLUs. Following other studies from Zimbabwe and the broader region, a value of 0.7 was used to convert cattle numbers to TLUs, while a 0.1 conversion factor was used for goats and sheep.

Livestock were valued in terms of revenues from livestock sales and gross margin terms. Due to significant differences in the production systems, the valuation was conducted separately for commercial farmland areas on the one hand and resettlement areas and communal land on the other. Livestock sale is the primary aim of production in the commercial farming sector, resulting in much higher livestock offtake rates and thus sales revenues. In contrast, livestock (particularly cattle) serves a wide range of roles in small-scale farming systems, with draught power, *lobola* payments, and milk and manure production regarded more important than sale for meat by small-scale farmers in Zimbabwe (Mukhebi et al. 1999; Scoones 1992). Given the low importance of livestock sales, these other factors were incorporated in the estimates used for gross revenue and margin of livestock in communal and resettlement areas.

Tourism value

Nature-based tourism value was estimated using the InVEST Visitation: Recreation and Tourism model in combination with land cover data and national tourism statistics. The InVEST model estimates the relative tourism value across a landscape from the density of PUDs derived from geotagged photos uploaded to the website Flickr. PUD densities are calculated across a user-specified grid size. A 300 m grid size was chosen, as the model failed to run using smaller grid sizes due to the higher number of calculations required.

The national value of tourism was obtained from ZTA (2020). This was the most recent pre-COVID-19 year, thus providing a more representative estimate of tourism value before the pandemic and a better indication of potential value as international travel continues to recover. Estimating the value of nature-based tourism involved isolating tourism expenditure on visiting attractions from visitors spending on other purposes (for example, business or visiting friends and family). Data on the expenditure and proportion of different visitor categories were obtained from ZTA and World Travel and Tourism Council (WTTC) reports (WTTC 2021; ZTA 2020).

Attraction-based tourism across the Mazowe Catchment was isolated by clipping the InVEST PUD density map to the extent of the catchment, and the proportion of national PUDs which fall within the catchment was calculated. This was then applied to the national attraction-based estimate for Zimbabwe to arrive at the value of attraction-based tourism in the Mazowe Catchment. To isolate the value of nature-based tourism specifically, PUD data were disaggregated across broad land use categories (natural vegetation, plantation, cultivation, and urban) based on the dominant land cover within each 300 m PUD grid cell. The proportion of PUDs taken within grid cells dominated by natural land cover was then again applied to the overall attraction-based tourism value to obtain an estimate of nature-based tourism in the catchment.

Carbon storage

Carbon storage by landscapes of the Mazowe Catchment was estimated from the total of AGB and BGB. For AGB, the study primarily used the AGB map of African savannas and woodlands (Bouvet et al. 2018), as this dataset has

[29] http://www.gmbdura.co.zw/index.php/grain-producer-prices-go-up.

been specifically designed to give more accurate biomass assessments for African woodland and savannah habitats. However, it is less accurate for higher biomass forest areas, which are masked out and given a uniform biomass value by Bouvet et al. (2018). In such areas, the GlobBiomass AGB layer generated by Santoro et al. (2018) was used instead. For BGB, the global belowground carbon density map (Spawn et al. 2020) was used. All datasets were reprojected and resampled to 100 m resolution as necessary. Biomass values were converted to carbon equivalent using a 0.5 conversion factor. Carbon was converted to equivalent tons of carbon dioxide using a 3.67 conversion factor.

Carbon stored in the catchment was valued using the social cost of carbon (SCC), which is the value of avoided climate change-related damages through the retention of carbon by the landscape. Carbon was valued both in terms of avoided damages to Zimbabwe (country-level SCC) as well as to the rest of the world (global SCC). Values of the country-level and global-level SCC were obtained from Ricke et al. (2018).

The SCC is a net present value of avoided costs, typically over 100 years. However, for accounting purposes, values must be determined for the year in question. Thus, the annualized social cost of carbon (ASCC) was then estimated as

$$ASCC = \frac{(\delta \times SCC)}{(1-(1+\delta))^{-t}},$$

where δ is the discount rate and t is the time period of the SCC calculation in years. For this study, we assumed t = 100 years and used a social rate of discount of 4.56 percent. This is the mean social rate of discount for all Southern African countries based on Addicott, Fenichel, and Kotchen (2020) who did not provide a figure for Zimbabwe.

