



SERVICES FOR AN INTEGRATED EFLOWS ASSESSMENT TO
FACILITATE THE DEVELOPMENT AND AGREEMENT OF
“OBJECTIVE FLOWS” AT KEY SITES IN THE PUNGWE BASIN



SUPPORTING SPECIALIST STUDIES:
Delineation and Preliminary Status and Trends Interim Report



October 2022



EFlows Assessment of the Pungwe River Basin
Supporting Specialist Studies – Delineation and Preliminary Status and Trends Interim Report

27 October 2022

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PROJECT SUMMARY

Project number	GWPSA/0120/010/March 2022
Assignment	SERVICES FOR AN INTEGRATED FLOWS ASSESSMENT TO FACILITATE THE DEVELOPMENT AND AGREEMENT OF “OBJECTIVE FLOWS” AT KEY SITES IN THE PUNGWE BASIN
Countries	Zimbabwe and Mozambique
Objectives	The objective of the assignment is to support the Mozambique and Zimbabwe governments to facilitate the consultation process of determining ‘objective’ EFlows at strategic points in the transboundary Pungwe Basin that will, among other considerations, inform specifications on EFlows in the Pungwe Basin Agreement. Downstream flows agreed between the two countries will depend on EFlows allocations based on environmental targets as specified by Basin stakeholders, and abstraction allocations.
EFlows Methodology	<p>The EFlows Assessment for the Pungwe will use the Downstream Response to Imposed Flows Transformation (DRIFT) method for seven sites in the Basin. DRIFT is a process and Decision Support System (DSS) for managing and interrogating knowledge on the links between river flows (water, sediment and biota), ecosystem functioning and social uses. DRIFT allows for:</p> <ul style="list-style-type: none"> • Time-series based evaluation of changes to hydrology, hydraulic or sediment characteristics. • Incorporation and evaluation of measured or modelled time-series data. • Use of models, data, knowledge and experience to model ecosystem functioning. • Calibration or evaluation of time-series predictions against ecological data, where available. • Inclusion of social and management criteria. <p>The results from the DRIFT assessment, augmented with results from other studies as required, will be extrapolated to a further 15 sites in the Basin using the EFlows Basin Configuration Excel Model.</p>
Technical Team	<p>Project Leader: Prof. Cate Brown Knowledge Management: Dr Alison Joubert, Hassan Bukhari and Herminio Mulungo/José Sawanguane Hydrology: Gerald Howard <u>River Team</u> Team Lead and Water Quality: Dr Patsy Scherman Ecohydraulics: Dr Drew Birkhead Geomorphology: Prof. Kate Rowntree Riparian vegetation: Dr Karl Reinecke and Tongai Castigo Macroinvertebrates: Dr Justine Ewart-Smith, Prof. Tamuka Nihwatiwa (plus water quality) and Ricardo Guta Fish: Dr Stephen Lamberth and Dr Lightone Marufu <u>Estuarine and Marine Team</u> Team Lead and Physical Habitat: Dr Lara van Niekerk Hydrodynamics: Roy van Ballegooyen Water quality: Dr Susan Taljaard and Prof. Antonio Hogueane Macrophytes: Prof. Celia Macamo and Prof. Janine Adams Invertebrates: Fiona MacKay Fish: Steven Weerts and Dr Bernardino Sérgio Malawene Fisheries: Dr Bernardino Sérgio Malawene and Dr Stephen Lamberth <u>Social Team</u> Team Lead: Dr Jane Turpie Resource economics: Gwyn Letley and Luke Wilson Sociology: Prof. Lindah Mhlanga</p>

Stakeholder Engagement Strategy	<p>The EFlows project is part of a much bigger process with various Stakeholder fora; and the role of the EFlows Assessment team is to provide information and inputs that enhance the outcomes of that process. Thus, the Stakeholder engagement for this project will build on an earlier stakeholder mapping exercise by the International Union for Conservation of Nature (IUCN) and the GWPSA. GWPSA will mobilise these stakeholders on various platforms as needed during the delivery of this assignment: virtually, in workshops and meetings, but also for the main field data collection trips to the river and estuary. As part of the broader project implementation framework for stakeholder engagement, the issue of gendered participation is cross-cutting and the GWPSA gender expert will liaise with the EFlows team’s socio-economic experts on the adequate handling of this aspect of the work.</p>
Phases and Tasks	<p>The phases and tasks are for the assignment are:</p> <p>Phase 0: Inception</p> <p>Phase 1: Delineation and status</p> <ul style="list-style-type: none"> Task 1.1: Delineation and confirmation of EF zones Task 1.2: Preliminary selection of indicators for EF zones Task 1.3: Desktop status and trends assessment for EF zones Task 1.4: Preparation of baseline hydrology Task 1.5: Write-up Phase 1 Reports <p>Phase 2: Field work and model set up</p> <ul style="list-style-type: none"> Task 2.1: Topographic and bathymetry surveys Task 2.2: Collection of ecologically-relevant data at EF zones Task 2.3: Sectoral use of water Task 2.4: Ecosystem services assessment Task 2.5: Hydraulics and hydrodynamic modelling for EF zones Task 2.6: Set-up and calibrate EFlows model for rivers Task 2.7: Set-up and calibrate EFlows model for estuary Task 2.8: Write-up Phase 2 Reports <p>Phase 3: Assessment and EFMP</p> <ul style="list-style-type: none"> Task 3.1: Analyse the scenarios Task 3.2: Marine EFlows assessment Task 3.3: Development of Holding EFlows for key remaining parts of the Basin Task 3.4: Develop an EFlows basin configuration model/balance model Task 3.5: Write-up Phase 3 Reports <p>Integrated tasks</p> <ul style="list-style-type: none"> Task I.1: Project management Task I.2: Stakeholder engagement Task I.3: Capacity building.
Capacity Building	<p>The Pungwe EFlows assessment includes provision for capacity building at several levels such as:</p> <ul style="list-style-type: none"> Formal information sharing workshop Technical workshops for the project team Opportunities for interactions between team, GWPSA Project Management Unit (PMU) and country representatives Close links with and liaison between river, estuarine and marine scientists from South Africa, Mozambique and Zimbabwe
Project start date	April 2022
Project period	18 months

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ACRONYMS

ARA-Centro	Regional Water Administration of Central Mozambique
ASGM	Artisanal and Small-scale Gold Mining
ASPT	Average Score Per Taxon
BES	Baseline Ecological Status
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CPUE	Catch Per Unit Effort
DDT	dichlorodiphenyltrichloroethane
DO	Dissolved Oxygen
DRIFT	Downstream Response to Imposed Flow Transformations
DSS	Decision Support System
EFlows	Environmental Flows
EFZones	Focus zones for EFlows assessment
EGSA	Ecosystem Goods, Services and Attributes
EMA	Environmental Management Agency
EPT	Ephemeroptera, Plecoptera and Trichoptera
GAI	Geomorphology Driver Assessment Index
GDP	Gross Domestic Product
GE	Google Earth
GIS	Geographic Information System
GNP	Gorongosa National Park
GRP	Gorongosa Restoration Project
GSM	Gravel Sand Mud
GWPSA	Global Water Partnership Southern Africa
IUCN	International Union for Conservation of Nature
IWRM	Integrated Water Resources Management
LULC	Land use and land cover
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
masl	metres above sea level
Mm ³	million cubic metres
PAI	Physico-chemical Driver Assessment Index
PMU	Project Management Unit
RSF	Rippled Surface Flow
SASS5	South African Scoring System version 5.0
SBT	Smooth Boundary Turbulent
SIC	Stones-in-current
SE Zone	Socio-economic Zone
SIDA	Swedish International Development Co-operation Agency
SOOC	Stones-out-of-current

TDS	Total Dissolved Solids
VEGRAI	Riparian Vegetation Response Assessment Index
VIC	Vegetation-in-current
VOOC	Vegetation-out-of-current
WEAP	Water Evaluation and Planning System
WQ	Water Quality
WRSM	Water Resources Simulation Model
ZINWA	Zimbabwe National Water Authority
ZISS	Zambian Sampling System

1 INTRODUCTION

1.1 THIS ASSIGNMENT

This assignment is the INTEGRATED EFlows ASSESSMENT TO FACILITATE THE DEVELOPMENT AND AGREEMENT OF “OBJECTIVE FLOWS” AT KEY SITES IN THE PUNGWE BASIN. It is referred to more colloquially as **EFlows Assessment of the Pungwe River Basin**.

The objective of the assignment is to support the Mozambique and Zimbabwe governments to facilitate the consultation process for determining ‘objective’ EFlows at strategic points in the transboundary Pungwe Basin that will, among other considerations, inform specifications on EFlows in the Pungwe Basin Agreement. Downstream flows agreed between the two countries will depend on EFlows allocations based on environmental targets as specified by Basin stakeholders, and abstraction allocations. The project’s main objective is therefore to strengthen the management of transboundary water resources and connected ecosystems for sustained ecological benefits and improved resilience for riparian communities.

The EFlows Assessment for the Pungwe River and Estuary will use the Downstream Response to Imposed Flows Transformation (DRIFT) method (King *et al.* 2003; Brown *et al.* 2013). DRIFT is a process and Decision Support System (DSS) for managing and interrogating knowledge on the links between river flows (water, sediment and biota), ecosystem functioning and social uses. Within DRIFT, each specialist uses discipline-specific methods to derive the links and develop the relationships (response curves) between river flows and river condition. The central rationale of DRIFT is that different aspects of the flow regimes of a river elicit different responses from the riverine, estuarine and marine ecosystems. Thus, removal of part or all of a particular element of the flow regimes (of water, sediment or biota) will affect the ecosystems differently than will removal of some other elements.

The Terms of Reference for the assignment require that the DRIFT EFlows Model is set up for five locations representing zones of the river and the estuary (Section 3.5). The results from the DRIFT assessment, augmented with results from other studies as required, will be extrapolated to a further 15 sites in the Basin using the EFlows Basin Configuration Model.

1.1.1 Progress to date

The EFlows Assessment of the Pungwe River Basin started in May 2022 and will run until September 2023, in two phases. The key deliverables are listed in Table 1.1.

Table 1.1 Key deliverables

#	Title	Status
1	Inception Report	Complete
Phase 1		
2	Delineation Report	Complete
3	Preliminary Status and Trends Interim Report	This report
Phase 2		
4	Hydrology, Hydraulics and Hydrodynamics Report	
5	Resource Economics Report	
6	River supporting Specialists' Report	
7	Estuary supporting Specialists' Report	
8	Marine EFlows Assessment Report	
Phase 2		
9	Scenario Assessment Report for Rivers and Estuary	
10	EFlows Basin Configuration Model	
11	DRIFT-Pungwe DB, and associated files and User Manual	

1.2 THIS REPORT

This report is an interim report on the *Delineation and Preliminary Status and Trends* for the riverine, estuarine and associated socio-economic environments. It describes the delineation of the Pungwe River Basin into EFlows and socio-economic zones, preliminary indicators for use in the EFlows assessment and a preliminary baseline status and historical trends for the indicators. This information part of the Set-up stage of DRIFT, and will be used to prepare the response curves in the DRIFT-PUNGWE EFlows Model for the indicators.

Data are still being sourced and the preparatory work for the various disciplines is at different stages, thus information in this report will be updated as the study progresses. The final version thereof will be included in the SUPPORTING SPECIALIST STUDIES Reports due in March 2023.

1.3 ASSUMPTIONS AND LIMITATIONS

In general, ecological and socio-economic data for the study area are limited. Data requests have been fulfilled slowly, with little information forthcoming for all components despite reports (e.g., Consultec 2013) suggesting that data are available. Thus, the information reflected in this report represents the data that have been received, information contained in published paper and reports, and data collected first hand for the river during a reconnaissance visit to the Basin by the team in June 2022 and a river data collection field trip in August 2022. The estuary data collection field trip took place in the last week of October 2022, and so the data collected on that trip are excluded from

this interim report. The socio-economic component is based on existing literature, plus context gained during the reconnaissance visit in June 2022.

2 BASIN OVERVIEW

The Pungwe River is a perennial river with a low degree of water-resource development, i.e., abstractions, diversions and/or regulation. The river rises in Zimbabwe and flows through Mozambique to the Indian Ocean.

The main drivers of river and estuarine ecosystem condition are hydrology, hydraulics, sediment and water quality, which dictate the physical and chemical habitats for biota, and human pressures on the system, such as fishing and gold mining.

The large temporal variation in precipitation within the region leads to great inter-annual variations in the Pungwe flows, meaning that very wet and very dry years are experienced relatively frequently (SWECO 2008). Climate change is likely to exacerbate the already dynamic situation (Feresu 2017).

2.1 TOPOGRAPHY, CLIMATE, DRAINAGE AND LAND COVER

The Pungwe Basin covers an area of 31 022 km², of which 1 465 km² (4.7%) are in Zimbabwe (generating 24.2% of the Mean Annual Runoff; MAR = ~62.1 Mm³), and 29 555 km² (95.3%) are in Mozambique (generating 75.8% of the MAR; MAR = ~194.1 Mm³). The Pungwe River is ~414 km long (SWECO 2008) with its source in the foothills of the Nyanga Mountains, which form the northernmost extent of the Eastern Highlands of Zimbabwe (Figure 2.1). The river rises below Mount Inyangani, which at an altitude of 2592 metres above sea level (masl) is the highest mountain in Zimbabwe. The river flows south-eastward through the Honde Valley, crossing into Mozambique near the previously named Katiyo Tea Estate, ~60 km from its source (Alferes *et al.* 2006). It then flows through the Mozambican provinces of Manica and Sofala for ~340 km before reaching the coastal floodplains and estuary. The low-lying and gentle slopes that characterise most of the basin give rise to a wide meandering river with large floodplains and extensive wetlands. The Pungwe River flows into the Mozambique Channel in the Indian Ocean at Beira Port (Gumbo and Kapangaziwiri 2021).

The principal tributaries of the Pungwe River in Zimbabwe are the Honde River on the right bank and the Nyazengu, Chiteme, Nyamhingura, Nyawamba, Nyamukombe and Rwera rivers on the left bank (Governments of the Republics of Mozambique and Zimbabwe 2006). The catchment area in Zimbabwe includes parts of Nyanga National Park, exotic forest plantations, and commercial and small scale agriculture (SWECO 2004).

The main tributaries in Mozambique are the Nhazonia, Txatora, Vunduzi and Urema rivers rising from the north to join the main river on its left bank, and the Honde, Metuchira and Muda from the south (Governments of the Republics of Mozambique and Zimbabwe 2006).

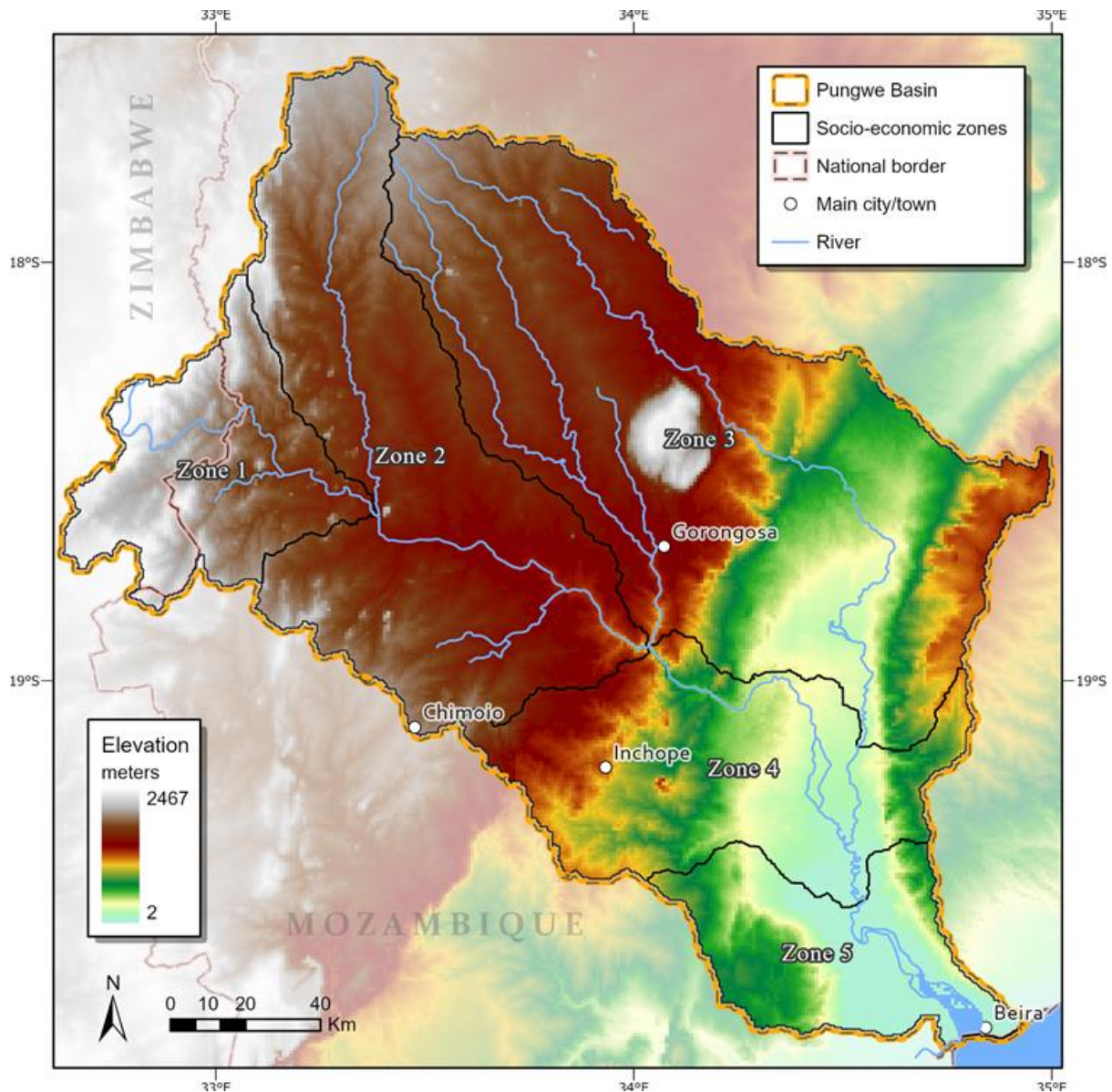


Figure 2.1 Topographic elevation of the Pungwe River Basin in Zimbabwe and Mozambique. Source: WordClim 2 (Fick and Hijmans 2017)

The topography of the basin influences temperature, rainfall availability, soil fertility, natural vegetation and drainage, which determine the population and settlement patterns and consequently land use and socio-economic activities. In the upper reaches of the basin, the terrain is characterized by steep hilly landscapes covered by dense natural forests (SWECO 2004). In Mozambique, the river flows through a plateau at 1 000-3 000 masl (Terink and Droogers 2014) to the confluence with the Vunduzi River, after which the altitude decreases rapidly to <100 masl (Figure 2.1). The distinctive features of the middle reaches are the Gorongosa Mountain (1863 masl), and the Urema Trough or Rift Valley, which is a broad lowland alluvial plain that drains into Lake Urema (Beilfuss *et al.* 2007). The Urema system is fed from the Vunduzi River in the north-west and the Mucambezi River in the north-east (Alferes *et al.* 2006; Bohme *et al.* 2006). The Vunduzi River originates from the Gorongosa

Mountain at an elevation of 1 863 m masl. The Mucambezi system rises south of the shallow divide separating the Pungwe and Zambezi sub-systems. Both tributaries flow southwards into the seasonal Urema Lake, which exits into Urema River and joins Pungwe River (Alferes *et al.* 2006). Much of this area is protected within the Gorongosa National Park, an area of approximately 3770 km² (Arvidsson *et al.* 2011) that includes Urema Lake. Urema Lake varies considerably in size from ~10 km² in the dry season to ~120 km² in the wet season. Around the lake, the terrain is very flat with a floodplain ecosystem that is sensitive to changes in the flow regime. The waters of the lake and downstream Urema River are generally referred to as ‘white waters’ due to their distinctive yellow-ochre colour and opaqueness. Downstream of Lake Urema, the lower reaches of the basin are characterised by seasonally flooded, swampy pans and floodplains. The lower basin is just a few metres above sea level and is often subjected to flooding during the rainy season. During times of low river flow, sea water flows back into the river for 80 to 100 km from the mouth (Alferes *et al.* 2006).

Rainfall in the Pungwe Basin is strongly seasonal, with a pronounced dry season from May to November (Beilfuss *et al.* 2007; Terink and Droogers 2014). The mean annual precipitation (MAP) across the basin is variable, but generally high (Table 2.1). The smallest sub-basin (Pungwe Zimbabwe) in the Eastern Highlands of Zimbabwe receives the highest rainfall of ~2000 mm per annum (Table 2.1). The upper middle and middle sub-basins receive on average 850 to 950 mm each year, with the exception of the Vunduzi sub-basin which receives over 1100 mm each year. The lower reaches of the basin receive on average 1000 to 1200 mm of rainfall each year, i.e., higher than the middle reaches of the basin (Table 2.1). This mountainous areas are also significantly cooler, with average temperatures of 10 to 20°C, compared with the surrounding non-mountainous areas and the tropical humid coastal areas where average temperatures range from 22°C in the cooler months to 30°C in the warmer months (Alferes *et al.* 2006; Beilfuss *et al.* 2007; Terink and Droogers 2014). In the middle and lower reaches, the potential evapotranspiration exceeds rainfall by up to 600 mm in some areas, which can result in a water deficit during the dry months (Beilfuss *et al.* 2007).

Table 2.1 Area, mean annual precipitation (MAP) and mean annual evaporation (MAE) for each of the twelve sub-basins of the Pungwe River Basin. Source: Consultec 2013.

Zone	Sub-basin name	Area (km ²)	MAP (mm)	MAE (mm)
Zone 1: Nyanga mountains	Pungwe Zimbabwe	687	2000	1 450
	Honde	1245	1 340	1 450
	Upper Pungwe	2846	1 130	1 450
Zone 2: Upper Middle Pungwe	Nhazonia	2829	1 140	1 450
	Upper Middle Pungwe	2400	900	1 450
	Lower Middle Pungwe	3439	950	1 380
Zone 3: Gorongosa	Vunduzi	2990	1 120	1 450
	Nhandugue	2830	850	1 450
	Urema	5572	900	1 590
Zone 4: Lower Pungwe floodplains	Lower Pungwe	3512	1 050	1 590
	Muda	1336	1 050	1 380
Zone 5: Estuary and coast	Pungwe Estuary	2933	1 180	1 400

Water demand is dominated by agriculture, largely due to the commercial sugar-cane estates, with urban supply being the second largest users (SWECO 2008). There are two large water supply dams in the Pungwe River Basin. Wamba Dam in Zimbabwe is used to irrigate ~20 000 ha of tea plantation, and Muda Dam in Mozambique supplies the irrigation areas of Lamego and Mafambisse Sugar Estate (~25 000 ha). Other major water abstractions include the Pungwe Mutare Water Supply Transfer and Beira Water Supply System. There are also small piped water supply systems on tributaries of the Pungwe River in Zimbabwe and several small irrigation schemes in both countries. Sanitation facilities in the catchment are largely based on pit latrines for rural villages with the exception of Beira City where there are water-based sewage systems.