Flow regulation

Hydrological regulating services were quantified using the InVEST SWY model. This was done at a finer scale than in the preliminary assessment report through the use of a 30 m DEM. The InVEST SWY model estimates the contribution of the landscape to both quickflow and infiltration. Quickflow is surface runoff associated with a rainfall event. Precipitation that does not run off as quickflow or get lost through evapotranspiration can infiltrate the soil and contribute to groundwater recharge and baseflows. While quickflow only occurs during or shortly after rainfall events, baseflow provides a more sustained source of water during dry periods. Higher quickflow can also result in elevated flood risks. The model calculates quickflow using a curve number (CN)-based approach.

The study drew on available CN estimates for land cover class and hydrological soil group combinations (Baker and Miller 2013; Beatty et al. 2018; Descheemaeker et al. 2008; Wischmeier and Smith 1978). For monthly rainfall, the finest-scale data (1 km) available from WorldClim were used (Fick and Hijmans 2017). To calculate the amount of water left for infiltration and recharge, the model requires information on reference evapotranspiration and the water requirements of different land cover and vegetation types. For monthly reference evapotranspiration, the Global Reference Evapotranspiration (Global-ET_0) dataset was used (Zomer and Trabucoo 2022). The water requirements of different vegetation/land cover types are measured by the plant evapotranspiration coefficient (Kc) parameter. As it is the dominant crop throughout the catchment, monthly Kc values for cultivation were based on the Kc values for maize and typical planting and harvesting times in Zimbabwe (Allen et al. 1998; Igbadun et al. 2006; Mhizha et al. 2012). Kc values for natural land cover types drew on studies of leaf area index (LAI) from similar natural habitats in the region (Pfeifer et al. 2012; Ribeiro et al. 2008). LAI estimates were converted to Kc by dividing by three. Urban land Kc values were assigned using the equation $F \times 0.1 + (1 - F) \times 0.6$, where F is the fraction of impervious cover and evapotranspiration from pervious areas is assumed to be 0.6. There is significant uncertainty around setting the Kc of bare soil. Following the SWY user guide and other studies, Kc for bare ground was set at 0.5 (Belete et al. 2018; Sharp et al. 2020b).

As recommended in the InVEST user guide, the model was refined by comparing modelled actual evapotranspiration (AET) with remotely sensed measured AET. The Kc values for different land cover types were then adjusted accordingly to improve alignment between modelled and measured AET.

Monthly variation in average flows was calculated from the quickflow and net infiltration. A sequential mass curve procedure (Rippl method) was used to estimate reservoir capacity requirement for a given yield (defining a yield capacity relationship) for the reservoir catchment areas under the current and bare ground scenarios. Since infiltration is given as a single quantity and the proportion which ends up as surface flow was unknown, it was treated in three ways in a sensitivity analysis: as a constant flow (assuming all infiltrated water eventually reaches dams), distributed in relation to rainfall with a 1-month lag (again assuming all infiltrated water eventually reaches dams), and omitted (that is, no infiltration reaches dams). Reservoir storage capacity is valued in terms of average costs of dam construction per m^3.

The impact of ecosystems on net infiltration was presented in terms of the absolute difference in net infiltration between the current land cover and bare ground scenario. In the absence of detailed field data on hydrological fluxes, from which the relationship between infiltration, groundwater table levels, and the cost of extracting groundwater could be inferred, as well as uncertainties with estimating Kc for bare ground, no estimate has been made of the monetary value of this service.

The InVEST model does not partition net infiltration into water that contributes to long-term aquifer recharge and water that is eventually discharged into streams to form baseflow. This requires more detailed hydrological study. Groundwater dynamics remain poorly studied in Zimbabwe as a whole (Davis and Hirji 2014). However, some guidance was obtained from a preliminary report on groundwater dynamics within the Zimbabwean portion of the Zambezi Basin (encompassing the Mazowe Catchment), which used a factor of 60 percent of net infiltration to estimate the 'safe yield' of groundwater, after accounting for discharge to streams and other losses (NUST 2019). Applying this assumption to modelled net infiltration suggests annual groundwater recharge is around 2,145 Mm^3. Assuming that the remaining 1,430 Mm^3 contributes to baseflow, total streamflow (quickflow plus baseflow) is estimated to be 4,562 Mm^3. The baseflow index (that is, the contribution of baseflows to total streamflow) of the catchment was thus estimated to be 0.31. This estimate aligns with NUST (2019), which reported that ZINWA estimated baseflow indexes across the Zambezi River range from 0.05 to 0.40, with values in the upper Mazowe Catchment toward the high end of the range. This lends confidence to the assumptions used to partition net infiltration into groundwater recharge and baseflow.

Due to limited availability of flow monitoring data, the estimates are not extensively calibrated. However, flow data that could be found do lend confidence to the modelling estimates. First, the modelled annual streamflow (4,562 Mm^3) is close to the reported mean annual runoff of the Mazowe Catchment of around 4,582 Mm^3 (ZINWA 2007, in World Bank 2021). The modelled value for groundwater recharge (2,145 Mm^3) is also close to the value of 1,918 Mm^3 estimated by Davis and Hirji (2014). There was also an opportunity to compare modelled flows with measured flow data from two gauging stations (D27 and D28) in the Upper Mazowe Catchment reported by Nhedzi (2008). For D28, measured annual river discharge between 1987 and 2006 varied from 5 to 27 Mm^3. The InVEST estimate for total flows was 17.7 Mm^3/year, close to the median measured value of river discharge at station D28. For gauging station D27, measured river discharge ranged from <1 to 8 m^3 between 1987 and 2006. In this case, the modelled estimate of total streamflow (9.5 Mm^3) is relatively high, though still reasonably close to the observed flows.

There is some uncertainty around the estimation of the evaporation coefficient for bare ground (Kc), and the model results for the bare ground scenario are sensitive to this parameter. For example, the InVEST user guide notes that Kc for bare ground can range from 0.3 to 0.7 and recommends using a value of 0.5 (Sharp et al. 2020b), as done in this study. However, other studies have used lower estimates (for example, Nistor and Porumb 2015). Indeed, this is in line with the metanalysis of 75 groundwater recharge studies in semi-arid and subtropical environments by Owuor et al. (2016), who found that groundwater recharge generally declined where bare ground is converted to cropland or restored natural land cover. Unfortunately, since there are no extensive bare ground areas in the catchment, it was not possible to calibrate Kc values by comparing modelled AET with remotely sensed AET, as was done for other land cover types. A clearer understanding of relative changes in groundwater recharge and baseflow following more realistic land cover changes (for example, woodland to cultivation) will emerge from the scenario analysis, as there is less uncertainty associated with the Kc estimates for these land cover types.

Sediment retention

The sediment retention service was quantified using the InVEST SDR model and a 30 m resolution DEM. The model estimates sediment retention and export through combining soil loss, calculated using the RUSLE with an SDR, that is, the proportion of soil loss actually reaching a stream. Inputs required by the InVEST SDR model for calculation of the RUSLE include a soil erodibility (K-factor) layer, which estimates the inherent vulnerability of soil in an area to erosion based on various soil properties. In the absence of such a layer for Zimbabwe, a K-factor map was generated from various soil property layers obtained from the Africa