The Pungwe Basin is relatively undeveloped with large expanses of natural vegetation covering more than 92% of the area. Overall, forest (closed and open) is the most dominant land cover class across the Pungwe basin, accounting for just under 75% of the area, followed by grassland (7%) and shrubland (3.4%, Table 2.2, Figure 2.2). The Zimbabwean portion of the catchment comprises mostly forest, which covers >80% of the basin area in the country (Table 2.2, Figure 2.2). Cultivated land covers only 10% of the catchment, mainly in Honde Valley along the edges of the river channels. In Mozambique, forest or woodland vegetation accounts for >79% of the land cover, grassland 8%, shrubland 4% and wetland 3%. Approximately 135 km² of the entire 31 022 km² are classified as urban.

Table 2.2 Land cover summary for the Pungwe Basin per country. Data source: Copernicus Global Land Service: Land Cover 100 m dataset (Buchhorn *et al.* 2020).

Land cover type	Zimbabwe		Mozambique		Total	
	km ²	%	km ²	%	km ²	%
Closed forest	653	42%	12 304	36%	12 957	34.4%
Open forest/woodland	724	46%	14 692	43%	15 415	41.0%
Shrubland	19	1%	1 261	4%	1 279	3.4%
Herbaceous vegetation	10	1%	2 628	8%	2 638	7.0%
Wetland	0	0%	877	3%	877	2.3%
Permanent water	2	0%	15	0%	1 710	4.5%
Bare / Sparse vegetation	0	0%	0	0%	24	0.1%
Cropland	151	10%	2 456	7%	2 607	6.9%
Urban/built-up	1	0%	135	0%	136	0.4%

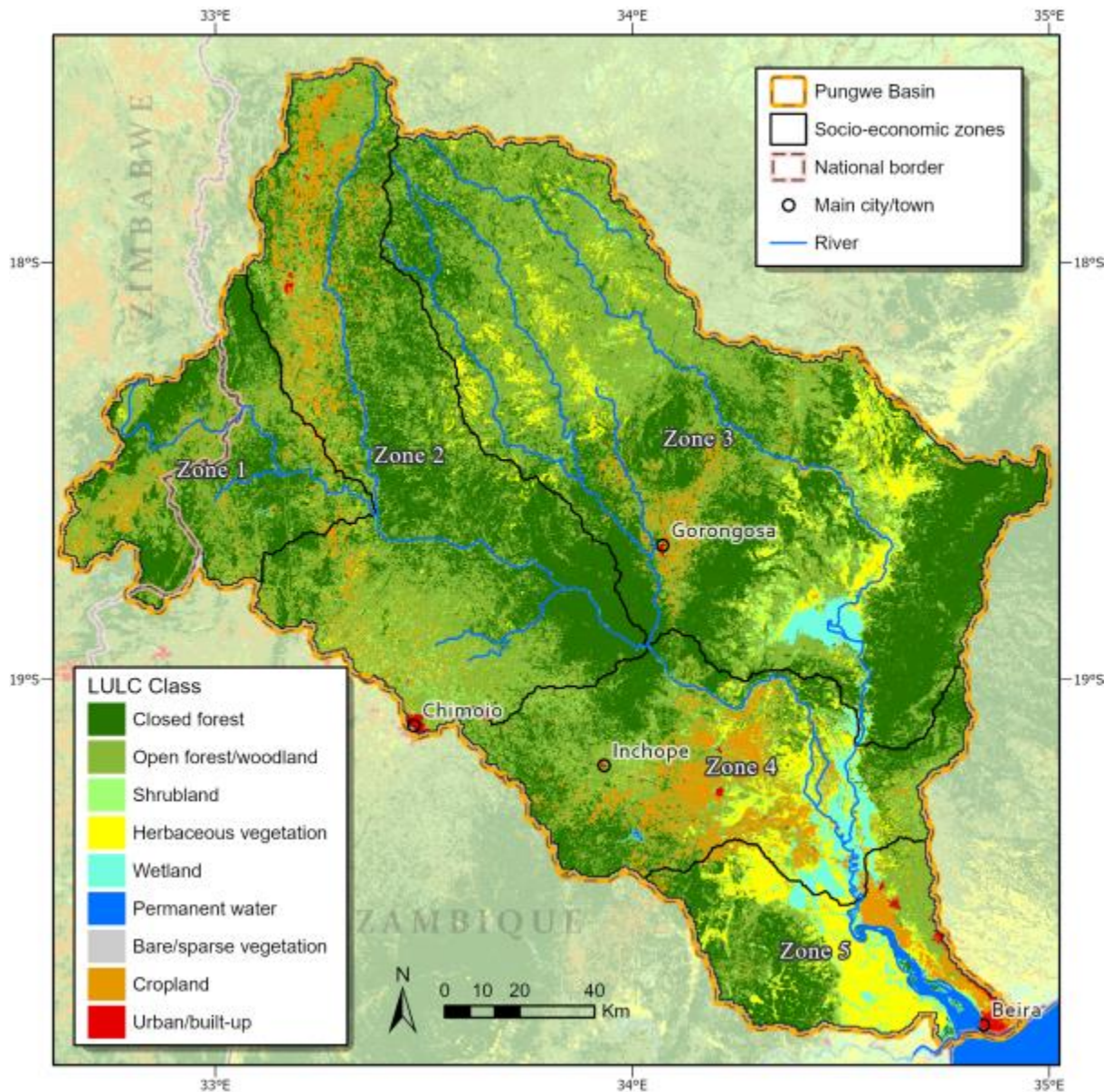


Figure 2.2 Land use and land cover (LULC) of the Pungwe River Basin in 2020. Source: Copernicus Global Land Service: Land Cover 100 m (Buchhorn *et al.* 2020)

2.2 ADMINISTRATION, LAND TENURE AND PROTECTED AREAS

Administratively, the Pungwe River Basin covers part of the Mutasa and Nyanga districts in Manicaland province in Zimbabwe and extends across large parts of Sofala and Manica provinces in Mozambique covering areas of 11 districts (Figure 2.3).



Figure 2.3 Administrative districts and wards in the study area. Data source: Sub-national administrative boundaries (OCHA ROSEA 2018, 2021)

Around 92% of the basin is covered by natural vegetation of which Nyanga National Park in Zimbabwe protects ~1.1% in the headwaters and Gorongosa National Park in Manica Province, Mozambique protects ~20% (Figure 2.4). Gorongosa National Park is surrounded by an extensive buffer zone where livelihood activities of the residents are managed (Figure 2.4). Controlled hunting reserves (known as Coutadas; Figure 2.4) in Mozambique occupy 20% of the basin (SWECO 2004). There are also managed state forests in the upper reaches of the basin in Zimbabwe.

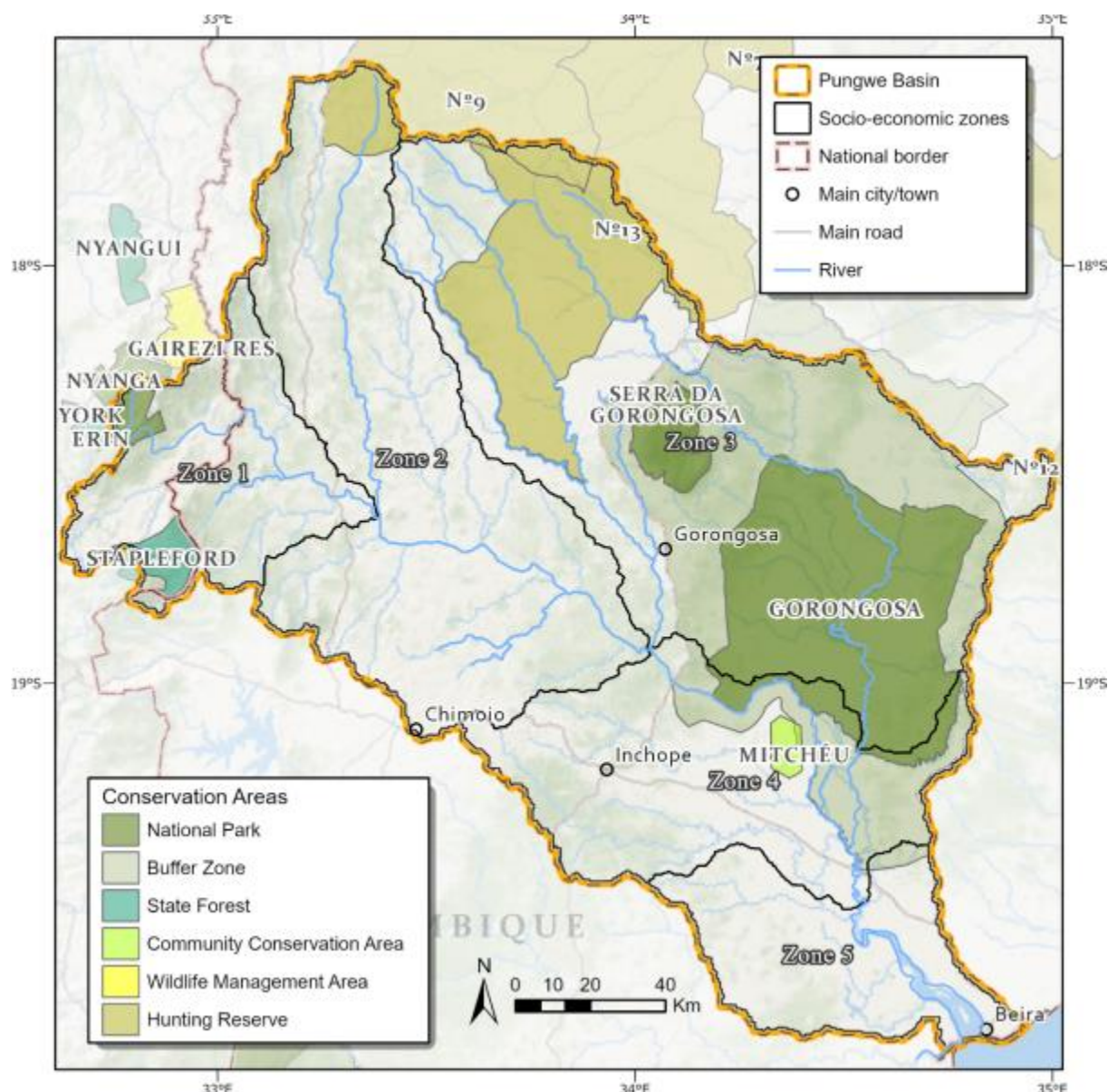


Figure 2.4 Protected and managed areas in and around the Pungwe River Basin in Zimbabwe and Mozambique. Source: WDPA and WD-OECM (UNEP-WCMC and IUCN 2022)

The regional water authority in the Mozambique, which contains the largest part of the basin, is ARA-Centro. According to Resolution No 22/2021 of June 2021, ARA-Centro is responsible for, inter alia: a) Management of hydrographic basins, with a focus on land occupation plans and water domain protection zones; b) Elaboration of mapping and technical coordination, with the environment sector, in territorial planning, in order to guarantee the standardization of the land register; c) Management and inspection of protected areas on the banks of rivers, lakes, reservoirs and lagoons and authorization of projects that may be developed in these areas; d) Inventory of water resources and water needs to update the National Water Resources Register; e) Collection, processing, analysis and storage of hydro-climatological data and systematic dissemination of hydro-climatological information; f) Updating the National Water Resources Information System; g) Issuance of Licenses

and Concessions for the use and exploitation of non-treated water, authorizations for the discharge of effluents; h) Implementation of measures to protect water resources; i) Definition and implementation of structural measures against floods and drought; j) Approval and inspection of hydraulic works.

The Water Law, Law Nr. 16/91, governs water resources management in Mozambique. Stakeholder participation is via the Basin Committees, which have a consultative role (SWECO 2008).

2.3 POPULATION, SETTLEMENT PATTERNS AND SOCIO-ECONOMIC STATUS

In 2020, the population of the Pungwe River Basin was 1.9 million persons, with 1.8 million (96%) of those in Mozambique (WorldPop 2020). The split between males and females is similar across the two countries, with ~52% of the population recorded as female (51.9% in Zimbabwe, 51.7% in Mozambique). The mean population density for the basin is 49 persons per km² (Figure 2.5) and is slightly higher in Mozambique (48.7 persons/km²) than in Zimbabwe (44.7 persons/km²).

Settlements in the basin consist predominantly of scattered rural village communities with a few larger urban centres. The central northern parts of the Basin are generally sparsely populated, with higher population densities in the lower eastern parts. Most of the urban centres are located on the N1, N6 and N7 roads that cross the basin, connecting southern and northern Mozambique, and Mozambique to Zimbabwe. Along these roads there are a series of trading centres and towns, and ribbon development along much of the main N6 highway that connects the port city of Beira in Mozambique with the city of Mutare in Zimbabwe (Figure 2.5). In Zimbabwe, settlements occur largely in parts of Mutasa district and a small portion of Nyanga district. Hauna Growth Point is the major settlement in the Honde Valley in Zimbabwe. Beira is the largest urban industrial centre in the basin. Other notable towns in Mozambique are Chimoio, Dondo, Inchope and Gorongosa.

The rural people in Mozambique reside primarily in traditional pole and mud/clay houses while in Zimbabwe homesteads tend to be made of brick and roofed by zinc or asbestos sheets. Most households in the basin rely on boreholes or shallow wells for their drinking water. However, in the remote rural areas of the basin, there are a number of villages that rely solely on the water collected from rivers and streams. In some households, female household members travel long distances to fetch water, especially in the dry season. In Zimbabwe, there are some small, piped water supply schemes, but individual house connections and treated water supplies remain poorly developed across the Basin. Rivers and streams are also used for washing clothes and for bathing (Figure 2.6). Sanitation is poor, with most households in the Basin lacking adequate sanitation facilities. Traditional pit latrines are used in the rural villages and in some urban centres. In the larger cities, such as Beira and Hauna, water-based systems have been developed.

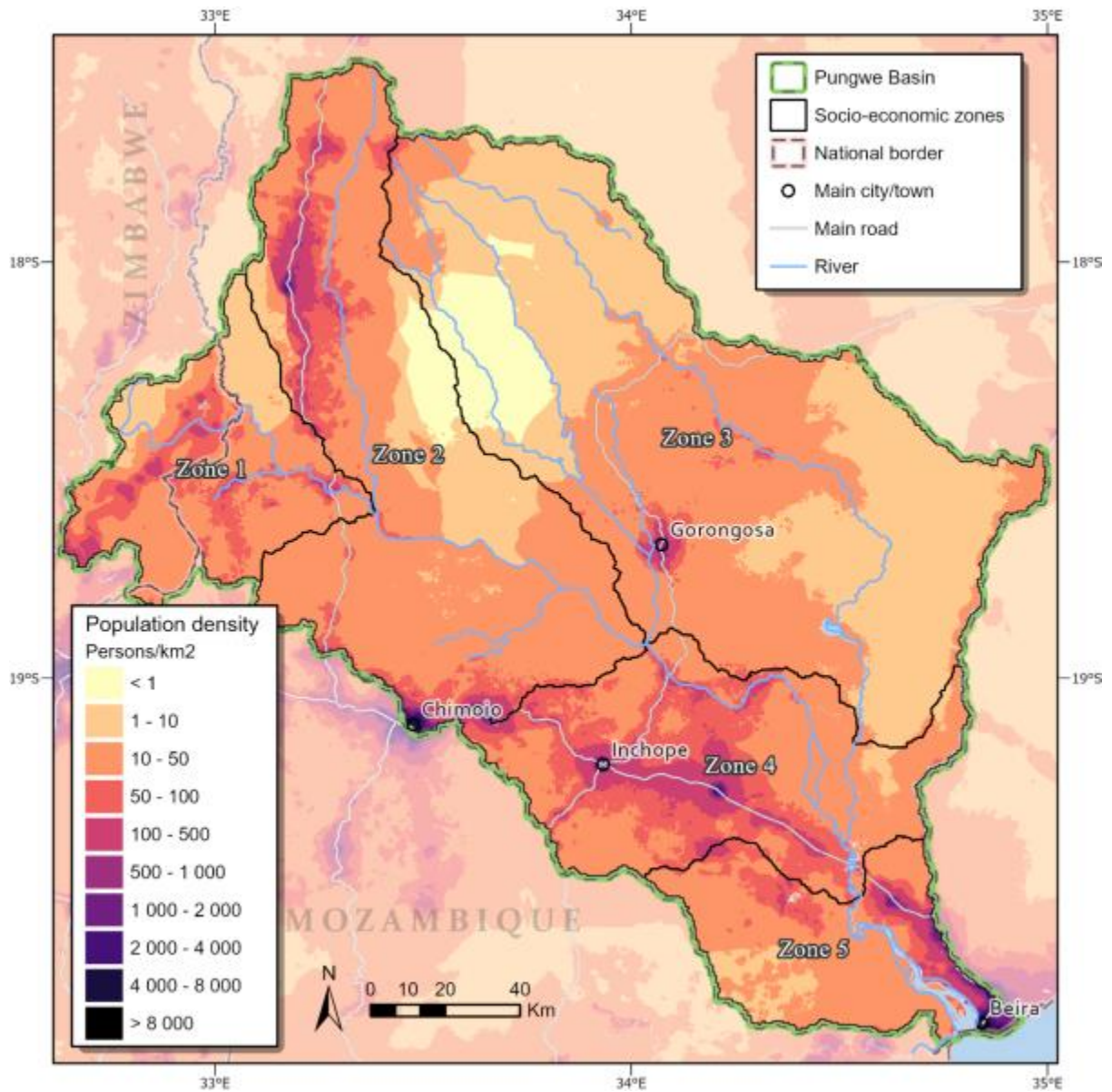


Figure 2.5 Population density (persons/km²) across the Pungwe River Basin. Data source: Population count, UN adjusted (WorldPop 2020)



Figure 2.6 Women from the village of Mukupe, Zimbabwe washing clothes in the Pungwe River

2.4 ECONOMIC AND LIVELIHOOD ACTIVITIES

Water is directly critical to social and economic development, but also supports key ecological systems that provide essential ecosystem goods and services that underpin development and human wellbeing. In the study area, economic activities that depend on the licenced use of water include urban supply, irrigation agriculture, mining and industry. Economic activities whose outputs are linked to the quality of aquatic ecosystems include fisheries and nature-based tourism, for example. In addition, the functioning of aquatic ecosystems also plays a role in overall economic productivity through ecosystem services that lead to cost savings, such as flood attenuation and water quality amelioration. These cost savings manifest in both the private and public sector. Similarly, social wellbeing within the study area is determined by both water supply and instream flows, namely the abstraction and supply of water for domestic purposes, the supply of abstracted or instream water to economic activities which provide employment opportunities, and the supply of instream flows which lead to the provision of instream water, natural resources and opportunities for recreation and spiritual fulfilment. Ecosystem services are therefore an integral factor influencing the economic and social status of the different parts of the study area.

Economic activities in the Pungwe River Basin are largely based on agricultural production, fishing and the use of forestry and wildlife resources, as reported in 2004 (SWECO 2004). Ecotourism is important for some communities that border the Nyanga National Park in Zimbabwe and Gorongosa National Park in Mozambique. The resurgence of Gorongosa National Park and associated tourism has the potential to stimulate significant economic development in the basin. However, particularly in Mozambique, tourism remains limited due to issues around safety, access and appropriate infrastructure.

Agriculture is a mixture of dryland subsistence and irrigated crop farming. Smallholder (or subsistence) farmers¹ dominate the landscape across most of the basin. Smallholder farmers living in close proximity to rivers tend to keep dryland fields as well as floodplain gardens which they plant during the low flow season. Men, women and young girls are involved in farming. Throughout the Basin, maize is the dominant staple crop and appears to be grown by the majority of households who engage in crop production. Other important crops include sorghum, sugarcane, sesame, tomatoes, beans, sweet potatoes, yams and green leafy vegetables (e.g., covo and tsunga).

In the upper Basin in Zimbabwe agriculture is relatively intensive with smallholder farms on communal lands, and large-scale commercial farms and forestry plantations. The smallholder farms focus on banana and sugarcane, with some horticultural produce such as tomatoes, yams and beans also grown. Smallholder farmers, both men and women, transport and sell their produce at markets in Harare. Commercial farms produce coffee and tea, as well as high value crops such macadamia nuts and avocados being more recently cultivated in the study area (Figure 2.7).



Figure 2.7 Recently planted macadamia nut trees on a commercial farm in the Honde Valley, Zimbabwe which was previously Katiyo Tea Estate. Avocados are also grown on this farm.

The middle parts of the Basin in Mozambique are relatively undeveloped and sparsely populated. However, in sections along the main N6 and N7 roads in Manica Province, there is large-scale irrigated

¹ These farmers comprise a continuum between subsistence production and crop production for market.

commercial farming. Maize and horticultural products appear to be the main crops being cultivated here. Large scale commercial sugarcane farms are situated in the lower basin in the floodplain areas that surround the estuary. Among households which keep ruminant livestock, goats appear to be the most abundant type, especially in Mozambique where communities in the central and western parts of the basin report that cattle are rarely kept due to Tsetse fly disease and theft. Some cattle are kept in the upper basin in Zimbabwe. Generally, men are responsible for rearing livestock.

Across the Basin, people harvest wild plant and animal resources for nutrition, health, energy and raw materials, particularly where other economic opportunities are limited. Resources are harvested predominantly by poorer households on a subsistence basis or to generate small cash incomes. Dependence on aquatic resources is limited to harvesting of fish, reeds and papyrus.

Fishing is a dominant activity throughout the Pungwe River Basin from the rich coastal waters off Beira to the Pungwe estuary and on the main Pungwe River and its tributaries. Fishing is undertaken predominantly by men. However, women might be involved in the processing and sale of the fish at markets. In Beira, there are industrial, semi-industrial and artisanal fishermen who operate offshore and, in the estuary, catching a wide variety of fish, prawns, squid and other shellfish such as clams (Figure 2.8). Inland fishing is an important source of protein for households as well as for household income. Fishing on the main river and its tributaries is more productive during the high flow season.



Figure 2.8 A wide variety of fish, molluscs and crustaceans are sold on the beach at Mercado Praia Nova in Beira

Reeds and papyrus are important plant resources commonly harvested by men and used to make sleeping mats, fences and baskets. Sleeping mats and fences are usually made by the men and the baskets are made by the women. These are used by the household but are also sold or bartered. While households do harvest wild foods and medicines for health and nutrition benefits, information on the collection and use of such resources is limited.

Alternative livelihood activities in the basin include artisanal sand and gold-mining, firewood harvesting and charcoal production, all of which are major contributors to environmental degradation and erosion. In keeping with most of rural sub-Saharan Africa, firewood is the dominant source of cooking energy in the Basin, mostly collected by women. However, there is a growing demand for charcoal, which is a major source of cooking energy in the urban centres. The production of charcoal, sand mining and gold panning are activities undertaken by men and young boys. Poverty is a key driver of these destructive activities, which are viewed as additional or alternative income sources by local residents, and for some are significant. The other key driver is the growing demand for charcoal and building materials from urban markets (Figure 2.9).



Figure 2.9 Charcoal is sold along most of the main roads in Mozambique and is transported to the urban centres where it is the main cooking fuel

2.5 MAIN IMPACTS ON THE AQUATIC ECOSYSTEMS

The main impacts on the Pungwe river and estuary are related to impaired water quality in the river and estuary, including salt water intrusion into the river, and harvesting pressure on key aquatic resources.

The process of saltwater intrusion is natural, but water abstraction during low flows have extended the distance to which saline water penetrates up the Pungwe River.

The main sources of pollution (Governments of the Republics of Mozambique and Zimbabwe 2006) are:

- Artisanal and Small-scale Gold Mining (ASGM)
- Agriculture
- Afforestation
- Rural and urban settlements
- Invasive alien fauna.

A significant impact in the system is due to the proliferation of AGSM, particularly downstream of the Nyamukwarara River, a tributary in Mozambique. AGSM activities result in the release of large quantities of sediment into the system, particularly at EF sites 2 and 3. This fine suspended sediment load has a significant impact on the turbidity levels of the systems and extends down the main stem of the Pungwe.

In addition to formal mining, there appears to be a significant increase in informal gold-mining activities, with the impact spreading from Manica Province as far downstream as the Muda River in Sofala Province in Mozambique. Impacts associated with AGSM include increased sediment loads in the water column as a result of intensive and direct panning activities in the riverbed, unintentional release of tailings into waterways through erosion and runoff, dumping of tailings directly into the river, diversion of river and stream courses to allow access to mineralized alluvial gravel deposits on the existing riverbed, trenching paleo-channels and floodplains increasing connectivity and sedimentation into the channel and washing stockpiles of abandoned gold mines in the river. Mercury (Hg) (and cyanide (Cn)) is used in ASGM because it simplifies the process of gold recovery at a low cost. An estimated six tons of Hg are used annually by illegal gold-mining in Zimbabwe (cited in Southern Waters 2022a). Most of the illegal panning is carried out unsystematically in Zimbabwe, usually in river beds, banks and floodplains. No rehabilitation is conducted and deep pits are left behind, resulting in conflict with farmers. Figure 2.10 shows the extensive illegal mining taking place in Zimbabwe as at 2015 (Source: Environmental Management Agency (EMA; Feresu 2017).

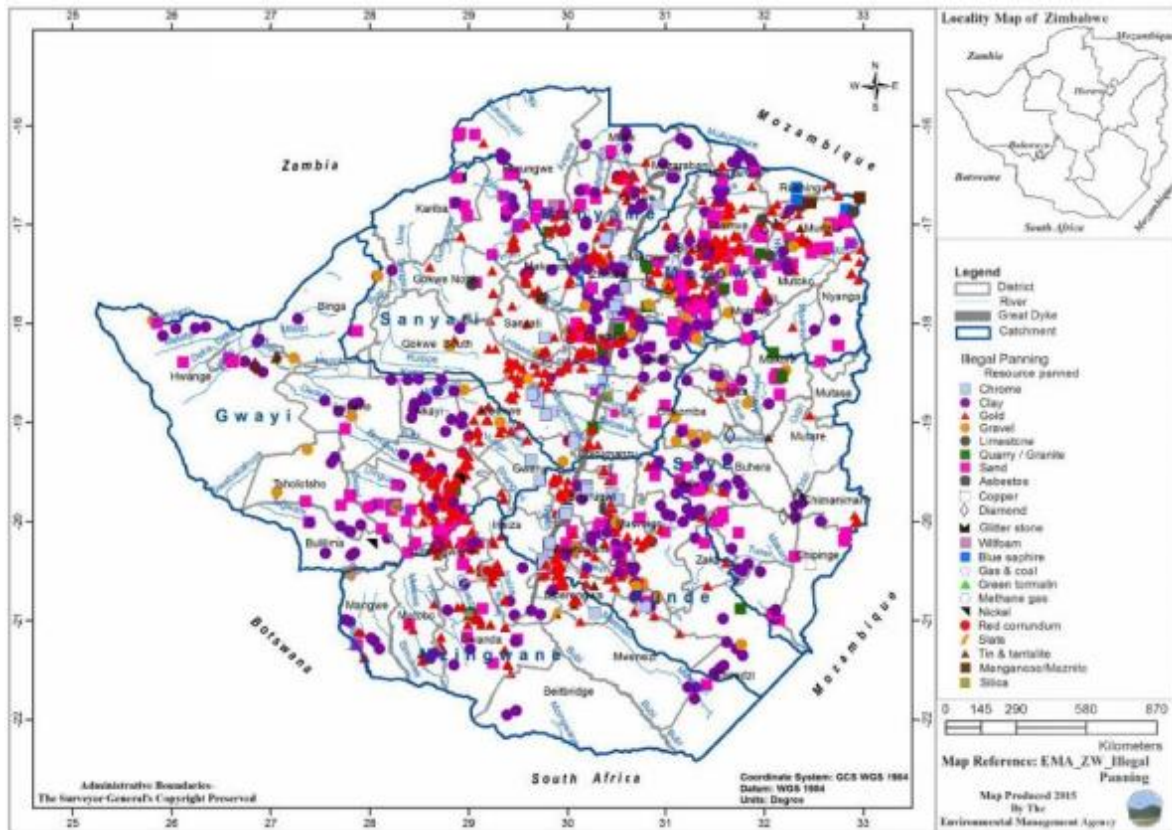


Figure 2.10 Illegal mining in Zimbabwe as at 2015 (Feresu 2017)

Mercury-dependent ASGM is the largest source of mercury pollution on earth, as reported by Esdaile and Chalker (2018), posing significant concern to miners (primarily through inhalation of mercury vapour) and communities living near mines due to contamination of soil and food.

Reports prepared in 2018 and 2020 (SIDA 2018, 2020) showed deterioration in water quality in the Basin. Initially water quality issues were identified due to pollutants from mercury and suspended sediments from artisanal gold panning, as gold-mining activities are mainly poverty-driven with the majority of the miners being rural people, but ten large companies conducting gold-mining in the basin were identified in 2018, further aggravating pollution. Note that formalized and regulated gold-mining are generally mercury-free and use sophisticated ore processing equipment, flotation techniques, and cyanide leaching to recover gold. Although cyanide is highly toxic, it does not persist and accumulate in the environment to the same degree as mercury, and is more effective at extracting gold (Esdaile and Chalker 2018).

In the lower parts of the basin, surrounding land-use and sanitation practices also play a major role on the water quality. Land-use is primarily:

- rural domestic consumers through piped schemes and undeveloped abstraction facilities;
- urban domestic and industrial consumers of Beira/Dondo and Mutare cities;
- instream activities such as laundry washing;
- small and large-scale irrigators (e.g., Mafambisse Sugar Estate);

- use of herbicides and fertilizers (as noted in June 2022 during the reconnaissance survey in both Zimbabwe and Mozambique and verified by FAO 2016); and
- forestry.

Water quality is also a major challenge in upstream Zimbabwe, with the drivers of water pollution being rapid urbanization and inadequate water supply and sanitation infrastructure. This leads to uncontrolled discharges of domestic and industrial waste, sewer overflows, poor solid waste management, destructive land-use changes and unsustainable cultivation in off-site plots including in wetlands. These issues are compounded by the deterioration of wastewater collection, treatment and disposal; and inadequate testing of potable water sources (Feresu 2017).

Stream-bank cultivation leads to erosion and siltation, although prohibited under Section 20 of the Environmental Management Regulations. Over-use or inappropriate use of pesticides (e.g., DDT was reintroduced to Mozambique in 2005 and used until 2017 (Munhequete 2019), other organophosphates, dieldrin and organochlorines) pollute the soil, groundwater and runoff. Use of poor quality irrigation water results in accumulation of salts, while toxins from mining further degrade land and water resources (Feresu 2017).

EMA and ARA-Centro are responsible for conducting regular water quality monitoring in the respective countries. Although a number of toxicants are monitored, neither agency monitors for either Hg or Cn, meaning that the full impact of ASGM or commercial gold-mining is unknown. It is assumed that most informal gold-mining is by panning and sluicing in alluvial operations, but without monitoring the impact cannot be determined or verified.

Standards or objectives used for data interpretation in both countries also do not include aquatic ecosystem guidelines, meaning that either effluent or drinking guidelines are used for comparative purposes.

The main sources of estuary water pollution are rural and urban settlements (e.g., Beira), agriculture, afforestation, and gold panning. Since 2003 observations shown a drastic increase in sediment concentrations in the river and estuary due to the proliferation of informal gold-mining activities. In the rainy season, between November and April, turbidity of the water at the secondary intake can be as high as 500 NTU, with an average value of 400 NTU. Outside of the rainy season, the turbidity levels at the secondary intake range between 60 and 100 NTU (Morón 2014).

Droughts in combination with abstraction of baseflows during the low flow season has resulted in significant salinity creep in the Pungwe Estuary at times, with salinity measured about 80 km upstream during the 1992/3 drought necessitating the relocation of the Beira water intake further upstream (Burns *et al.* 1993).

The mangrove cover of the Beira district (which covers a large part of the Pungwe Estuary mangroves) reduced from 8 587 ha to 7 133 ha between 2009 and 2019 (17% reduction). Much of this loss was directly related to Cyclones Idai (2019), cyclone Eloise (2021) and storm Chalane (2021) which made landfall in the region (Macamo *et al.* unpublished data; Menoussanga *et al.* 2020).

Media reports indicate that the invasive Rainbow prawn *Mierspenaeopsis sculptilis* (Heller 1862) from southeast Asia were caught by fisherman from 2013 onwards. The catches of *Mierspenaeopsis sculptilis* are now higher than native penaeids. Presumably the species competes for food and space with other natives by occupying a large niche across sand and mud and utilises mangroves.

Population pressures and poor implementation of fisheries input and output controls result in most of the coastal fisheries being effectively open-access with serial-overfishing ubiquitous throughout estuaries and the nearshore. There are an estimated 250 000 fishers currently reliant on fisheries as their primary source of livelihood, of which over 50% are in the small-scale sector. The Pungwe Estuary, adjacent nearshore and Sofala Bank are fished by a substantial proportion of these fishers, which results in growth overfishing (fish are harvested before they reach full reproductive potential), recruitment overfishing (most breeding adults have been removed), and ecosystem overfishing (entire trophic levels removed). Mozambique's effective fishing effort has increased from $< 1 \times 10^6$ kWday in 1950 to 2×10^6 kWday by 1980 and then quintupling to $> 10 \times 10^6$ kWday by 2016 (Zeller *et al.* 2021). This has resulted in Catch Per Unit Effort (CPUE) crashing from > 275 kg.kWday⁻¹ in 1950 to 75 kg.kWday⁻¹ in 1980 to < 20 kg.kWday⁻¹ in the present day (Zeller *et al.* 2021). Predators and high-value, long-lived large-bodied fish have been removed from the ecosystem with catches now dominated by short-lived, early-maturing small-pelagic species (REFERENCE). Similar has occurred with the more sought-after invertebrates e.g., the tiger prawn *Penaeus monodon*, resulting in an invasive penaeid rainbow prawn *Mierspenaeopsis sculptilis* occupying an ever-increasing niche that is largely devoid of predators.

3 DELINEATION OF THE PUNGWE RIVER BASIN

The objectives of this task are to divide the river into relatively homogeneous longitudinal zones in terms of biophysical and socio-economic characteristics, and to harmonise these zones so that the social and ecological data focus on compatible zones.

Biophysical delineation considered hydrology and geomorphology. Thereafter EF zones and their representative EF sites were selected, and the sites compared on the basis of water quality², vegetation and macroinvertebrates. Socioeconomic delineation considered demographics, land use, water use and household use of aquatic resources.

3.1 HYDROLOGICAL ZONATION

The WRSM2000 software was used by Consultec (2004) to generate flows at 21 sub-catchments in the Pungwe Basin. These sub-catchments coincided with flow gauges (used for model calibration) and major tributaries. Model flows were then cumulated and analysed to identify trends in hydrological zones in the Pungwe Basin. These zones are based on 12 sub-basins (Figure 3.1), according to WWF HydroSHEDS.

These 12 sub-basins were reduced into nine sub-basins (Consultec 2013). This aggregation consisted of creating a new sub-basin called Middle Pungwe (consisting of Upper Middle Pungwe and Lower Middle Pungwe), extending the Urema sub-basin to include the upstream Nhandugue sub-basin and finally combining the Lower Pungwe and Pungwe Estuary sub-basins. **Table 3.1** shows the incremental catchment area, incremental mean annual runoff (in million cubic metres; Mm³) and incremental runoff depth for each of the nine sub-basins.

² To the extent possible given the paucity of data for the river.

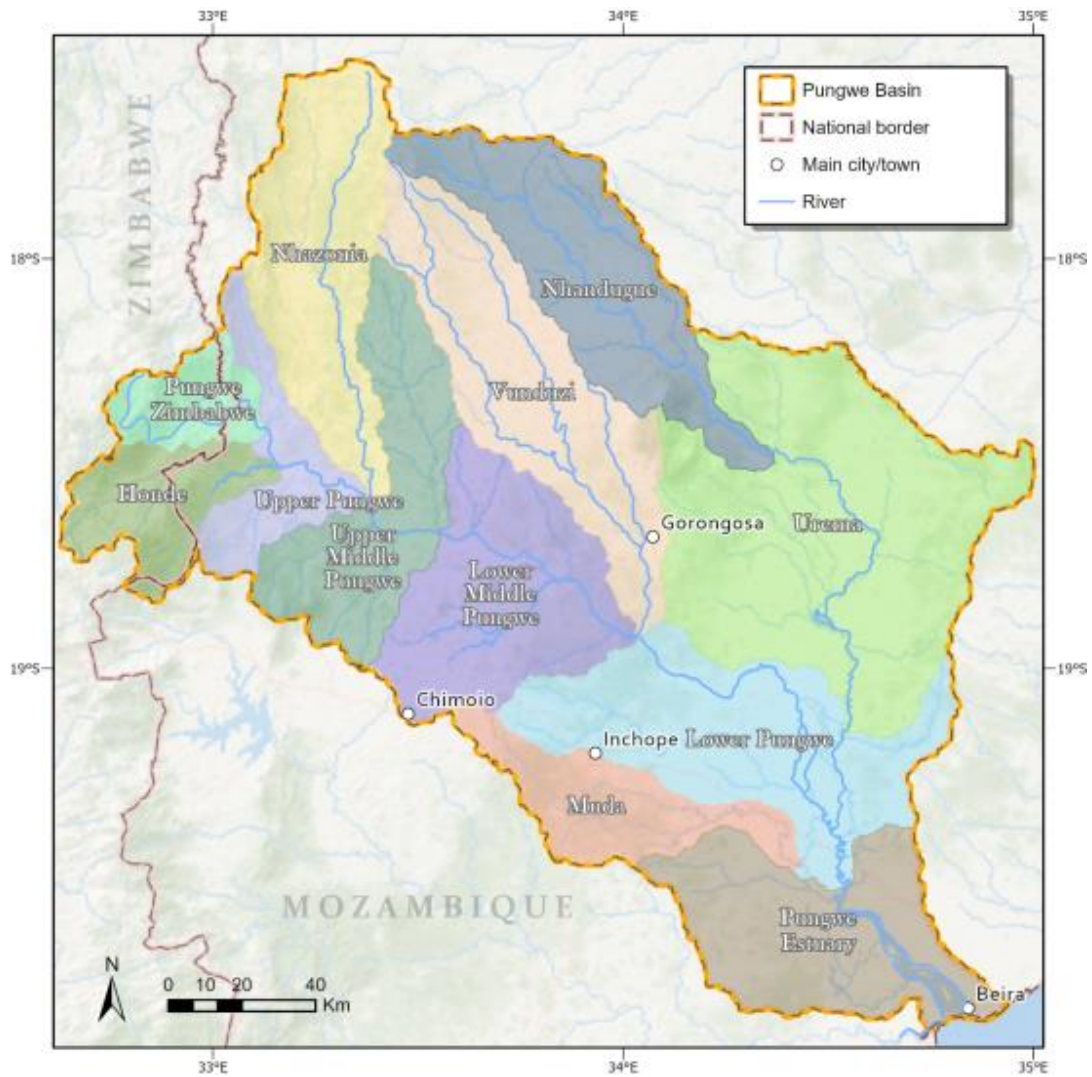


Figure 3.1 Sub-basin and principal tributaries of the Pungwe River. Data source: HydroSHEDS v1 (Lehner *et al.* 2008)

Table 3.1 Hydrological characteristics of the nine sub-basins (Consultec 2004)

#	Name	Sub-basin Area (km ²)	MAR (Mm ³)	MAR (mm)
1	Pungwe Zimbabwe	687	772	1 124
2	Honde	1 245	530	426
3	Upper Pungwe	2846	328	241
4	Nhazonia	2 829	442	155
5	Middle Pungwe	5 390	574	107
6	Vunduzi	3 439	499	145
7	Urema	8 402	509	61
8	Muda	1 336	160	120
9	Lower Pungwe	6 445	458	71
	Pungwe Basin	32 619	4 272	131

3.2 GEOMORPHOLOGICAL ZONATION

The headwaters of the Pungwe are deeply incised into granite with local dolerite dykes. Further downstream the river flows over gneiss of the basement complex before crossing the Holocene alluvium of Urema Rift. The lower Pungwe River is confined on the left bank by sandstones of the Cheringoma Plateau. Further details of the geology can be found in the report by the Governments of Mozambique and Zimbabwe and (2006), Steinbruch (2010) and Scoon (2016).

Seventeen macro-reaches were delineated along the Pungwe River, based on channel gradient, valley form and channel type. The key features of macro-reaches are illustrated in Figure 3.2 to Figure 3.15. Salient features of groups of reaches are described below.

In its upper reaches the Pungwe flows as a narrow single thread channel for 14 km across an undulating plateau (reaches 15-17, Figure 3.3 and Figure 3.4), steepening and widening (reach 14) as it approaches the top of the Pungwe Falls and Gorge where it drops steeply through 567 m over a distance of 19 km (Figure 3.5 and Figure 3.6). A single thread channel is maintained with evidence of bedrock outcropping in the bed, together with large boulders. Valley slopes are steep and the channel is confined with the exception of reach 12 (Figure 3.5) where a reduced gradient is associated with a limited valley floor.

As the river leaves the gorge (macro reaches 9 and 8; Figure 3.7 and Figure 3.8) the gradient is lowered and the valley opens out (reach 10). The channel widens from a range of 10 to 30m to a range of 30 – 72m. The single thread form is maintained with locally occurring islands. There is some evidence of sand or cobble bars and the valley floor is well developed. Woody riparian vegetation lines the banks and there is widespread cultivation and dispersed settlements on slopes away from the valley floor. The valley floor is cultivated. The valley becomes more confined in reach 9 and the valley floor is lost. The channel is dominated by bedrock and boulder rapids. There is some bush clearing with localized settlements and cultivation on the valley slopes. Reach 9 extends to the border with Mozambique and follows it for some distance.

The character of the river changes dramatically downstream of the confluence with the Namuchuru River; through macro-reaches 6 and 7 (Figure 3.9 and Figure 3.10). The water carries a high sediment load from artisanal mining in the headwaters of the Namuchuru River (Dondeyne *et al.* 2009). The channel form alternates between single thread and multi-thread, in a bead-like sequence. Measured channel width varies from 136 to 200 m in the multi-thread channels of macro-reach 7, and 282 to and 560 m in the multi-thread channels of macro-reach 6. The single thread channels of macro-reach 7 are ~57 to 60 m and those in macro-reach 6, 85, 106 and 120 m. Valley side slopes are relatively gentle. The Nhazonia River joins the Pungwe in macro-reach 6.