SoilGrids dataset (Hengl et al. 2015). Soil erodibility was calculated using the following equation:

$$K = \frac{2.1 \times 10^{-4}(12 - OM)M^{1.14} + 3.25(s-2) + 2.5(p-3)}{759},$$

where M is a parameter linked to particle size, OM is organic matter content (percent), s is soil structure class, and p is soil permeability class. For rainfall erosivity (R), the Global Rainfall Erosivity Database (GloREDa) (Panagos et al. 2017) was used, which provides a global map of rainfall erosivity at 250 m resolution. The land cover management (C) component of the RUSLE equation accounts for how different land cover types affect soil erosion relative to bare fallow areas (Wischmeier and Smith 1978). A C-factor value was assigned to each of the land cover and habitat types through reference to values used in the literature for comparable vegetation and land cover types (Angima et al. 2003; Fenta et al. 2020; Panagos et al. 2015; Wischmeier and Smith 1978). As different crops have different C-factor values, the C-factor value for cultivated land was calculated from the proportional area of different crop types in the constituent provinces of the Mazowe Catchment. The support practice (P) factor in the RUSLE equation is primarily relevant to agriculture lands and indicates the ratio of soil loss after implementation of soil conservation measures. Different P-factor values were assigned to large-scale commercial farmland on the one hand and communal, resettlement, and small-scale commercial farming areas on the other, due to the significant differences in field sizes and farming practices. The P-factor estimate for the latter recognized that contour ploughing and contour hedgerows are widely practiced in small-scale farming areas, while the P-factor estimate for large-scale commercial farmland incorporated the adoption of conservation tillage, cover cropping, and other soil conservation measures on some farms.

Since reservoir sedimentation is one of the major negative impacts of sediment export to watercourses, mapping of dams and their catchment areas was conducted. While the GOOD2 (Mulligan, van Soesbergen, and Sáenz 2020) does map the location and catchment areas of 38,000 dams globally, it was found that dam wall locations were not always corrected, resulting in incorrect catchment areas. Additionally, certain dams were not captured in the GOOD2 dataset. Hence, dam wall locations were updated and missing dams added using a combination of GOOD2, HydroLAKES data (Messager et al. 2016), and satellite imagery. Once dam locations had been accurately mapped, catchment areas were modelled using the 30 m DEM through the InVEST DelineateIT watershed creation tool.

Erosion and sediment modelling was validated and refined using sediment yield data from Van Den Wall Bake (1985), who reports average sedimentation rates of the Mazowe Dam and three other small dams in the study area (Masunswa, Nyamasa, and Nyamembwe), as well as the sediment yield for Chimanda Dam catchment from Tundu et al. (2018). This was the most recent sediment yield data that incorporated the study area in the comprehensive review of African sediment yield studies conducted by Vanmaercke et al. (2014). Our own literature search also did not reveal any more recent reliable sediment yield data. For the four small dams (Chimanda, Masunswa, Nyamasa, and Nyamembwe), modelled rates of sediment export from the respective catchment areas were within 4–25 percent of measured sediment accumulation rates. For Mazowe Dam, modelled sediment export was over twice the measured estimate. However, the sediment accumulation value for Mazowe Dam was an old long-term average between 1920 and 1984. It is quite likely that the greater loss of natural habitats to cultivation and urbanization and expansion of artisanal mining has increased sediment export rates in recent years, as has been reported by Tundu et al. (2018). Furthermore, one would expect sediment export to be somewhat higher than reservoir accumulation rates, as dams do not trap all exported sediment. Overall, the available data on reservoir sedimentation rates thus appear to lend confidence to the validity of the modelled sediment export rates.

The service was only valued within the catchment areas of existing dams. Options for valuation include estimating the cost of preventing sedimentation of dams by constructing sediment check dams or estimating the replacement cost of lost storage capacity through building additional water storage. For this study we used an estimated cost of check dam construction, obtained from Mekonnen et al. (2015). The volume of sediment was estimated from mass using a density of 1.35 t/m^3 (Haarhoff and Cassa 2009; Rooseboom 1992).

Appendix 6. Relative Future Potential for Maize and Sorghum

This appendix provides further details on the analysis that was performed to evaluate the potential benefit of switching from maize to sorghum, particularly under a hotter and drier future climate scenario. Modelling conducted as part of the CSAIP found that suitability for maize is low over much of the Mazowe Catchment and could decline further under future climatic conditions (World Bank 2019). The CSAIP recommends considering switching from maize to more drought-resistant crops such as sorghum. However, sorghum is generally lower yielding than maize under current conditions. Across the constituent provinces of the Mazowe Catchment, the average sorghum yield over the most recent three rainy seasons for which data are available was 0.47 tons per ha, compared to 0.99 tons per ha for maize (MoLAWFRR 2020, 2021). This yield gap is mirrored even in the drier provinces of the country such as Matabeleland. However, future declines in maize suitability in parts of the catchment could be severe enough that sorghum becomes a higher yielding option. Thus, the analysis described below aimed to evaluate whether there would be any parts of the Mazowe Catchment where declines in future suitability for maize would be severe enough that switching to sorghum would result in an increase in aggregate production.

Future suitability ratios for maize and sorghum

The below maps (Figure 42) indicate the FSRs for maize and sorghum. This was obtained by dividing future suitability by current/historical suitability, as per the layers produced for the CSAIP (World Bank 2019). The CSAIP modelled future suitability by 2050 under a hot and dry future climate scenario. In the figures below, an FSR value of 0.5 indicates an area where future suitability is projected to be 50 percent of current suitability. Values in green (that is, FSR > 1) thus indicate areas where future suitability is similar to or higher than present suitability.

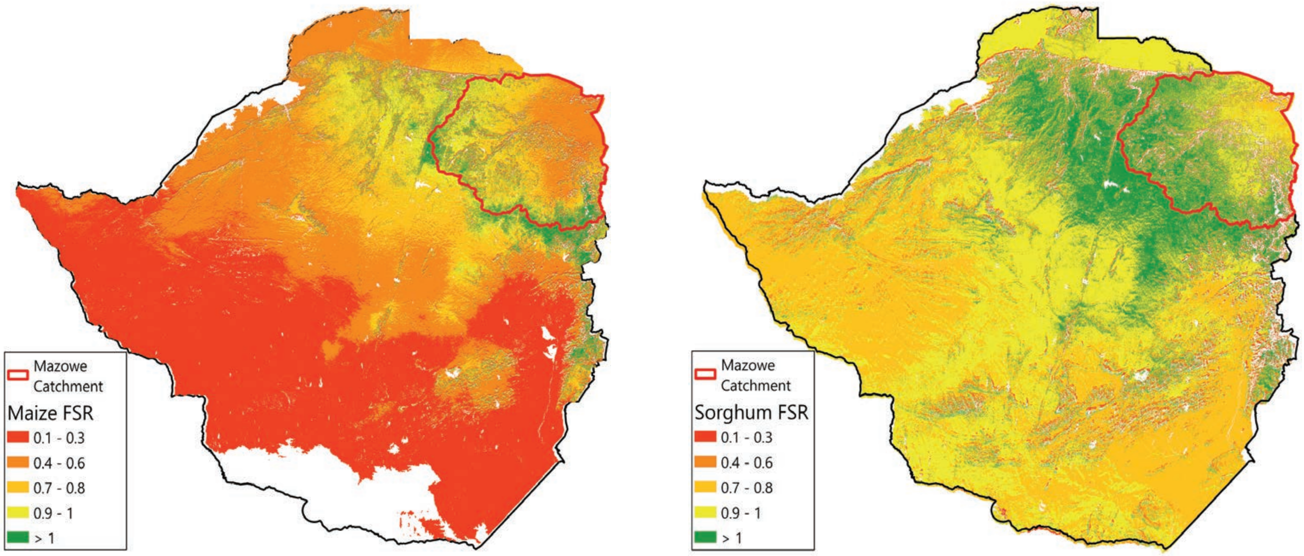
Future suitability for maize is predicted to decline over most of the country under a hot and dry future climate scenario, with particularly large declines in southern and western Zimbabwe (Figure 42). Future suitability for maize is projected to be less than 30 percent of present suitability over much of this region. Notably, the southern and western boundaries of the Mazowe Catchment are some of the only areas where suitability for maize is projected to remain stable or increase. Future suitability for sorghum is also projected to decline over much of the country, though the declines are generally less drastic than for maize. Furthermore, suitability for sorghum is projected to increase over the northern and eastern parts of Zimbabwe’s central watershed, including over the southern and western parts of the Mazowe Catchment.