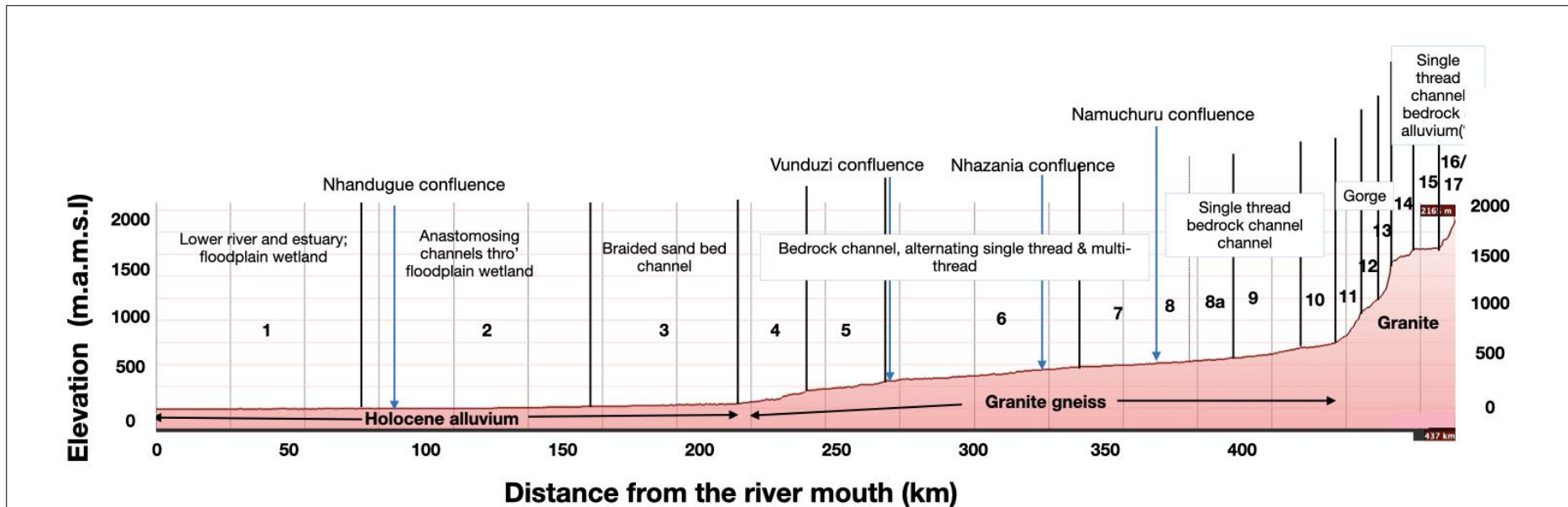


Figure 3.2 Longitudinal profile of the Pungwe River showing macro-reaches 1 to 17

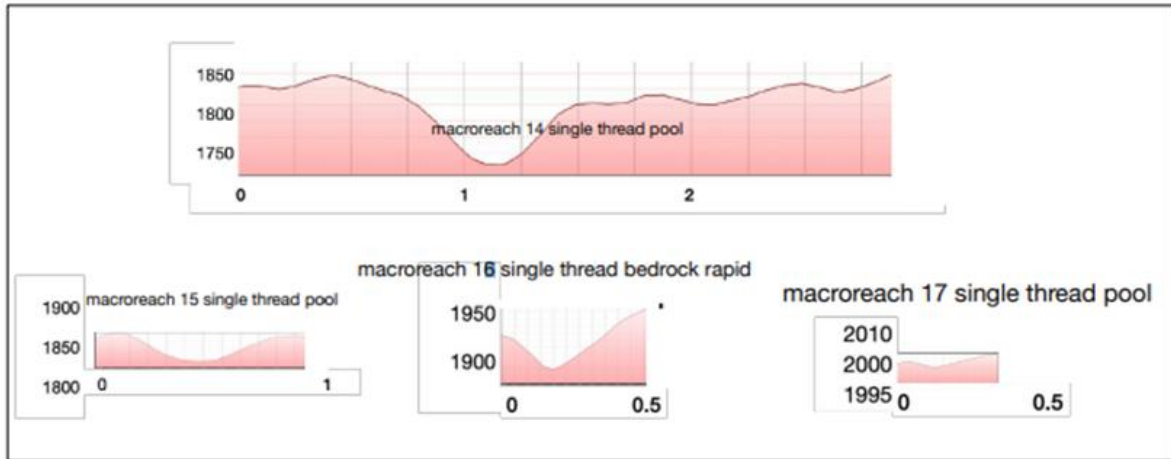


Figure 3.3 Valley transects in the upper reaches of the Pungwe River

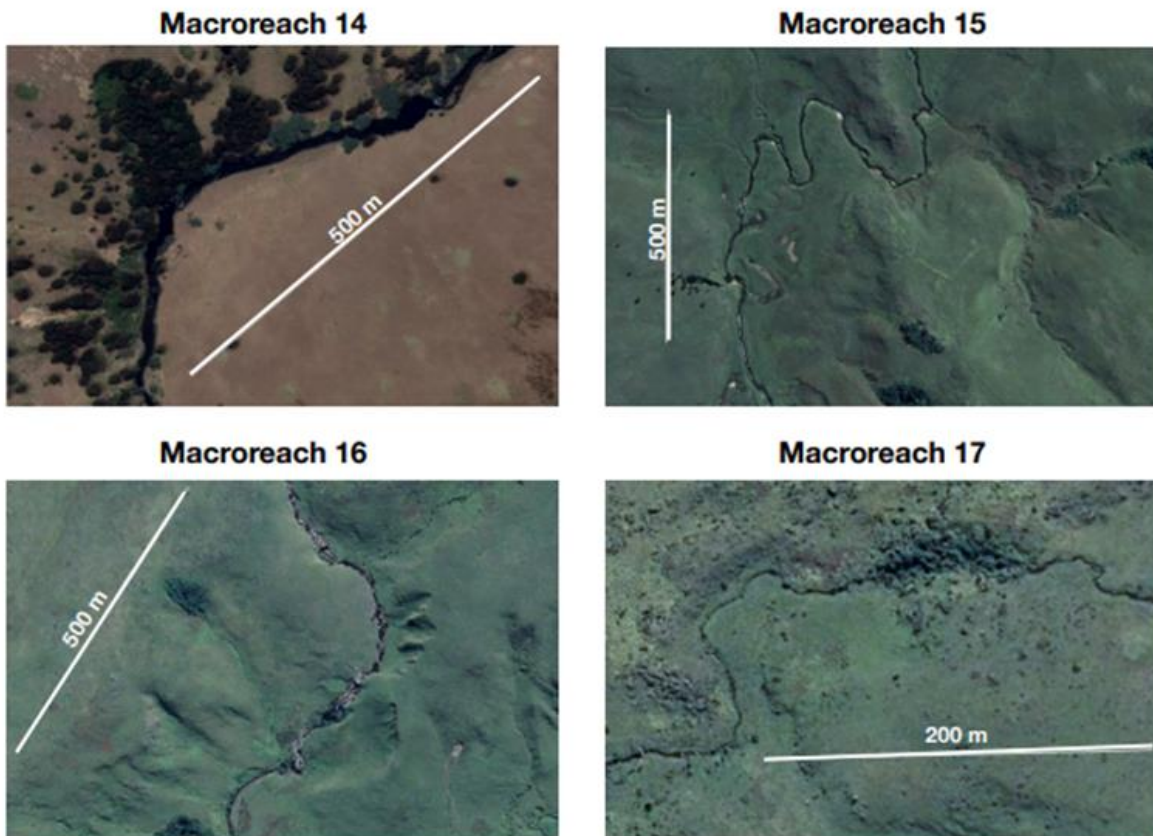


Figure 3.4 Channel form in the upper reaches of the Pungwe River

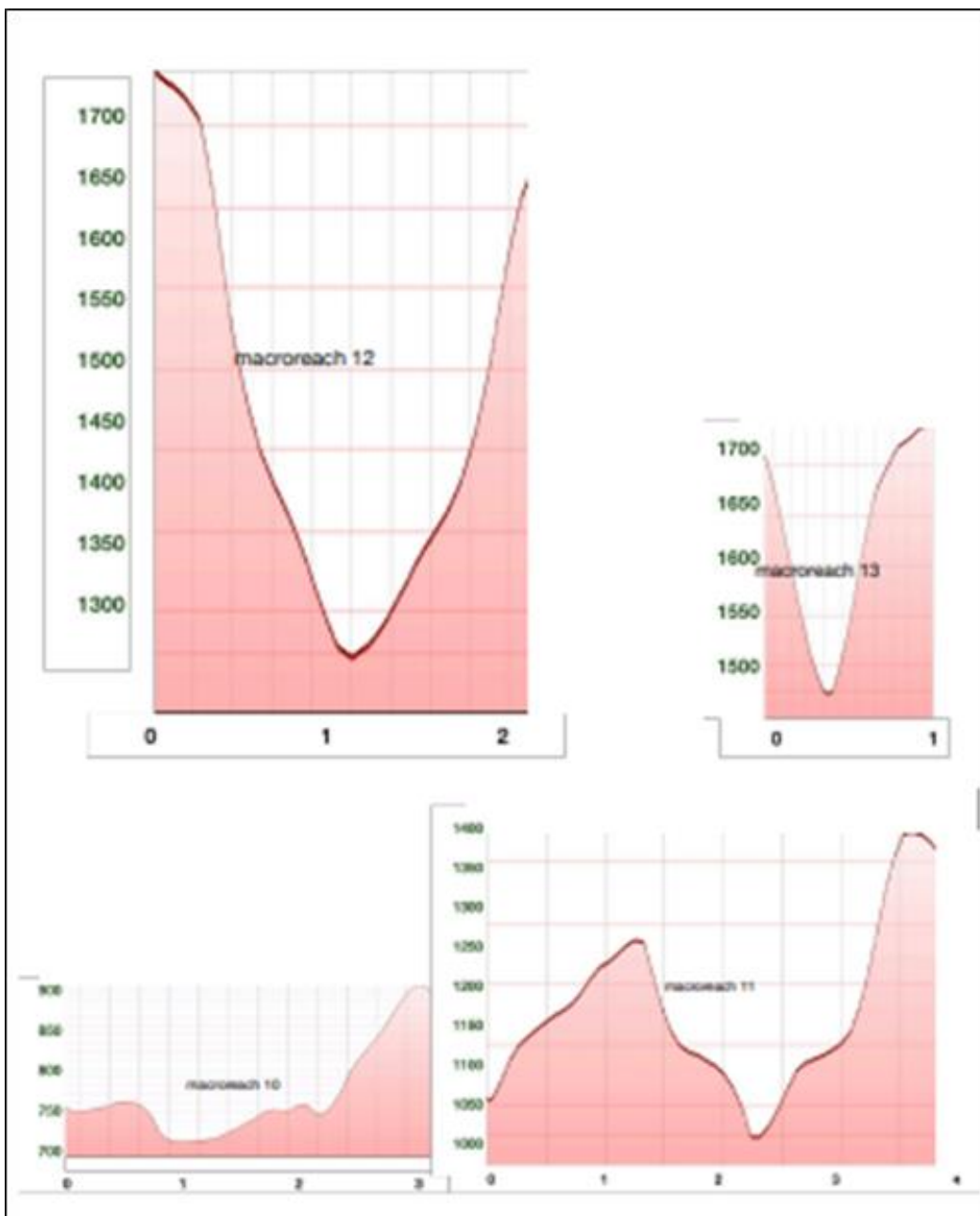


Figure 3.5 Valley transects in the Pungwe Falls and Gorge macro-reaches

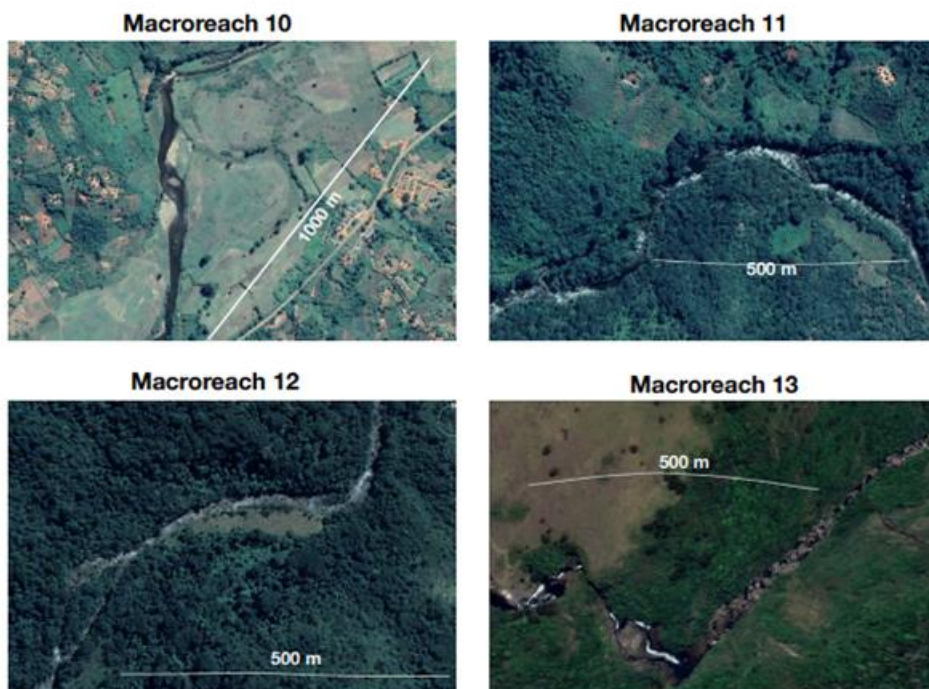


Figure 3.6 Channel form in the Pungwe Falls and Gorge macro-reaches

Reach 8 (Figure 3.7 and Figure 3.8) follows the border with Mozambique before flowing into Mozambique. The gradient of valley side slopes is lower than upstream. The upstream reach of this macro-reach has a significant valley floor but the valley becomes more confined downstream. The channel is predominantly single thread but there are local stretches of multi-thread channels over exposed bedrock. The confluence with the Namuchuru River marks the end of macro-reach 8.

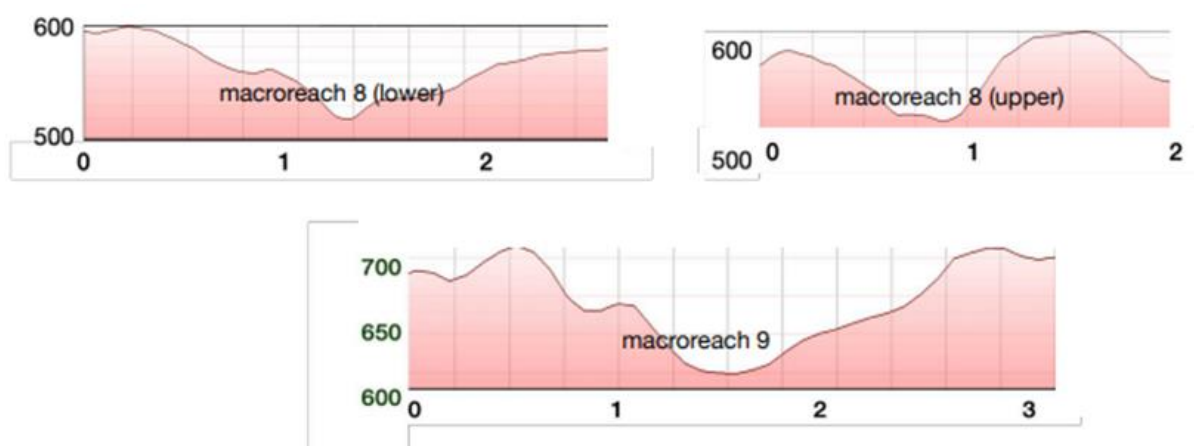


Figure 3.7 Valley transects in the macro-reaches above the Namuchuru confluence

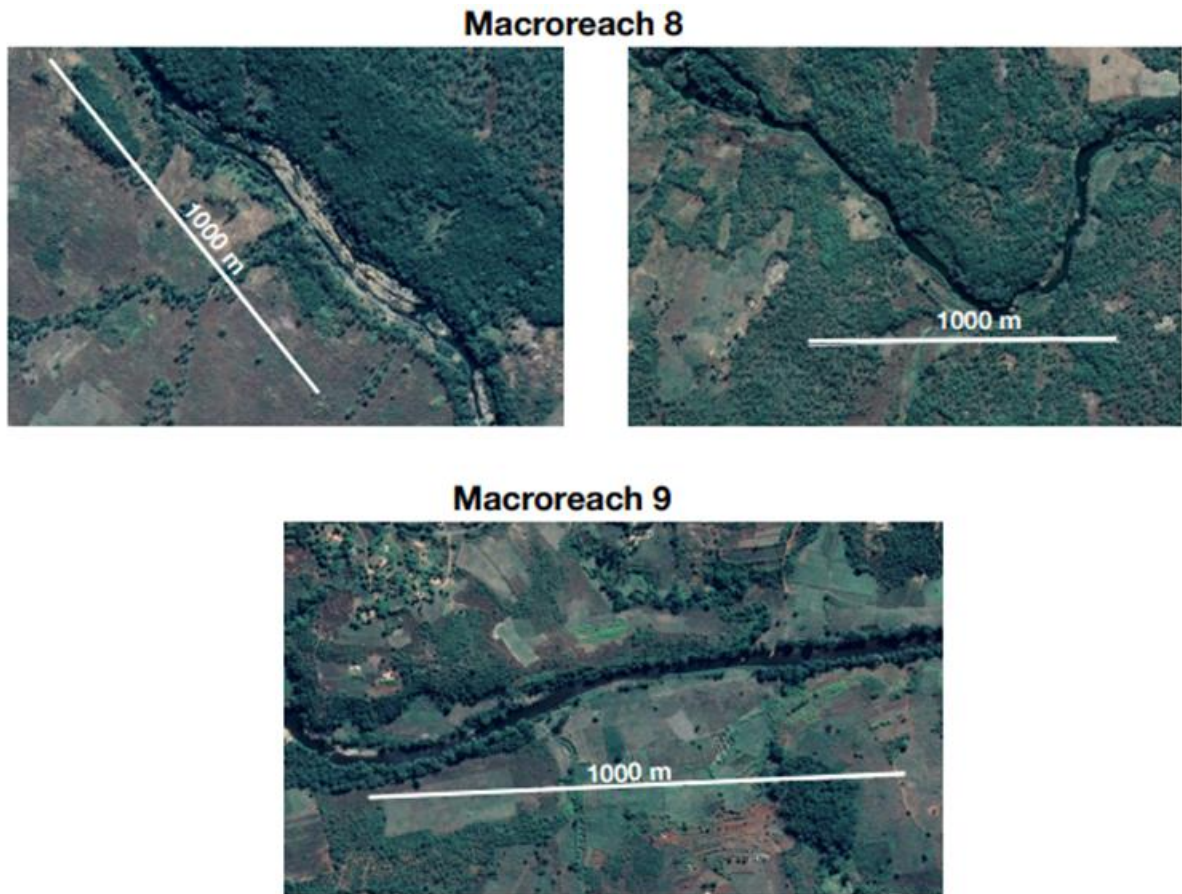


Figure 3.8 Channel form in the macro-reaches above the Namuchuru confluence

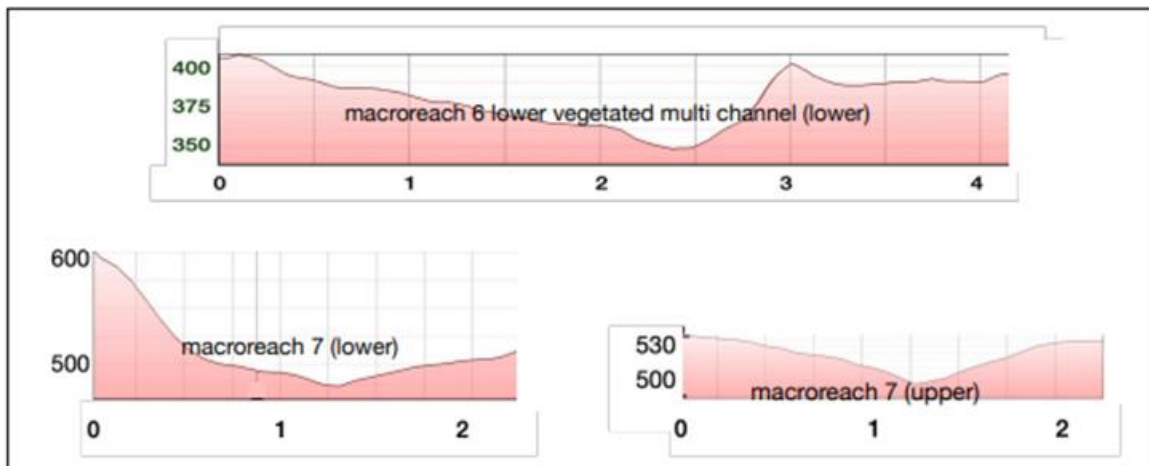


Figure 3.9 Channel form in the macro-reaches above the Namuchuru confluence

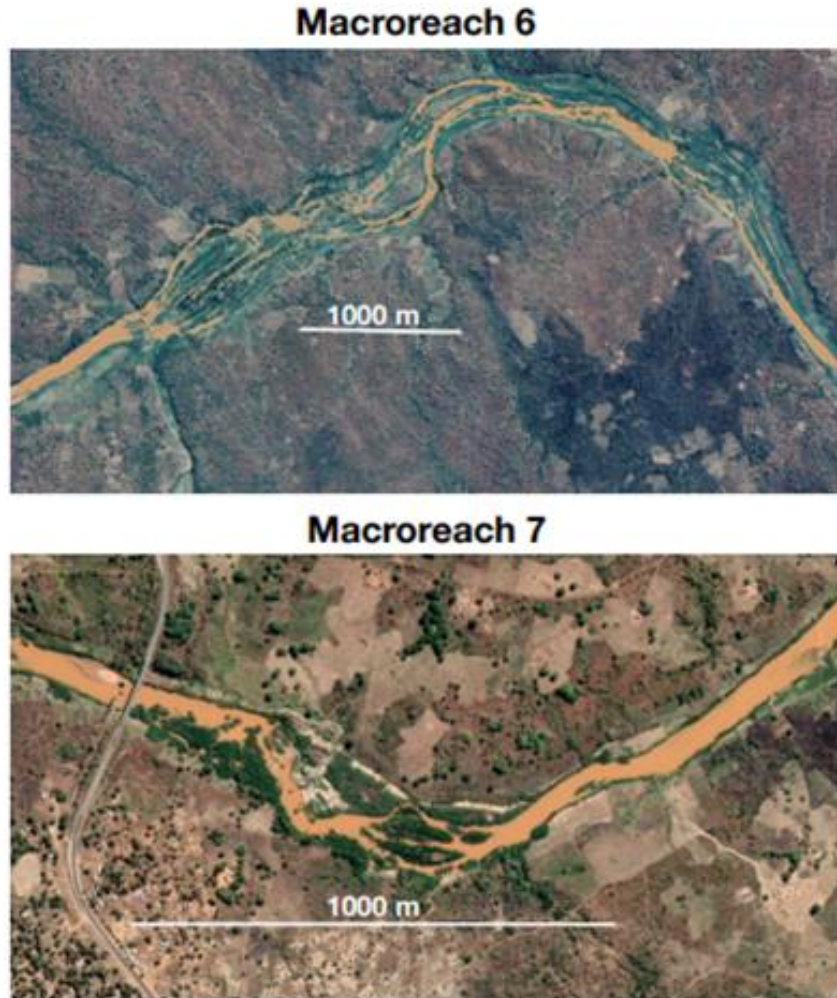


Figure 3.10 Channel form in the macro-reaches below the Namuchuru confluence

The channel gradient steepens in macro-reaches 5 and 4 (Figure 3.11 and Figure 3.12) and the valley becomes more confined. An elevation drop of 23 m divides the two reaches. Possible terrace features are evident in macro-reach 5 at a measured height of 35 and 38 m above the valley floor. Both single thread and multi-thread channels are again evident. There is possible evidence of vegetated alluvial point bars in macro-reach 5. The measured channel width in the two macro-reaches varies from 180 to 540 m.