Estimating future yields of maize and sorghum in the Mazowe Catchment

To estimate future maize and sorghum yields, current yields in the Mazowe Catchment were first obtained by averaging the yield values recorded in recent National Crop and Livestock Assessment reports (MoLAWFRR 2020, 2021). The future suitability ratio layers for maize and sorghum were then used to adjust the current yield values, to give an indication of predicted yields under a hotter and drier climate scenario. To evaluate the potential benefit of increasing the adoption of sorghum in the catchment, future production under the current maize/sorghum mix was compared to a scenario where 50 percent of maize fields are converted to sorghum. This analysis was done at a sub-catchment scale.

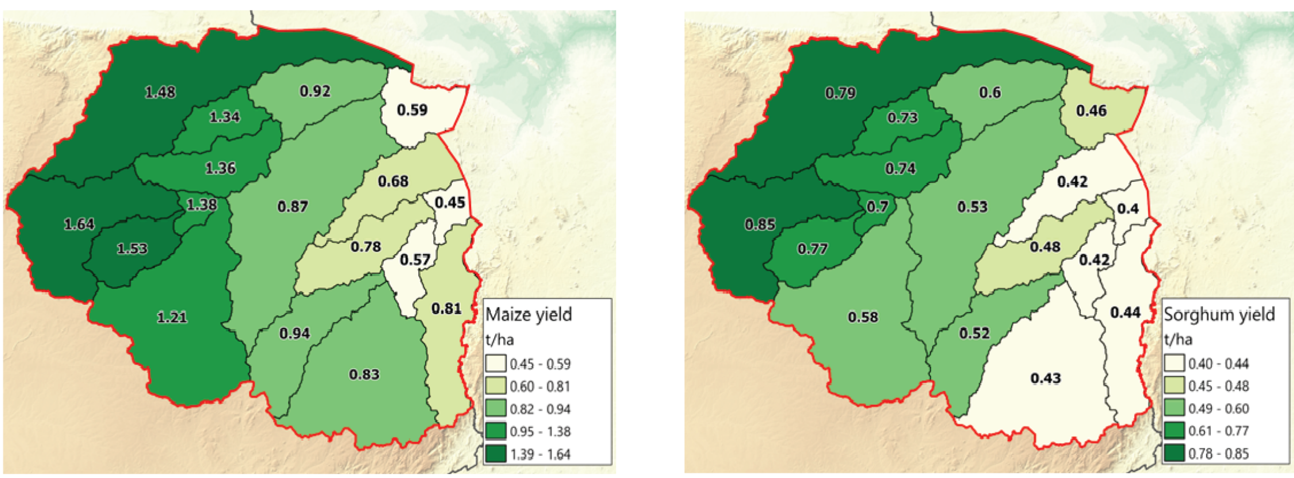
The projected future yields of maize and sorghum at sub-catchment after adjustment of current yields by the future suitability ratio layers are shown in Figure 43. Predicted yields for both maize and sorghum exhibit a similar spatial pattern, with higher yields in the wetter south and west of the catchment. Notably, even though declines in future suitability for maize are generally more drastic than for sorghum (Figure 42), predicted maize yields remain higher than predicted sorghum yields in all sub-catchments

FIGURE 42: FSR VALUES FOR MAIZE (LEFT) AND SORGHUM (RIGHT)



Source: CSAIP (World Bank 2019).

FIGURE 43: PROJECTED FUTURE YIELDS OF MAIZE (LEFT) AND SORGHUM (RIGHT) BASED ON ADJUSTMENT OF CURRENT YIELD BY THE ESTIMATED CHANGE IN FUTURE SUITABILITY



Source: Original calculations from this study. Numbers indicate average yield per sub-catchment in tons per ha per year.

(Figure 43). In other words, the modeling suggested that there is no part of the Mazowe Catchment where a switch from maize to sorghum would increase aggregate production. The difference in projected yields is generally smallest in the dry northeast of the catchment, where conditions for maize are most marginal. In these areas, switching to sorghum may be beneficial for increasing drought resistance among small-scale farmers. On a similar note, the modeling estimates were based on average yields over three previous rainy seasons. In drought years, switching to sorghum may result in higher overall grain production in certain parts of the catchment, contrary to what was modelled.