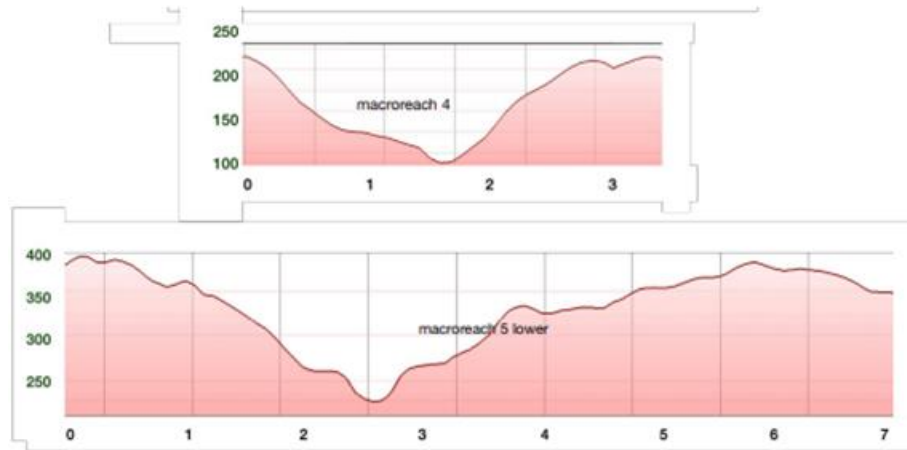


Figure 3.11 Valley transects in macro-reaches 4 and 5

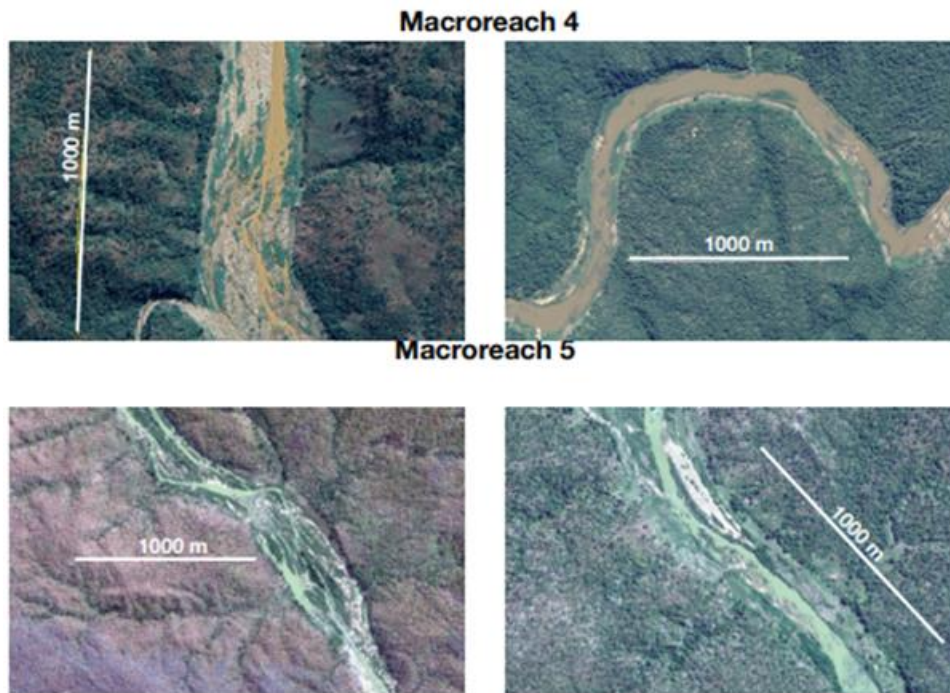


Figure 3.12 Channel form in macro-reaches 4 and 5

The break between macro-reach 4 and macro-reach 3 marks the break between the basement gneiss and the alluvium of the Urema Rift (Figure 3.13 and Figure 3.14).

The character of the river changes from a bedrock dominated channel to a low gradient braided sand bed channel. The active channel, with a measured width of 500 m, lies between terraces positioned at 20 m above the channel and measuring 2.65 km across. The terraces are densely cultivated.

In macro-reach 2 the channel divides to form an anastomosing system within a floodplain wetland some 15 km across. The Nhandugue River joins the Pungwe in this macro-reach. The Nhandugue has six delineated macro-reaches (referred to as Zone 1-6 on Figure 3.19). The river is considerably shorter than the Pungwe and lacks elevated headwaters.

The final macro-reach of the Pungwe (macro-reach 1) includes the estuary. There is evidence of widespread cultivation on the floodplain, which extends for a width of 20 km. Close to the main channel the floodplain is elevated 6m above the river so is likely to be frequently flooded.

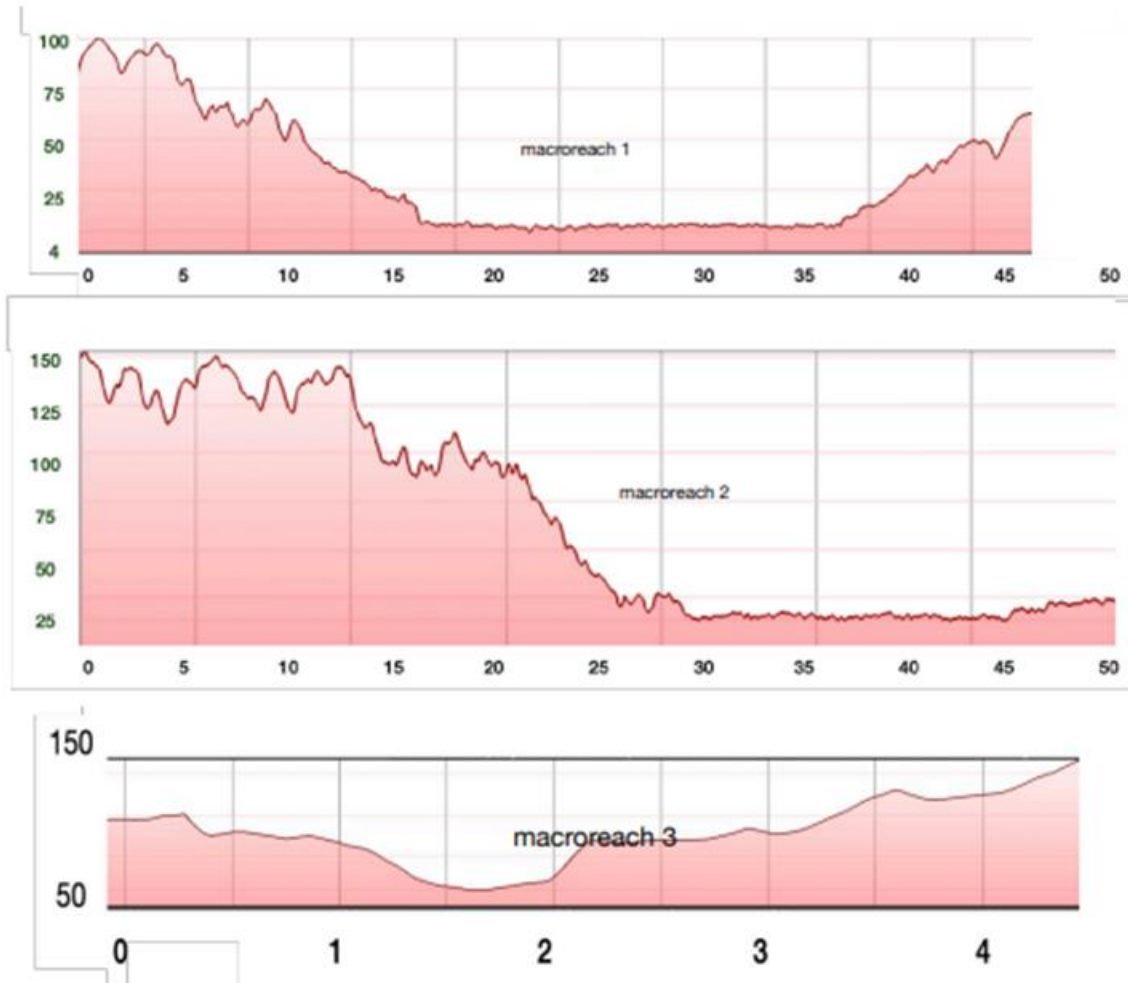


Figure 3.13 Valley transects in the lower Pungwe River

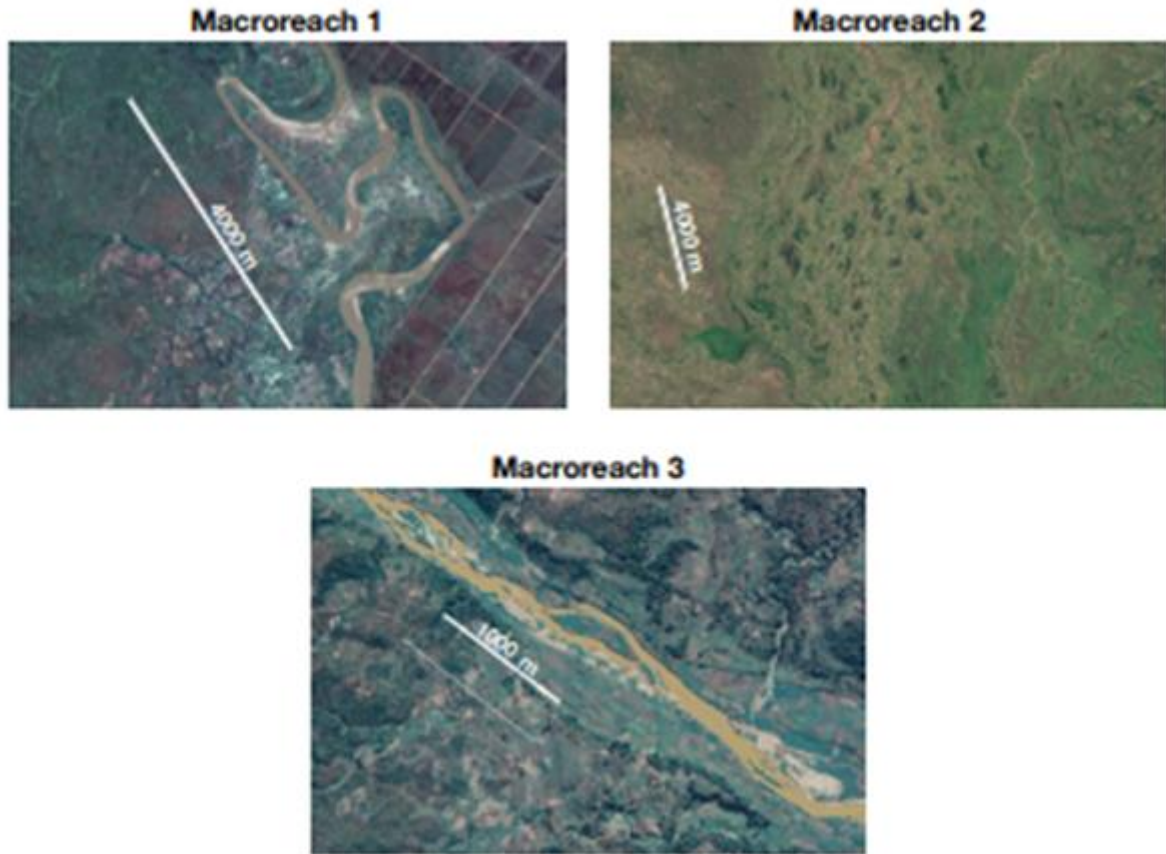


Figure 3.14 Channel form in the lower Pungwe River

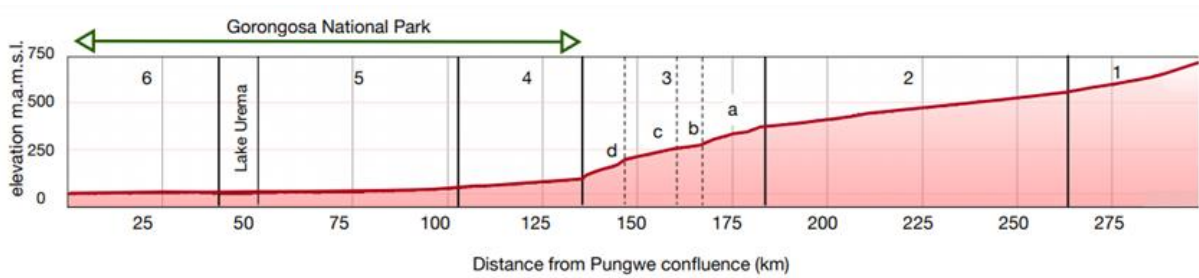


Figure 3.15 Nhandugue River longitudinal profile

The longitudinal profile and demarcated macro-reaches of the Pungwe River is shown in Table 3.2. Key features are described.

Table 3.2 Summary of macro-zone characteristics of the Pungwe River

Reach	Upper distance	Upper height	Gradient	Channel type	Channel width (m)	Local catchment
1	70	5	0.000071	low gradient channel including estuary; can be flooded by sea water	floodplain 20.2 km	
2	145	31	0.000347	anastomosing channels; wetland floodplain	floodplain 15 km	higher land to east, low hills to west (40 m)
3	193	57	0.000542	braided sand bed channel	500	crosses the alluvial filled Urema Graben. densely cultivated, scattered settlements
4	220	173	0.004296	single thread channel alternating with bedrock outcrops of Barue Complex gneiss	180 - 315	dense bush, locally cleared for cultivation
5	247	323	0.004704		275 - 343	
6	312	480	0.002415		106 - 560	increased cultivation
7	332	505	0.001250		60 - 200	increased bush, areas of bush clearing and possible abandoned cultivation then denser bush with clearing and abandoned cultivation
8	347	547	0.002469		single thread channel alternating with bedrock outcrops above confluence with Namuchuru River	35 - 80
9	385	701	0.004053	single thread channel with some boulder and bedrock rapids, lacking a valley floor	20	gentle slopes, woodland with cleared patches for settlement and cultivation
10	396	761	0.005455	single thread channel with local islands and secondary channel; one meander cut-off; evidence of sand or cobble bars; well-developed valley floor.	30 - 72	moderate slopes, widespread cultivation and dispersed settlement on slopes away from valley floor, valley floor cultivated.
11	406	1162	0.040100	steep bedrock and boulder channel, weir leading water into a canal; moderately wide valley floor	24 - 30	bush clearing with local settlements and cultivation

Reach	Upper distance	Upper height	Gradient	Channel type	Channel width (m)	Local catchment
12	413	1293	0.018714	bedrock channel; islands with secondary channels; limited valley floor	13	moderately steep wooded slopes, some open patches
13	415	1600	0.153500	ravine; bedrock channel	10 - 22	very steep wooded slopes
13A	415	1674	0.370000	waterfall		
14	423	1816	0.017750	single thread	10 - 13	
15	431	1830	0.001750	single thread channel; with local pools; frequent meander cut-offs	2 - 3	grassland with forest patches
16	434	1930	0.033333	steep single thread channel with bedrock rapids	2 - 3 (locally 28 m over rapid)	grassland
17	437	2165	0.078333	narrow single thread channel with bedrock and boulder. Bedrock rapids? Source area wooded scarp	1 - 2	grassland with forest patches

3.3 WATER QUALITY ZONATION

The headwaters of the Pungwe in Zimbabwe are near pristine there are no human settlements in Nyanga National Park. Despite extensive cultivation and settlements in the Honde Valley, and on 17th June 2022, water leaving Zimbabwe (Figure 3.16 at Pungwe Katiyo Hydrometric Station F22 of the Zimbabwe National Water Authority (ZINWA)) was clear and fast-flowing.

Further downstream, however, evidence of the water quality impacts associated with AGSM became apparent, particularly downstream of the Nyamukwarara River.

Indications of the high suspended sediment loads and high iron levels in this section can be seen in Figure 3.17, with highest loads seen at EFlows Site 2.



Figure 3.16 Pungwe River at ZINWA hydrometric station F22



Figure 3.17 Conditions in backwater pools at EF 2 indicating water quality state

An approximate zonation of the Pungwe mainstem on the basis turbidity, suspended sediment loads and salinity is provided in Table 3.3. Information on other water quality parameters, such as nutrient concentrations, toxicants, temperature and oxygen saturation levels, would not adequately differentiate between the zones on the Pungwe mainstem. Water quality profiles on the Nhandugue and Nhandare rivers are distinct and represent different water quality zones.

Table 3.3 Water quality delineation of the Pungwe River

EF Zone and Site	Water Quality (WQ) Zone
The Pungwe River in Zimbabwe	WQ Zone 1: Clear, low turbidity water. Clear “green” water.
The Pungwe River in Mozambique, from downstream the Honde confluence to the freshwater inflow to the estuary	WQ Zone 2: High suspended sediment loads. Turbid “orange/mud coloured” water.
The Pungwe Estuary	WQ Zone 3: Defined by saline intrusion linked to river inflows and tidal action

3.4 SOCIO-ECONOMIC ZONES

Based on an inspection of maps of the basin’s geography, vegetation, aquatic ecosystems, population distribution and land use, as well as information gathered during the reconnaissance visit (14-17 June 2022), the basin was divided into five relatively homogenous socio-economic (SE) zones (Figure 3.18).

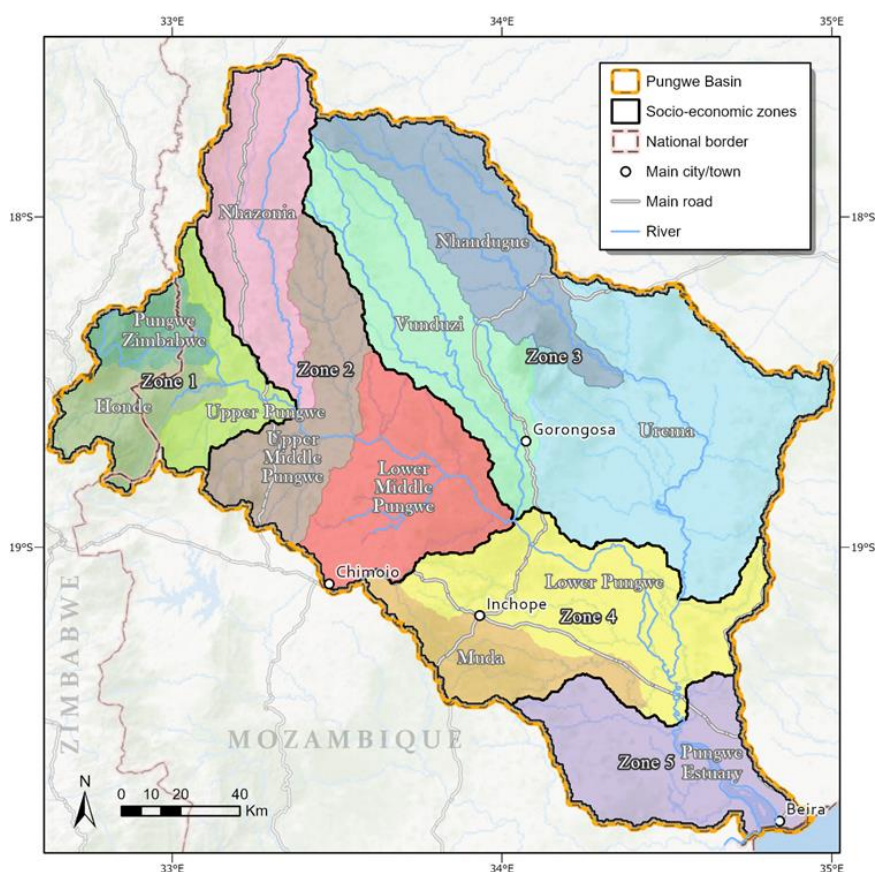


Figure 3.18 Socio-economic zones of the Pungwe River Basin

3.4.1 SE Zone 1 a and b: Nyanga mountains

SE Zone 1 occurs in (a) Manicaland Province in Zimbabwe and (b) Manica Province in Mozambique. The zone includes the Upper Pungwe and Honde sub-basins covering an area of 3 639 km². The terrain of the zone is uneven and mountainous with steep to gentle undulating slopes covered by upland vegetation. The zone receives high rainfall up to 2020 mm/year, has numerous perennial local streams and makes a significant contribution to river discharge despite representing just 10% of the total basin area (Table 2.1). The zone is generally unsuitable for settlement due to the hilly terrain and is thus relatively sparsely populated (39 people/km²). Settlements are scattered across the hilly terrain and are concentrated along river valleys and hillsides. Fairly intensive small-scale dry land and irrigated agriculture is practiced by rural communities and there is some high value irrigated commercial crop production (e.g., coffee, avocados and macadamias) in the Honde Valley. The smallholder farmers in Zimbabwe typically grow sugarcane and bananas as well as some horticultural produce such as tomatoes for sale at the market in Harare. The Upper Pungwe sub-basin in Mozambique is relatively remote with subsistence farming being the dominant activity. Zone 1 is primarily rural in nature, except for a large service centre called Hauna Growth Point in Zimbabwe. Commercially grown exotic forestry plantations (pine and wattle) cover parts of this zone. Part of Nyanga National Park falls within this zone and is an important tourism destination, offering hiking, horse riding, fly fishing, river swimming and tubing.

3.4.2 SE Zone 2 Middle Pungwe

SE Zone 2 comprises the Nhazonia, Upper Middle Pungwe and Lower Middle Pungwe sub-basins which span across parts of the districts of Barue, Macossa, Manica and Gondola in Mozambique. The zone covers approximately 9277 km², which represents 26% of the basin area. This zone is more heavily populated than the other zones (29% of basin population), with more urban areas and a number of main transport links. Average annual rainfall and mean annual runoff is lower than in zone 1 but slightly higher than in zone 3. Population density is high in the Lower Middle Pungwe sub-basin (70 people/km²), due to the urban settlement of Chimoio which is on the southern edge of the basin, and Nhazonia sub-basin (67 people/km²). It is lower in the Upper Middle Pungwe sub-basin (18 people/km²) which is sparsely populated, and its hinterland is largely uninhabited. In this sub-basin the town of Nova Vanduzi has the highest population. In the Lower Middle Pungwe sub-basin the population is highest in the peri-urban areas of Cafumpe, Matsinho and Villa de Gondola which are all situated along the main N6 highway between Chimoio and Inchope. Off the main highway, the area is sparsely populated. The communities in this zone depend heavily on agriculture, farming large fields of maize and some horticultural products for sale at markets. Cropland extends down through this zone from top to bottom (Figure 2.2). Commercial irrigated agriculture is largely constrained to the Nhazonia sub-basin along the Nhazonia river where large pivot irrigated fields can be seen in satellite imagery. The main N7 highway linking the towns of central Mozambique with Tete and other towns in the north runs through this zone which provides opportunities for sale of agricultural produce and harvested resources to those passing through. Charcoal production and gold-mining are prevalent in this zone.

3.4.3 SE Zone 3 Gorongosa

SE Zone 3 is made up of the Vunduzi, Nhandugue and Urema sub-basins which cover 14 092 km² or 39% of the study area. Natural vegetation covers most of this zone (98%) with cropland covering just 299 km², constrained to the southern parts of this zone along the N1 road that runs north from Inchope to the town of Gorongosa. The Vunduzi sub-basin receives high rainfall in comparison to the other two sub-basins in this zone, as a result of the high altitudes associated with Gorongosa Mountain from which the Vunduzi river originates. The Vunduzi sub-basin spans across Manica and Sofala Provinces and it is generally poorly inhabited since it experiences drier weather which limits dryland farming to the north. High populations occur in the wetter parts of Gorongosa sub-basin due to high agricultural productivity. The Nhandugue sub-basin which spans across parts of Macossa district in Manica province and Gorongosa district in Sofala Province is remote and poorly inhabited and is characterized by a few scattered rural settlements. The Urema sub-basin falls in Sofala Province covering parts of the Gorongosa district, Muanza district and Cheringoma district. Gorongosa National Park falls within the Urema sub-basin. Seasonal inundation of the Gorongosa floodplain forms “*tandos*” that link the Zambezi Valley with the Pungwe System via the Urema trough (Rift Valley). This zone is generally undeveloped and sparsely populated. There is some tourism in this zone, which is linked to Gorongosa National Park, but this remains fairly limited.

3.4.4 SE Zone 4: Lower Pungwe floodplains

SE Zone 4 ‘Lower Pungwe floodplains’ comprises the Lower Pungwe and Muda sub-basins covering an area of 5876 km² (16% of study area). The zone is characterised by seasonally inundated grasslands and perennial wetlands where plants such as papyrus and water lilies grow. The area falls within the districts of Gondola, Dondo, Nhamatanda and Gorongosa. Nhamatanda is the most densely populated district in the zone which covers the area above the Pungwe estuary to the urban settlement of Inchope on the main N6 highway. This zone contains 494 747 people, the second highest in the basin, and the population density is high at 77 people/km². The people living in this zone are attracted by the extensive fertile floodplains with rich soils which support high agricultural productivity. The zone contains a mix of smallholder and commercial farms with the smallholder farms cultivating maize and some rice as well as vegetables and the commercial farms producing mostly sugarcane. Part of Mafambisse Sugar Estate falls within this zone. Livestock farming is also more prominent in this zone compared to the other zones in the basin. The major socio-economic activities in this zone are commercial sugar plantations, smallholder agriculture, urban settlements along the main N6 road, and fishing.