Appendix 7. Benefits and Costs of Sustainable Landscape Investments in the Subcatchments

All values in $ millions	PV costs and benefits, 25 years @ SDR of 4.56%																	
	SubC 1	SubC 2	SubC 4	SubC 5	SubC 6	SubC 7	SubC 8	SubC 9	SubC 10	SubC 11	SubC 12	SubC 13	SubC 14	SubC 15	SubC 16	SubC 17	SubC 18	Mazowe catchment overall
Costs	**10.6**	**27.1**	**77.2**	**2.8**	**13.8**	**64.6**	**21.7**	**15.1**	**5.4**	**15.9**	**35.3**	**6.2**	**13.3**	**47.2**	**4.1**	**44.8**	**17.0**	**422.0**
Restore degraded natural habitats	5.3	11.1	38.9	1.7	5.4	22.7	12.8	6.0	2.1	6.4	9.3	3.6	6.0	19.7	2.9	36.1	10.6	**200.5**
Establish conservancies	0.6	—	—	—	—	0.1	0.1	—	—	—	—	—	—	—	—	—	—	**0.8**
Implement conservation agri (50% adoption)	3.9	13.3	31.6	1.0	7.0	35.0	7.4	7.6	2.7	8.2	21.1	2.2	6.0	21.6	0.6	5.7	4.9	**179.7**
Install riparian buffers	0.8	2.8	6.7	0.1	1.4	6.9	1.4	1.4	0.6	1.3	4.8	0.4	1.3	5.9	0.6	3.0	1.5	**41.0**
Benefits	**23.9**	**56.0**	**118.1**	**8.2**	**24.4**	**154.6**	**31.9**	**22.5**	**8.6**	**31.5**	**55.0**	**11.1**	**23.1**	**117.7**	**−6.4**	**−2.4**	**32.0**	**709.9**
Avoided dredging (sediment)	0.6	1.0	14.0	0.0	1.2	2.9	0.6	0.0	—	5.4	4.8	1.0	3.8	17.0	4.5	30.4	20.5	**107.8**
Avoided dam costs (change in recharge)	—	13.4	10.9	—	2.1	35.9	—	2.2	—	2.1	7.6	—	2.4	43.6	—	—	4.7	**125.0**
Gains in wild harvested resources	0.2	1.5	2.4	0.0	0.4	1.3	0.2	–0.1	0.1	0.8	1.3	0.1	0.6	8.5	0.1	3.1	0.6	**21.1**
Changes in agricultural production	12.1	32.1	58.5	1.2	7.5	95.0	20.0	13.5	2.5	15.6	24.1	3.8	10.4	33.7	–13.0	– 58.9	0.5	**258.7**
Revenue from carbon credits	6.7	8.0	32.2	6.9	13.2	19.1	10.6	6.9	6.0	7.6	17.1	6.2	6.0	14.9	1.9	23.0	5.7	**191.9**
Tourism gains	4.3	—	—	—	—	0.4	0.5	—	—	—	—	—	—	—	—	—	—	**5.2**
Net present value	13.28	28.91	40.87	**5.46**	**10.63**	**89.97**	**10.26**	**7.43**	**3.23**	**15.57**	**19.68**	**4.92**	**9.83**	**70.53**	**−10.49**	**−47.27**	**15.06**	**287.87**
B:C ratio/ROI	**2.3**	**2.1**	**1.5**	**3.0**	**1.8**	**2.4**	**1.5**	**1.5**	**1.6**	**2.0**	**1.6**	**1.8**	**1.7**	**2.5**	**−1.6**	**−0.1**	**1.9**	**1.7**
ROI for farmland interventions	3.12	2.42	1.85	1.31	1.07	2.71	2.70	1.77	0.93	1.90	1.14	1.74	1.72	1.56	**−22.42**	**−10.35**	0.10	**1.44**
ROI for natural land interventions	1.75	1.73	1.30	3.84	2.49	2.01	0.84	1.21	2.25	2.05	2.17	1.82	1.75	3.29	1.87	1.44	2.61	**1.86**

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