3.4.5 SE Zone 5: Estuary and coast

SE zone 5 includes the Pungwe estuary and nearshore coastal environment. The Pungwe river flows into the Indian Ocean at Beira Port where the coastal city of Beira is situated north of the mouth. Beira is the capital city of Sofala Province and the second largest city in Mozambique after Maputo. It is the largest settlement in the Pungwe River Basin with a population of some 490 000 people. Beira Port is a gateway for both the central interior of Mozambique as well as the landlocked countries of Zimbabwe, Zambia and Malawi (Alferes *et al.* 2006). At the coast the climate is tropical and humid

with rainfall ranging from 300 mm on average in January to just 20 mm on average during the dry season in July (Terink and Droogers 2014). The location of Beira in the low-lying wetlands between the estuary and the ocean result in regular flooding of the city which occurs during the rainy season. The main economic activities include trade and transport, smallholder and commercial farming, and fishing. Industrial, semi-industrial and artisanal fishermen operate offshore and, in the estuary, catching a wide variety of fish, prawns, squid and other shellfish such as clams.

3.5 EF ZONES AND SITES FOR THE DRIFT EFLOW ASSESSMENT

On the basis of the biophysical and socioeconomic zonations, the six EF zones were selected, plus a seventh representing the near-shore marine environment, as follows:

- EF Zone 1: The Pungwe River in Zimbabwe
- EF Zone 2: The Pungwe River in Mozambique, from downstream of the confluence with the Honde River to upstream of the confluence with the Vunduzi River
- EF Zone 3: The Pungwe River in Mozambique, from the Vunduzi confluence to the Nhandugue confluence
- EF Zone 4: The Nhandugue River upstream of Lake Urema
- EF Zone 5: The Nhandare River
- EF Zone 6: The Pungwe Estuary
- EF Zone 7: Near-shore marine environment.

The corresponding reaches and zones for hydrology, geomorphology, water quality and socioeconomics are shown in Table 3.4

Table 3.4 EF zones with corresponding reaches and zones for hydrology, geomorphology, water quality and socio-economics

EF Zone	Hydrological sub-basin	Geomorphological macro-reach	WQ zones	SE zones
1	1: Pungwe Zimbabwe	17-8	1	1a
2	3+5: Upper + Middle Pungwe	7, 6	2	1b
3	9: Lower Pungwe	5, 4 3, 2	2	2
4	7: Urema	Nhandugue macro-reaches 1-6	4	3
5	9: Lower Pungwe	Nhandare macro-reaches 1-6	5	2
6	9: Lower Pungwe	1	3	4 and 5
7	n/a	n/a	n/a	5

3.5.1 Representative River EF sites

The location of the river sites selected to represent EF zones 1-5 are shown on Table 3.5 and Figure 3.19, and images of each site are provided in Figure 3.20 to Figure 3.24.

Table 3.5 Location and co-ordinates of the five river EF sites.

EF Site	Location	Co-ordinates
1	Mukupe Village, Honde Valley Road, Pungwe River, gauge F24	-18° 26' 00''S, 32° 53' 49''E
2	Pungwasul Village, N7 road bridge crossing, Pungwe River, gauge E65	-18° 33' 10''S, 33° 16' 49''E
3	N1 bridge crossing Pungwe River, Matenga-Pungwe Village, gauge E651	-18° 59' 43''S, 34° 05' 05''E
4	Casa Banana Village, Nhandugue River	-18° 29' 33''S, 34° 23' 59''E
5	South of Gorongosa Village, Nhandare River	-18° 38' 12.9''S, 34° 03' 49.4''E

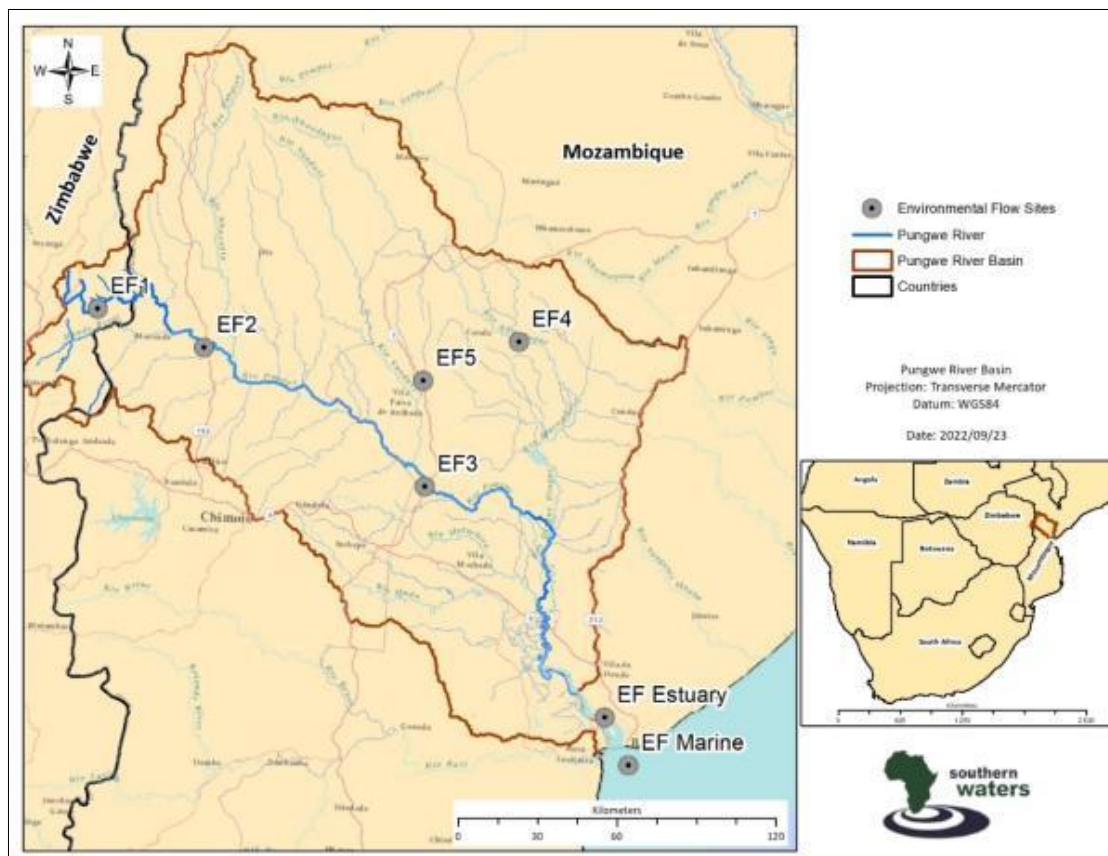


Figure 3.19 The EF sites and the estuarine and marine Zones for the EFlows assessment of the Pungwe Basin



Figure 3.20 EF Site 1



Figure 3.21 EF Site 2



Figure 3.22 EF Site 3

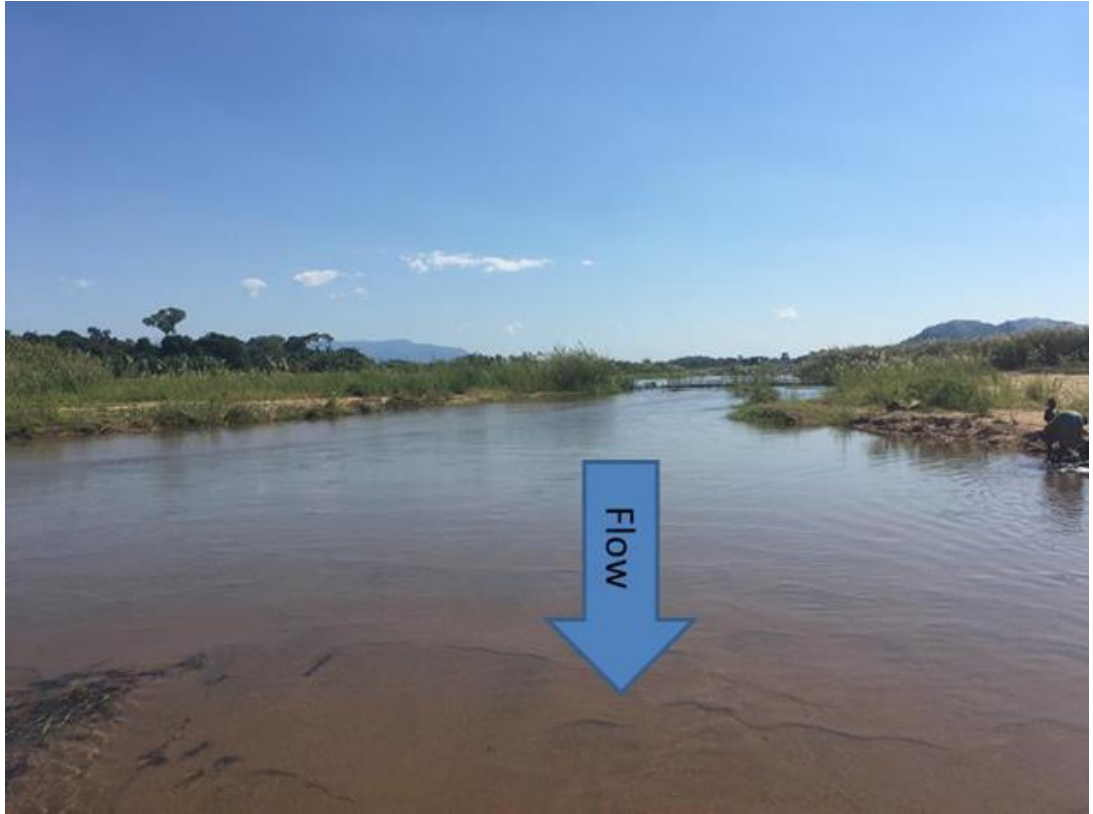


Figure 3.23 EF Site 4



Figure 3.24 EF Site 5

3.5.2 Estuarine (EST) zones

To simplify the complex abiotic processes observed in estuaries for interpretation by biotic specialists, the estuary (EF Zone 6) is further divided into a number of representative homogeneous sub-zones, referred to here as EST zones. A key criterion in the delineation of the EST zones is bathymetry, as the size and shape of an estuary play a determining role in its response to flow. Another criterion is the degree of stratification that provides an indication of dominant mixing processes in a system. Using measured/modelled data a conceptual model is developed that separates the estuary into homogenous zones of high and low retention. EST zones of high retention include, for example, deeper sections that tend to stratify and areas that can hinder tidal or fluvial flushing. Low retention zones are generally represented by shallow areas at the head of the estuary (easily flushed by river inflow) or the lower mouth areas (regularly flushed by tidal action).

Following this broad approach, the Pungwe Estuary has been provisionally zoned into five EST zones (Figure 3.25), which will be refined during the course of the assignment and the outputs of the numerical modelling study.

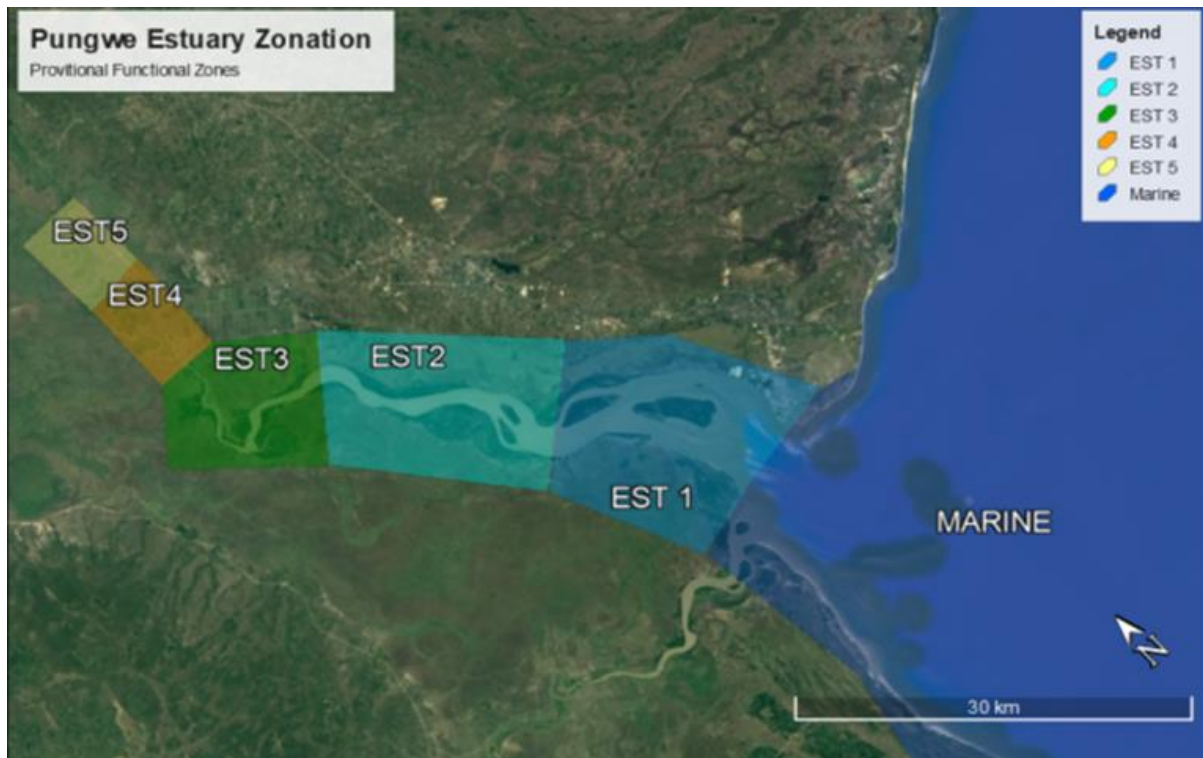


Figure 3.25 Estuary zonation into five EST zones that respond relative homogeneously to modification of river inflows

Zone EST 1 (Figure 3.26) is marine-dominated (>30) on all tides during the low flow season. This zone is subjected to significant salinity penetration even during the high flow season as a result of the macro-tidal conditions at sea (>5 m tidal amplitude). For example, at a high discharge of $300 \text{ m}^3/\text{s}$ the average high tide salinity is about 15, while low tide is about 5 to 10 in this zone (e.g., 27-2-2002). Numerical modelling will confirm the extent of the upper boundary based on sensitivity to higher flows and floods.

The zone is subject to strong tidal flows and characterized by extensive intertidal areas that support large areas of mangroves habitat. Important for marine and estuarine associated faunal species.

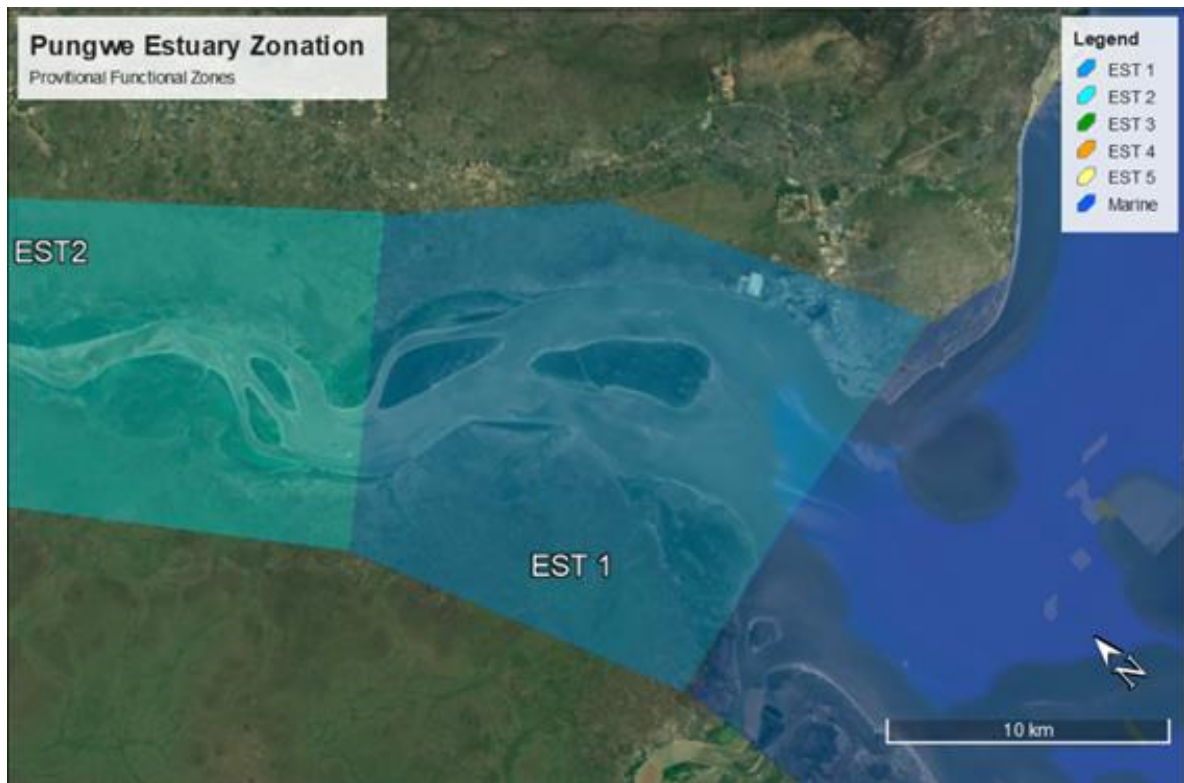


Figure 3.26 Estuary Zone 1 (0 - ~ 20 km upstream of the mouth)

Zone EST 2 (Figure 3.27) is marine-dominated (>30) during the low flow season, but can be brackish (e.g. 10 -25) during the high flow season for periods (Abas and Hagedooren 2017). Field work and numerical modelling will be used to confirm the extent of the lower boundary based on the system's sensitivity to higher flows and the salinity ranges used to characterise the zone. Extensive intertidal areas and mangroves are present in this zone, which are important for marine and estuarine associated faunal species.

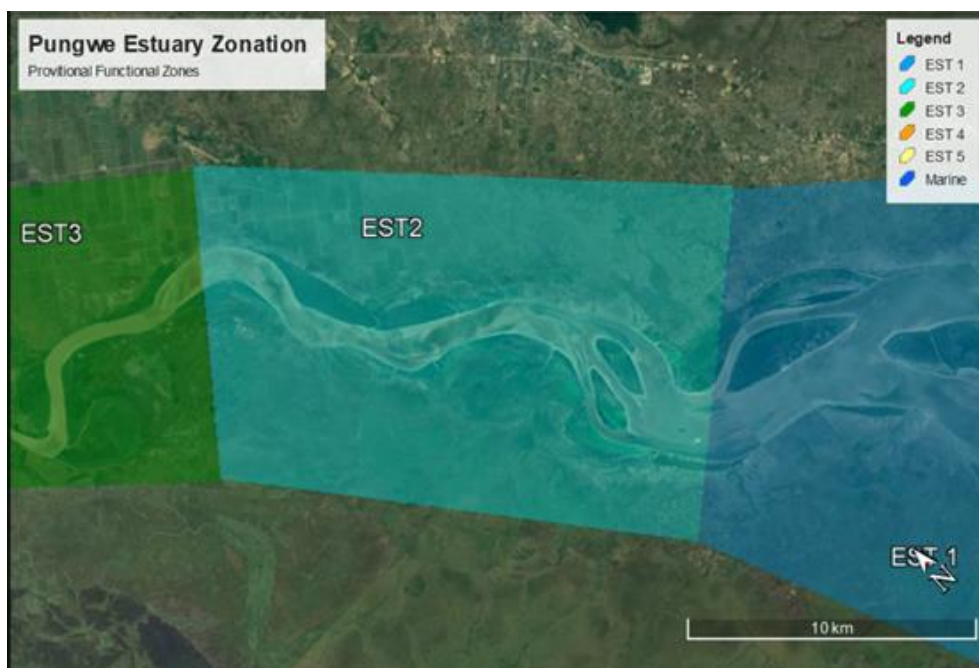


Figure 3.27 Estuary Zone 2 (~20 - 40 km upstream of the mouth)

Zone EST 3 (Figure 3.28) is brackish (10-25) during the low flow season, but can be fresh (<1) during the high flow season. Salinity creep is observed in this zone under low flow conditions, with salinity having a tendency to slightly increase under the influence of evaporation or as a result of the washing of salt from the adjacent floodplain during higher spring tides or rain events (Abas and Hagedooren 2017).

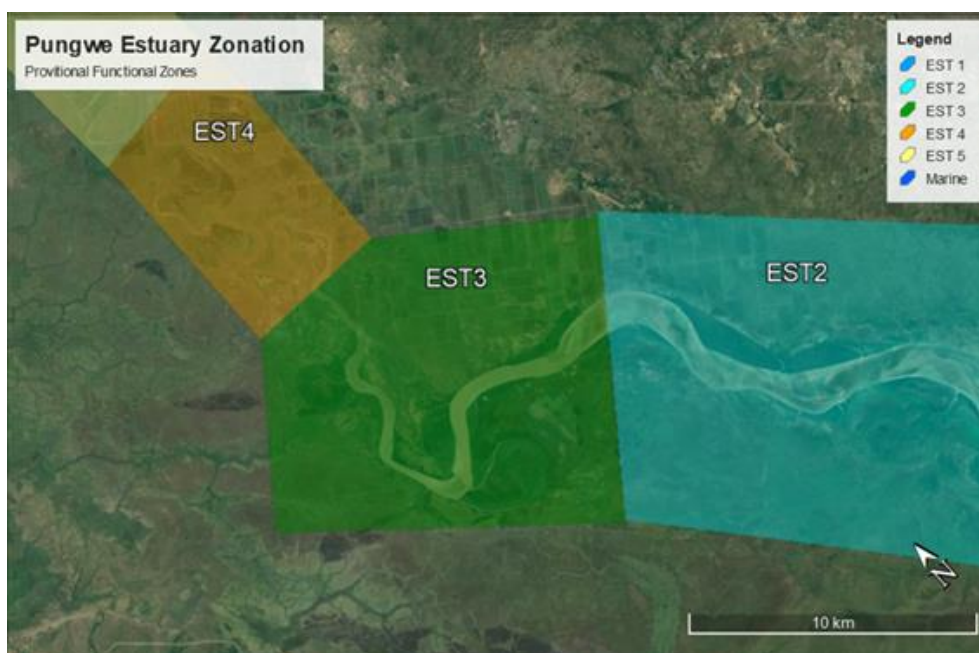


Figure 3.28 Estuary Zone 3 (~40 - 60 km upstream of the mouth)

The channel is confined, with limited flood plain. This zone represents the furthest extent of mangroves, and is important for estuarine and freshwater associated faunal species.

Zone EST 4 (Figure 3.29) is mostly fresh (<5), but during the low flow season salinity creep has been observed under low flow conditions (Abas and Hagedooren 2017). For example, during October and November 1992 after a severe drought in the region, the salinity creep in the estuary was so extreme that the historical Beira Water (FIPAG) Intake system, located ~77 km upstream from the mouth at that stage, was shut down for nearly seven weeks. The total water produced in 1991 was about two-thirds of the system's capacity and fell to less than half in 1992 (Burns *et al.* 1993).

The zone is characterized by a confined shallow channel that is highly responsive to freshwater flow changes. This part of the system is important for estuarine and freshwater associated faunal species.

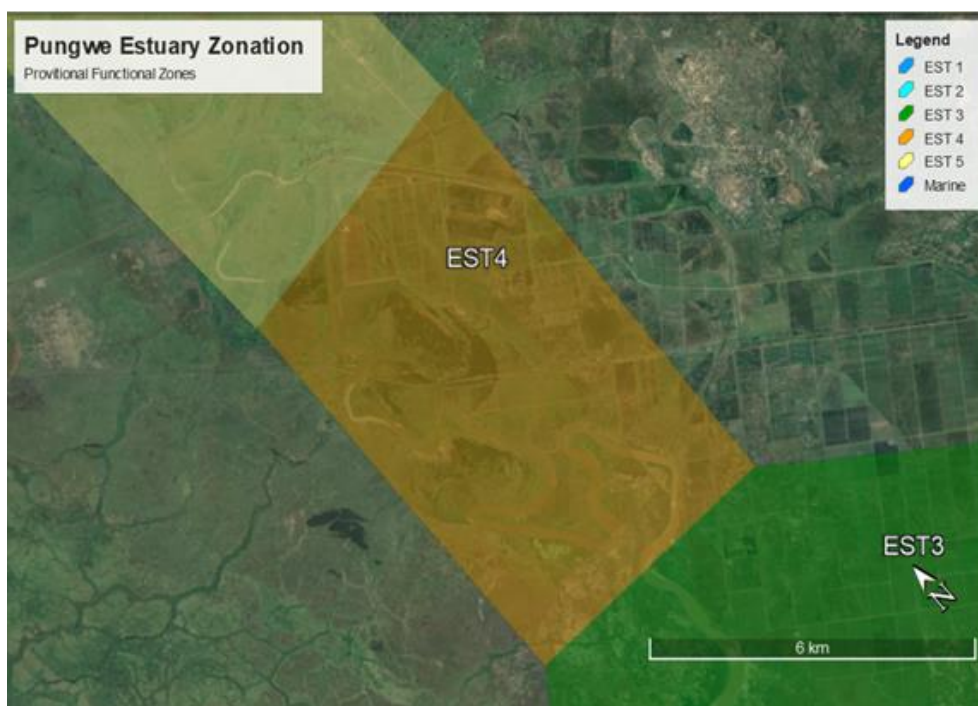


Figure 3.29 Estuary Zone 4 (~60 - 80 km upstream of the mouth)

The salinity in Zone EST 5 (Figure 3.30) is fresh (<1) throughout the year, but this section of the estuary is still under tidal action. Thus, salinity creep is possible if flow decreases below the present baseline under extreme conditions, e.g., large dam development; climate change increasing the intensity of droughts (Abas and Hagedooren 2017).

This zone is shallow with a narrow and confined channel, and is thus highly responsive to river inflow. The zone is important for freshwater-associated faunal species.



Figure 3.30 Estuary Zone 5 (80 - 100 km upstream of the mouth)

3.5.3 Marine zone

The marine EF Zone 7 (Figure 3.31) stretches from the Pungwe Estuary mouth to more than 150 km offshore into the ocean. While mostly marine (salinity = 35) this zone reflects the high turbidity associated with regular fluvial inputs and is subjected to freshwater inputs during floods. This zone is in the process of being refined through a hydrodynamic modelling study.

The marine zone is important for marine and estuarine-associated faunal of economic importance. The marine environment may also be further zoned, pending model results.

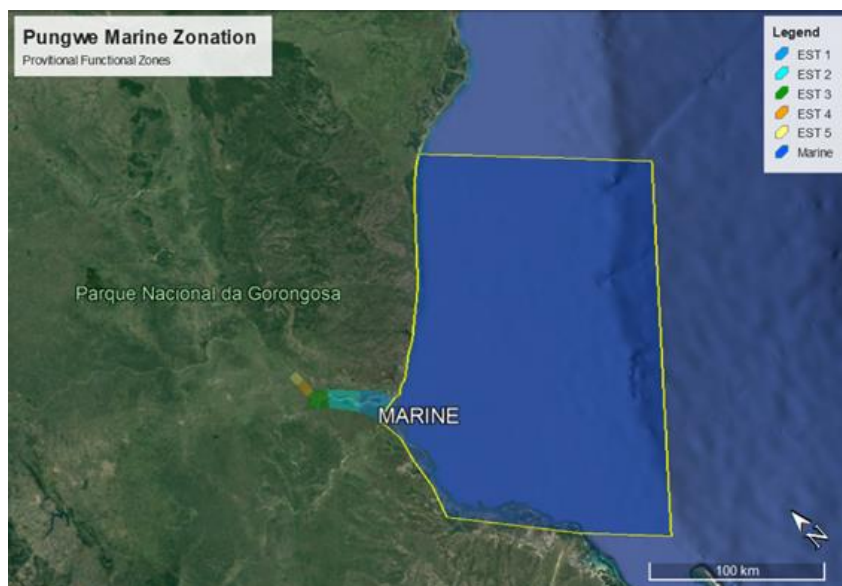


Figure 3.31 Marine Zone (EF Zone 7)

4 ECOSYSTEM AND SOCIO-ECONOMIC INDICATORS

To undertake the scenario analysis, the linkages that arise from the trade-off between water abstracted for use and water retained for environmental flows need to be formulated and their associated impacts determined. Discipline-specific indicators and the links between driving and responding indicators are derived by the EFlows specialist team, and are presented in this report. The time-series from which the hydrological and hydraulic/hydrodynamic driving indicators are derived are generated outside of DRIFT-Pungwe. The roles of water and aquatic ecosystem services in determining the economic prosperity and the social wellbeing of people living in the study area are summarised in Figure 4.1.

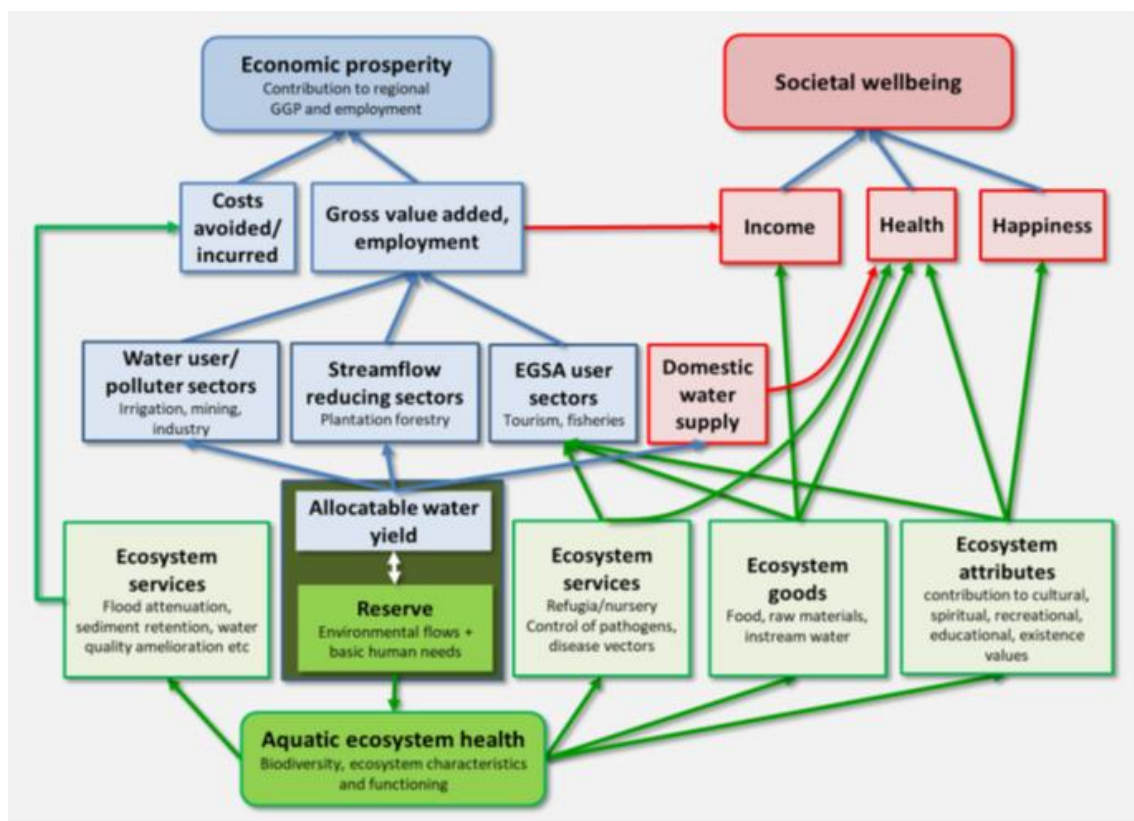


Figure 4.1 Linkages arising from the trade-off between water abstracted for use and water retained for the ecological Reserve. Source: DWS, 2017 modified from Turpie et al. (2006)³

The allocation of EFlows will determine the quantity of water that is available for water resources development and use. The latter influences the outputs of range of economic sectors for which water is a major input. These sectoral outputs contribute to the Gross Domestic Product (GDP) and

³ EGSA: Ecosystem Goods, Services and Attributes.

employment. The amount, timing and quality of instream water flows that are retained for aquatic ecosystems (relative to natural) generate ecosystem services that also benefit households and the economy. The supply of these ecosystem services, which include provisioning services such as fish and reeds, regulating services such as water quality amelioration and carbon retention, and cultural services such as recreation and tourism, are directly related to ecosystem health.

Thus, there is a trade-off in the allocation of water resources: Increasing water abstraction and supply come at the expense of ecosystem services. This trade-off is not linear – there are diminishing marginal returns to both development and conservation. Thus, a balance can be found that allows for maximising the combined benefits from water resources development and ecosystem services supply.

The evaluation of alternative scenarios requires metrics for comparison. These are typically reduced to two or three measures relating to the overall outcome for ecosystems and biodiversity on the one hand, and economies and society on the other. Ecosystem and social indicators are a set of indicators that reflect important aspects of the riverine ecosystem and the livelihood of the people who depend on it, and are the basis on which predictions as to how the river and the people who rely on the river will be affected by changes in drivers, which are water flows, sediment flow and levels of natural resource use. The ecosystem and social are deemed to be sensitive to a change in the driver indicators by changing in one of the following ways:

- Abundance/size, e.g., fish or catch per Unit Effort (CPUE)
- Extent (area), e.g., cover of riparian tree community on the upper dry bank
- Concentration, e.g., sediments and nutrients.

Discipline-specific indicators and the links between driving and responding indicators are derived by the EFlows team. An initial set of indicators was presented in the Inception Report. This has been refined, and the refined set of preliminary ecosystem and socioeconomic indicators are presented. Additional refinement will take place as data analysis is completed over the next months, and the final list of indicators will be presented in the SUPPORTING SPECIALIST STUDIES reports.

4.1 ECOSYSTEM INDICATORS

4.1.1 River EF sites

The river ecosystem indicators currently under consideration for inclusion in the DRIFT model and listed per discipline in Table 4.1, with reasons for their selection and an indication of the site at which they will be assessed. Additional detail on these, and a possible additional refinement of the list of indicators, will be presented in the Specialist Supporting Reports.

Table 4.1 Ecosystem indicators for River EF sites.

Indicator	Reasons for selection as indicator	EF1	EF2	EF3	EF4	EF5
Geomorphology						
Embedded gravel and cobble	Excessive sand or silt deposition due to upstream activities.					
Marginal zone extent	Extent dependent on marginal zone vegetation, and linked to indicators such as tree cover.					
Flood benches	Extent of flood benches dependent on dry bank vegetation. Loss of tree cover and cultivation impacts flood benches.					
Backwater pools and secondary channels	Linked to increased sediment loads resulting in increased deposition of sand and silt. Reduced flooding due to upstream water resource development.					
Flood channels	Area of disturbed flood benches linked to upstream activities.					
Active channel width	Would be subject to changes in flood regime, conditions favouring growth of marginal vegetation and sediment supply.					
Pool depth	Linked to sediment deposition.					
Bedrock core bar sediment	Fine silt deposition due to upstream activities.					
Water quality						
Turbidity	High turbidity levels impact on light penetration and coat habitats used by aquatic biota. <i>Excessive fine silt suspended in the water body, presumably due to upstream gold-mining activities, gold-panning on the banks and cultivation in the Honde Valley.</i>					
Water temperature	Many life-cycles characteristic of aquatic organisms are cued into temperature. Increases in water temperature impact on oxygen solubility and the toxicity of certain chemicals. <i>Relevant for all sites, but particularly EF4 due to shallow water over alluvial sand resulting in high instream temperatures.</i>					
Dissolved oxygen (DO)	Maintenance of adequate DO levels is critical for the survival of aquatic biota. Many toxicants become more toxic with a drop in DO. <i>Important at all sites, but particularly EF4 due to low flows.</i>					
Nutrient status; orthophosphate and nitrate as indicator	Organic enrichment leads to eutrophication and excessive plant growth, resulting in impacts such as lower oxygen availability to aquatic biota. <i>Some evidence of eutrophication at all sites, linked to activities such as instream clothes washing and settlements along rivers.</i>					

Indicator	Reasons for selection as indicator	EF1	EF2	EF3	EF4	EF5
Trace metals, such as mercury and cyanide	Trace metals can be toxic to aquatic biota, with a number of chemical and physical factors modifying their bioavailability and hence toxicity. Adsorption to sediment particles can reduce bioavailability. <i>Mercury (and cyanide) is used in gold extraction and may be evident at EF2 and EF3 where gold-panning is evident. Commercial gold-mining is located upstream of EF2 on the Nyamukwarara River. Extensive ASGM is seen in Zimbabwe, potentially impacting EF1. No data exists to evaluate levels or potential impacts.</i>					
Biocides, such as herbicides (used to control plant growth), and organochlorines such as DDT (pest control); and agrichemicals such as fertilizers	Biocides and agrichemicals can be hazardous to aquatic biota. DDT is hydrophobic and adsorbs to sediment or bioaccumulates in biota. An FAO survey (report date 2016) indicated that most farmers surveyed used pesticides. <i>Evidence of spraying seen near EF1. Fish specialist reports impacts at all sites; reports suggest widespread use.</i>					
Elevated salinities	Increasing salinities may impact on water quality for domestic use (in this instance). <i>Not relevant to EF sites, but at the FIPAG intake point upstream of Mafambisse for water supply to Beira.</i>					
Riverine vegetation						
Bryophyta sp.	Aquatic plants provide important habitat for aquatic invertebrates, which in turn are an important food source for fish.					
<i>Hydrostachys polymorpha</i>						
<i>Ischaemum fasciculatum</i>	Emergent grasses were growing at the water's edge over and into the water. They provide important habitat for aquatic invertebrates, which in turn are an important food source for fish. These grasses also provide important cover for fish from predators.					
<i>Phragmites mauritianus</i>	The common reed was prominent at all the EF sites and was the dominant member of the wet bank community.					
<i>Syzigium guineense</i>	Trees dominate the Riparian Forest and there was a slightly different combination of tree species at each EFlows site. The most prominent one was selected where relevant.					
<i>Ziziphus mucronata</i>						
<i>Dichrostachys cinerea</i>						
<i>Lantana camara</i>	Exotic shrubs were present along the Pungwe River and were not seen on the two tributaries. The seeds are bird dispersed so they can spread quickly in any direction to take over riparian, terrestrial and cultivated habitats.					

Indicator	Reasons for selection as indicator	EF1	EF2	EF3	EF4	EF5
Macroinvertebrates						
Species Richness	Measure of community integrity which would decline with a loss of habitat heterogeneity (EF site 1, 4 and 5)					
Perlidae	Indicator of fast flow (broken water) over cobbles and boulders (EF sites 1, 3 and 5)					
Simuliidae	Indicator of increased suspended organics and stable flows (all sites)					
Chironomidae	Proliferate under reduced flow and elevated algal biomass (all sites)					
Shrimps (Atyidae)	Important source of fish food found only in the Marginal Vegetation out of current (EF site 3)					
Ceratopogonidae	Indicator of increased silt and fine sediments (all sites)					
Thiaridae (snails)	May proliferate in the absence of flood disturbance (EF site 3)					
Fish						
Community structure, species composition	<p>Changes in the fish community and trophic structure will be manifest in the presence / absence and relative abundance / contribution of feeding guilds, these being detritivore, benthic herbivore, opportunistic predator, omnivore, piscivore, zoo-benthivore or zoo-planktivore.</p> <p>Trophic structure, the partitioning of biomass between different trophic levels is affected by community structure (in this instance feeding guild composition) disaggregated into both bottom-up (energy and nutrient uptake by primary producers) and top-down (predation suppresses lower trophic levels) factors.</p>					
Zoo-benthivore	Primarily an indicator of invertebrate prey availability. Also, visual selective feeders affected by turbidity & piscivorous predators albeit invertebrate, piscine, avian or human (fishing).					
Zoo-planktivore	Primarily an indicator of invertebrate prey availability. Also, visual selective feeders affected by turbidity & piscivorous predators albeit invertebrate, piscine, avian or human (fishing). Filter feeders or those able to switch between visual & filter feeding are tolerant of high turbidity.					
Omnivore	Versatile, tolerant & often opportunistic under poor water-quality conditions, increasing in abundance & biomass. Low numbers are mostly indicative of high predation / fishing pressure.					
Opportunistic predator	An indicator of prey (invertebrate, fish & amphibian) biomass. Anguillid eels also an indicator of water quality.					

Indicator	Reasons for selection as indicator	EF1	EF2	EF3	EF4	EF5
Benthic herbivore	Indicative of the availability of benthic algae, macrophytes, epiphytes & sessile invertebrates. Consequently, may be indirectly impacted by both herbicide & pesticide use.					
Piscivore	Respond to the availability of smaller-bodied fish prey, may also switch to invertebrates, amphibians or even birds by tigerfish <i>Hydrocynus vittatus</i> .					
Detritivore	Indicative of connectivity, <i>Labeo altivelis</i> , the only detritivore in the Pungwe system, migrates into tributaries to spawn. It's also an indicator of high predation, especially fishing, pressure.					

4.1.2 Estuaries and marine ecosystems

The river ecosystem indicators currently under consideration for inclusion in the DRIFT model and listed per discipline in Table 4.2 with reasons for their selection and an indication of the site at which they will be assessed. Additional detail on these, and a possible additional refinement of the list of indicators, will be presented in the Specialist Supporting Reports.

Table 4.2 Ecosystem indicators for use in DRIFT analysis for the estuary and marine ecosystems. EST 1 -5: Estuary zones; MAR: Marine zone.

Indicator	Reasons for selection as indicator	EST 1 - 5	MAR
HYDRODYNAMICS			
Salinity	Salinity is a measure of the amount of salt in water (seawater =35). It is an indicator used to understand the hydrodynamics and mixing processes of an estuary as freshwater mixes with seawater. A key factor in the ecology of an estuary as many organisms can only survive within a limited salinity range. It is thus the key indicator affected by environmental flows into estuaries. In open estuaries, reduced flow is the key driver of increase salinity under low flow conditions.		
Water levels	In estuaries the spatial and temporal variation of physicochemical and biological parameters is strongly influenced by tidal dynamics. Changes in water levels also result in the shift in the distribution of macrophyte habitats (e.g. mangrove species) or the ultimate loss of habitats. In addition, water level fluctuations drive access to food and shelter in intertidal and subtidal areas. Changes in the tidal amplitude are also an indicator of channel erosion or deposition and an effective way to monitor long-term change in physical habitat. Changes in water levels can be the result of flow changes, increase catchment erosion, dredging or infrastructure development (bridges/jetties). Sea level rise also poses a threat to many estuaries.		
Retention	The residence time of water in an estuary (inversely related to the flushing rate) is strongly influenced by freshwater flow. It affects the distribution of salinity, dissolved oxygen and resident organisms, sedimentation rates of particulates, processing times of nutrients, contaminants and pathogens, and contaminant exposure risk to resident organisms. Residence time can be highly variable across a range of time scales, from inter-annual to tidal, and modified by estuarine morphology (Chilton <i>et al.</i> 2021). A decrease in river flow result in an increase in residence time, often increasing an estuary's sensitivity to nutrient enrichment. While dredging and port construction can increase flushing by the sea under tidal action.		

Indicator	Reasons for selection as indicator	EST 1 - 5	MAR
Mixing tracer	Model output - A tracer can be used as a dilution proxy for other calculations such as nutrient concentrations or turbidity.		
WATER QUALITY			
Salinity	See above		
Dissolved oxygen (DO)	Decreases in DO are often related to increased organic load, such as from sewage, algal blooms and influx of organic matter into an estuary. This increase in organic load can lead to increased bacterial activity, resulting in greater oxygen consumption. As a consequence, the available oxygen, especially in bottom waters, can become depleted acting as a stressor to the estuary ecology.		
Turbidity	Turbidity is a measure of the suspended material in the water column. Increased turbidity reduces the penetration of light in water and affects the depth at which submerged aquatic vegetation can grow. Turbidity also impacts on the feeding ability of many faunal species. High turbidity may indicate erosion, sediment resuspension, wastewater discharge or algal blooms. Increased turbidity commonly occurs as a result of altered land-based activities, such as land clearing, intensive agriculture, mining and urban development.		
Nutrient concentrations	Dissolved inorganic nutrients are the most biologically available and in excess likely to impact on estuarine and marine systems, particularly through excessive plant growth leading to eutrophication. In estuarine and marine environment nitrogen is often the limiting nutrient for growth, whereas in freshwater it is mainly phosphorous.		
SEDIMENT			
Sediment load	The delivery, deposition and erosion of sediments in estuaries shape their geomorphology. Freshwater inflows transport sediment particulate material to estuaries that settles out in areas of low velocity. Settling rates can be enhanced by flocculation associated with increasing salinity (Chilton et al. 2021). Sediment delivery is important for building habitat structure in estuaries. Turbulent wave action in the coastal surf zone also re-suspends sediments which are transported by flood tides and deposited in the mouths of estuaries, forming sand bars. Scouring by freshwater flows can reduce sand bar development and maintain a connection to the sea. In the absence of flows estuary mouths tend to be come constricted or close.		

Indicator	Reasons for selection as indicator	EST 1 - 5	MAR
Change in intertidal area extent	Intertidal habitats are found between the high tide and low tide, experiencing fluctuating influences of land and sea. Intertidal ecosystems are a dynamic complex of plant, animal and micro-organism communities and their non-living environment that interact as a functioning unit, and are regularly exposed at low tides (e.g. mangroves or saltmarsh on muddy substrate).		
Change in supratidal area extent	That part of the estuarine floodplain located above the high tide that extends into higher lands. These areas are only inundated under spring tides and during floods. Supratidal areas are important refugia during floods.		
Change in subtidal area/volume extent	The size and shape of an estuary determines its inherent physical features – tidal variation, retention time, responsiveness to flow and structural habitat features such as inter- and supratidal area. The disturbance of the sediment erosion or deposition equilibrium in an estuary can lead to siltation, resulting in the estuary becoming shallower, or it can lead to the erosion of important estuarine habitats. Under natural conditions estuaries are in a long-term erosion or deposition equilibrium. However, this equilibrium can be disturbed because of changes in run-off, especially if the occurrences and magnitudes of major floods are changed.		
Mean sediment grain size	The deposition of fine-grained particles allows for colonisation by plants (e.g., saltmarsh, mangroves) and infauna (e.g., polychaetes). Change in volume of sediment entering the estuary can reflect in changes in the grain size fractions and resultant changes in biotic habitats. In addition, freshwater flow interacts with marine sediments at the mouth of estuaries (Chilton <i>et al.</i> 2021). Individual faunal species preferences are highly variable and often related to preferred food sources. Burying ability and crypsis of some species are governed by sediment characteristics.		
MACROPHYTES			
Habitat diversity	Estuary and coastal health depend on the maintenance of a diverse range of habitats. Loss of habitat results in the loss of organisms that need that habitat to survive and thus a decrease in biodiversity. It can also result in loss of recreational value and commercial use, tourism and conservation values. Habitat loss is caused by a variety of human activities including construction of marine facilities, roads, reclamation, urbanisation, dredging, trawling, aquaculture, tourism and unregulated recreational activities.		

Indicator	Reasons for selection as indicator	EST 1 - 5	MAR
Mangrove extent	<p>Mangroves are trees that establish in the intertidal zone in permanently open estuaries along the east coast of Africa. Mangrove forests protect the coastline acting as buffers against severe weather. They are extremely productive habitats that are home to a diversity of fish and invertebrate species. Mangroves are also important for filtering and improving water quality. They also have a high recreational, cultural and tourism value. More recently the value of mangrove forests as a carbon sink has been recognized. Mangroves are threatened by over-abstraction of freshwater, change in sediment inputs, overutilization such as the harvesting of mangrove wood for building material, and for removal for aquaculture and slash and burn cultivation. Climate change driven sea level rise and temperature changes has the potential to change the distribution range of mangrove species.</p>		
Saltmarsh extent	<p>Saltmarshes are a suite of herbaceous vascular plants that are adapted to endure the extremes of salinity, desiccation and tidal flooding characterizes salt marshes. Salt marsh plants show distinct zonation patterns along tidal inundation and salinity gradients. Zonation is well developed in estuaries with a large tidal range. Intertidal salt marsh occurs below mean high water spring and supratidal salt marsh above this. Salt marsh vegetation stabilizes the sediment protecting the banks of an estuary from eroding away. They are important filters of sediment and pollutants as well as zones of nutrient production and retention.</p>		
Reeds and sedges extent	<p>Reeds, sedges and rushes are important in the freshwater and brackish zones of estuaries, providing structure and shelter while protecting banks from erosion. Because they are often associated with freshwater input, they can be used to identify freshwater seepage sites along estuaries and an indicator of salinity creep.</p>		
Submerged Macrophyte extent	<p>Several estuarine resident species have a critical dependence on vegetated habitats. Seagrass is especially important, although other vegetation can be used. In clear water systems especially, fishes have a high dependency on vegetation as a predation refuge, especially during daylight hours. However, in turbid system like the Pungwe, habitat associations with structured habitats are generally weaker or habitat may even not be present.</p>		

Indicator	Reasons for selection as indicator	EST 1 - 5	MAR
INVERTEBRATES			
Species diversity	Estuarine invertebrate are important food sources for fish and birds, as well as being an important resource used by people for food and bait. They are also habitat formers that provide additional niches for other organisms, thereby increasing the diversity and carrying capacity of estuarine systems. As many are estuarine residents and act as good long term integrators and indicators of conditions. Marine migratory species or those with a marine phase in their life cycle can also provide important indications of land-sea connectivity. 'Species diversity' provides a good measure of community integrity which would change with change in salinity distribution, decline in water quality, loss of habitat, overfishing, introduction of invasive alien species and loss of habitat.		
Penaeidae prawns	Indicator of change in salinity and shifts in silt and fine sediment fractions. Important source of fish food		
Mud crab <i>Scylla serrata</i>	Indicator of change in salinity and shifts in silt and fine sediment fractions.		
<i>Mierspenaeopsis sculptilis</i>	Invasive penaeid rainbow prawn is an indicator of ecosystem change, potentially responding to change trophic structure due to fishing and outcompeting native species. Important indicator of change in the fisheries as it is of much lower value than the indigenous species.		
FISH			
Species diversity	Fish are important as a food source for one another and for birds and reptiles, as well as being an important resource used by people for food and bait. They are also highly mobile and respond rapidly to changes in flow and water quality. 'Species diversity' provides a good measure of community integrity which would change with change in salinity distribution, decline in water quality, loss of habitat, overfishing, introduction of invasive alien species and loss of habitat.		

Indicator	Reasons for selection as indicator	EST 1 - 5	MAR
Abundance of marine species	Increase under reduced flow conditions, decrease with increased turbidity or loss of habitat (subtidal / intertidal macrophytes).		
Abundance of marine vagrants	Increase under reduced flow conditions, decrease with increased turbidity or loss of habitat (subtidal /intertidal macrophytes).		
Abundance of estuarine-associated species	Decrease under reduced flow conditions and a decrease in floods, decline in water quality, loss of habitat (subtidal /intertidal macrophytes).		
Abundance of estuarine breeders	Decrease under reduced flow conditions and a decrease in floods, decline in water quality, loss of habitat (subtidal /intertidal macrophytes).		
Abundance of freshwater species	Decrease under reduced flow conditions and a decrease in floods, decline in water quality, loss of habitat (subtidal /intertidal macrophytes).		

4.2 SOCIO-ECONOMIC INDICATORS

The socio-economic outcome of a particular scenario will be based on changes in a range of socio-economic indicators. These in turn will be computed based on a combination of general trends (e.g., the background population and economic growth rates), assumptions regarding the sectoral allocation of water resources development, and ecological indicators.

A list of indicators that will be used in the socio-economic analysis is given in Table 4.3. The general indicators (population and economic growth) will underlie assumptions about water resources demand and will inform the water supply deficit indicator. The water resources development indicators are derived from the scenario, which determines how much water can be allocated to use after environmental flow requirements of the river health scenario are met. Certain assumptions will have to be made about how that water is used, which will vary zone to zone. In addition, the water supply cost indicator requires an input on water quality, specifically turbidity.

The baseline situation in terms of the socio-economic indicators is described in the following section (Section 5), along with information on the trends of underlying (general) indicators. The indicator measures are provided for each of the socio-economic zones. Trends in the supply of ecosystem services are not described again here, since these will be described for the underlying ecological indicators in the ecological reports. The way in which the socio-economic indicators will be derived from the primary input indicators will be explained in more detail in Section 6.

Table 4.3 Summary of the primary input indicators and derived socio-economic indicators for the evaluation of alternative flow scenarios. Note that alignment of rows does not show all linkages. General indicators link to a number of socio-economic indicators.

Group	Socio-economic indicators
Water resources development indicators	Urban water supply cost
	Irrigation agriculture value
	Plantation forestry value
	Mining and industry value
	Hydropower value
Aquatic ecosystem services indicators	Tourism sector value
	Biodiversity value
	Fisheries value
	Plant resources value
	Carbon retention value
	Household water access cost
	Small scale agriculture production value
Summary indicators	Net change in value from water resources supply and use
	Net change in value of ecosystem services

5 BASELINE STATUS AND HISTORICAL TRENDS⁴

5.1 OVERVIEW OF HISTORICAL EVENTS AFFECTING THE ECOLOGICAL INTEGRITY OF THE PUNGWE RIVER

Key historical events in the Pungwe Basin that would likely have impacted the aquatic ecosystems and/or the people of the basin are listed in Table 5.1.

Table 5.1 Historical events affecting the ecological integrity of the Pungwe Basin and/or the people of the basin.

Date	Action/development	Consequences	Reference
1960	Gorongosa National Park is proclaimed	Protected area, research and data curation in environmental databases.	GRP 2017
1960 onward	Gold Mining in Upper Pungwe/Honde River area	Water quality impacts (sedimentation)	Google Earth (GE)
1964-1979: Zimbabwe	Zimbabwean War of Independence	Disruption at all levels across the country	Wikipedia
Early 2000s	Water supply to Mutare (45 Mm ³ /a) via inter-basin transfer from the Pungwe	Low flow reduction	Consultec 2013
?	Irrigation abstractions in the Honde Valley	Low flow reduction	Consultec 2013
1972-1992: Mozambique	Civil War	Outmigration of population from the catchment; some recovery of vegetation cover	Jansen <i>et al.</i> 2008
1990s	Wamba Dam and Eastern Highlands Tea Plantation	Low flow reduction	GE
Opened 2007	Muda Dam for irrigation development (Mafambisse agricultural extension; sugar-cane)	Elevated high flows downstream due to river releases	Estimate
From 2003	Proliferation of informal gold-mining activities	Drastic increase in instream sediment loads	Morón 2014

⁴ The baseline status and historical trends presented here excludes the estuary and marine environments as the field data collected for the estuary were not available at the time of writing.

Date	Action/development	Consequences	Reference
1999, 2020: Leon-Eline; March 2019: Idai; Dec 2020-Jan 2021: Chalane; Jan 2021: Eloise	Extreme floods (cyclones and severe tropical storms)	Major geomorphic events - erosion and deposition on flood plains. Destruction of mangroves: Chalane and Idai	Modis NASA, Dartmouth Flood observatory, Alferes <i>et al.</i> 2006, SIDA 2008
1953 - present	Rural population of Mozambique increased from 6.1M to 19.3M	Loss/disturbance of natural vegetation cover leads to erosion and increased sediment loads	Worldometer (accessed 2022), Alferes <i>et al.</i> 2006, McCartney and Owen 2007, Jansen <i>et al.</i> 2008, Grinand <i>et al.</i> 2018
Early 2000s	Restoration efforts start in GNP; signing of the Gorongosa Restoration Project (GRP) in 2008. 2014: Edward O. Wilson Biodiversity Laboratory inaugurated.	Biodiversity protection and research; monitoring and data curation in environmental databases.	GRP 2017
2005-2017	DDT reintroduced in 2005 for malaria control until replaced by Acteclic 300 and deltamethrin in 2017	Unknown impact on ecological systems.	Munhequete 2019
2008-2009: Zimbabwe	Harsh economic climate	Few water samples collected for water quality analysis	Feresu 2017
Ongoing, increased activity since 2011	Gold mining (panning)	Disturbance of bed and banks, loss of vegetation for wood fuel, significant increase in suspended sediment	Alferes <i>et al.</i> 2006, Dondeyne <i>et al.</i> 2009, de Jesus Pereira 2009, Sørensen <i>et al.</i> 2018, GE
August 2014	Government of Mozambique cancelled the registration of 61 pesticide products, and announced risk reduction measures for another 52 products.	Pesticides are highly hazardous to aquatic systems.	FAO 2016

5.2 APPROACH TO THE STATUS AND TRENDS ASSESSMENT

Preliminary Baseline Ecological Status (BES 2022) and estimated historical trends assessments are presented for each of the discipline indicators, per EF site or zone. BES assessments are based on the a-F ecological states (Kleynhans 1997).

For the historical trends, the specialists estimated what the relative abundance, extent or concentration⁵, relative to BES, for 1900, 1960, and 2000; and provided supporting reasons. For each the abundance at BES is 100%. These are used to contextualise each indicator in terms of changes in the factors that have affected it, which is useful when setting up the DRIFT model.

Table 5.2 A-F ecological states (Kleynhans 1997)

A	Unmodified, natural	As close as possible to natural conditions.
B	Largely natural	Modified from the original natural condition but not sufficiently to have produced measurable change in the nature and functioning of the ecosystem/community.
C	Moderately modified	Changed from the original condition sufficiently to have measurably altered the nature and functioning of the ecosystem/community, although the difference may not be obvious to a casual observer.
D	Largely modified	Sufficiently altered from the original natural condition for obvious impacts on the nature and functioning of the ecosystem/community to have occurred.
E	Completely modified	Important aspects of the original nature and functioning of the ecosystem community are no longer present. The area is heavily negatively impacted by human interventions.

5.3 RIVER ECOSYSTEM

5.3.1 Geomorphology

The geomorphological BES and associated confidence of the assessment per site is shown on Table 5.3.

⁵ as relevant to each indicator

Table 5.3 BES: Geomorphology

Site	Status	Key characteristics and impacts	Confidence
EF1	C (75.9%)	This site had a pool-riffle morphology with narrow flood benches constrained within a high terrace. Moderate catchment erosion is indicated as the cause of extensive sand patches and embedded cobble. Local clearing of riparian vegetation has led to decreased stability of the channel banks and flood benches. Terraces are extensively cultivated.	Moderate (3.1). Good access to the river bed and riparian zone. Limited knowledge of upstream conditions that impact on system connectivity and sediment supply.
EF3	B (83%)	Extensive bedrock makes the site highly resistant to morphological change. Key habitat features are the main channel with alternating pools and rapids, and lateral flood channels over bedrock that support reed growth; dry season pools persist on the left bank. A low level flood channel that lies adjacent to the main channel on the right bank is devoid of vegetation and contains active deposits of cobble, gravel and sand, with patches of silt. This lateral channel contains a number of fish traps. so is likely to be activated under normal high flow conditions. The sand and gravels are disturbed by panning activities. High silt loads result from upstream panning but their impact on channel morphology is unlikely to be more than moderate and limited to low energy areas. Low gradient and resistant bedrock of surrounding terrain limits erosion rates so supply of coarse bed sediment (sand and greater) is unlikely to be elevated above natural.	Moderate (3.1) The bed of the main channel was not accessible to the scientist due to deep, fast water and visibility was impaired by high turbidity. Access to riparian areas good but scale of the site limited extent of the survey.
EF4	B (82.4%)	The mobile nature of the sand bed at this site means that inter-annual changes to the channel bed can be expected. Low gradient and resistant bedrock of surrounding terrain limits erosion rates so sediment supply is unlikely to be elevated above natural. Bank erosion was observed locally but could be due to natural causes. The most significant anthropogenic impact was the widespread cultivation of the annual or biennial flood benches.	Moderate (3.1) Good access to both river bed and riparian zone. Limited knowledge of upstream catchment and long term changes.
EF5	B (86.4%)	Strong bedrock control inhibits morphological change. Bedrock islands in rapid supported vigorous reed growth with fibrous roots trapping fine sediment. Increased population pressures on Gorongosa Mountain increases sediment supply leading to possible deposition of fine sediments in low velocity areas; widespread cultivation on flood zones disturbs riparian area.	Moderate (2.7) High instream velocities and significant water depth made access to stream bed difficult, rapid section inaccessible, limited knowledge of upstream conditions.

Estimated historical changes in the geomorphological indicators are provided in Table 5.4 to Table 5.7.

Table 5.4 Estimated historical trends as a percentage of baseline for geomorphology at EF site 1 (2022 = 100%).

Indicator	2000	1960	1900	Explanation
embedded gravel and cobble	95	50	10	Excessive sand or silt deposition linked to upstream cultivation that would have been minimal in 1900. Cultivation patterns changed little since 2000.
marginal zone	105	120	150	Extent of marginal zone dependent on marginal zone vegetation. Loss of tree cover impacts marginal zone.
flood benches	105	115	130	Extent of flood benches dependent on dry bank vegetation. Loss of tree cover and cultivation impacts flood benches.

Table 5.5 Estimated historical trends as a percentage of baseline for geomorphology at EF site 3 (2022 = 100%).

Indicator	2000	1960	1900	Explanation
backwater pools and secondary channels adjacent to main channel	100	110	120	No clear evidence of loss or gain of secondary channels but increased sediment loads could have increased deposition of sand and silt. Disturbance due to artisanal gold-mining. Would be vulnerable to reduced flooding resulting from upstream water resource developments.
marginal zone				marginal zone linked to flood channels (see below)
flood benches	97	70	10	Area of disturbed flood benches increased from a very low value to high at present day
flood channels	100	110	120	No clear evidence of loss of flood channels but increased sediment loads could have increased deposition of sand and silt. Would be vulnerable to reduced flooding resulting from upstream water resource developments.

Table 5.6 Estimated historical trends as a percentage of baseline for geomorphology at EF site 4 (2022 = 100%).

Indicator	2000	1960	1900	Explanation
active channel width	100	100	100	Would be subject to changes in flood regime, conditions favouring growth of marginal vegetation and sediment supply. None of these are known to have changed significantly since 1900.
backwater pools and secondary channels	100	100	100	
marginal zone	100	100	100	
flood benches	97	70	10	Area of disturbed flood benches increased from a very low value to high at present day

Table 5.7 Estimated historical trends as a percentage of baseline for geomorphology at EF site 5 (2022 = 100%).

Indicator	2000	1960	1900	Explanation
pool depth	105	120	150	Some decrease in pool depth due to sediment deposition
flood benches	95	50	10	Area of disturbed flood benches increased from a very low value to moderately high at present day
bedrock core bar sediment	95	90	70	Fine sediment from erosion upstream depositing in reed root matt on core bars. Recent increased cultivation on lower slopes of Gorongosa Mountain.
secondary channels	100	100	100	An important habitat feature but no evidence to indicate change over time.

5.3.2 Water quality

Water quality BES 2022 for the EF sites are shown in Table 5.8, based on a qualitative/quantitate assessment using the PAI spreadsheet model.

Table 5.8 An assessment of water quality state for the EF sites in the Pungwe Basin

Site	Ecological Category	Reason: driving water quality variables
EF1	B/C (81.8%)	Elevated nutrients and toxics expected.
EF2	C/D (59.4%)	High turbidities, elevated salts, some nutrients and toxics expected.
EF3	C/D (61.8%)	High turbidities, elevated salts, some nutrients and toxics expected
EF4	C (64.1%)	Elevated nutrients and toxics expected; elevated salts and impacts on temperature and oxygen expected due to low flows, and shallow water over alluvial sands.
EF5	B (82.7%)	Some elevation in nutrients expected.

Historical changes in water quality indicators of the Pungwe River system are estimated in Table 5.9 to Table 5.13.

Table 5.9 Estimated historical trends as a percentage of baseline for water quality indicators at EF site 1 (2022 = 100%).

Indicator	2000	1960	1900	Explanation
Turbidity	80	60	10	Mining upstream and cultivation upstream and at the site would have increased sediment loads over time, although levels still relatively low at this site.
Water temperature	100	100	100	No changes in temperature expected.
Dissolved oxygen	100	100	100	No changes in DO expected.
Nutrient status (orthophosphate)	100	50	20	Nutrient levels would have increased over time due to population pressures and anthropogenic use of the river at this site.
Trace metals such as Hg and Cn	80	40	0	Expected due to upstream mining activities.
Biocides and agri-chemicals	80	50	20	Indications of biocide and agrichemical use at this site.

Table 5.10 Estimated historical trends as a percentage of baseline for water quality indicators at EF site 2 (2022 = 100%)

Indicator	2000	1960	1900	Explanation
Turbidity	100	80	10	High suspended sediment load; presumably due to extensive gold-mining upstream and gold-panning at the site.
Water temperature	100	100	100	No changes in temperature expected.
Dissolved oxygen	100	100	100	No changes in DO expected.
Nutrient status (orthophosphate)	80	40	20	Nutrient levels would have increased over time due to population pressures and anthropogenic use of the river at this site, but limited due to access and security.
Trace metals such as Hg and Cn	90	60	0	Expected due to upstream mining activities.
Biocides and agri-chemicals	80	40	10	Indications of biocide and agrichemical use upstream, and possibly at the site.

Table 5.11 Estimated historical trends as a percentage of baseline for water quality indicators at EF site 3 (2022 = 100%)

Indicator	2000	1960	1900	Explanation
Turbidity	100	70	10	High suspended sediment load; presumably due to extensive gold-mining upstream and gold-panning at the site.
Water temperature	100	100	100	No changes in temperature expected.
Dissolved oxygen	100	100	100	No changes in DO expected.
Nutrient status (orthophosphate)	80	50	20	Nutrient levels would have increased over time due to population pressures and anthropogenic use of the river at this site.
Trace metals such as Hg and Cn	90	60	0	Expected due to upstream mining activities.
Biocides and agri-chemicals	80	40	10	Indications of biocide and agrichemical use upstream, and possibly at the site.

Table 5.12 Estimated historical trends as a percentage of baseline for water quality indicators at EF site 4 (2022 = 100%)

Indicator	2000	1960	1900	Explanation
Turbidity	100	70	50	Turbidity levels low; due to agricultural activities on the banks.
Water temperature	100	80	80	No changes in temperature expected. Additional abstractions may impact on water levels of an alluvial system.
Dissolved oxygen	100	80	80	Changes in water temperature would have a concomitant change in DO.
Nutrient status (orthophosphate)	100	50	20	Nutrient levels would have increased over time due to population pressures and anthropogenic use of the river at this site.
Trace metals such as Hg and Cn	90	40	0	Trace metals not expected at this site.
Biocides and agri-chemicals	90	70	10	Biocide and agrichemical use limited.

Table 5.13 Estimated historical trends as a percentage of baseline for water quality indicators at EF site 5 (2022 = 100%)

Indicator	2000	1960	1900	Explanation
Turbidity	80	60	10	Turbidity levels low; due to limited agricultural activities on the banks.
Water temperature	100	100	100	No changes in temperature expected.
Dissolved oxygen	100	100	100	No changes in DO expected.
Nutrient status (orthophosphate)	90	60	20	Nutrient levels would have increased over time due to population pressures and anthropogenic use of the river at this site.
Trace metals such as Hg and Cn	80	50	10	Trace metals not expected at significant levels at this site.
Biocides and agri-chemicals	90	70	10	Biocide and agrichemical use limited.

5.3.3 Riparian Vegetation

The ecological status of the riparian vegetation was scored using the Vegetation Response and Assessment Index (VEGRAI, Kleynhans *et al.* 2007), developed for tropical African rivers. Modification of the riparian plant community was determined by scoring the intensity and extent of modification of the current state relative to what would be natural. Riparian plant communities are arranged into a wet bank community, adjacent to the water's edge and onto the first river bank terrace, and a dry bank community, situated higher up on the second terrace (Reinecke *et al.* 2015). Using the VEGRAI system, the wet and dry banks were considered separately and the scores for each combined into an overall score. Consideration was given to:

- Removal of plants
- Presence of exotic plant species
- Changes in water quantity
- Changes in water quality
- The cover, abundance and species composition of woody and non-woody species.

The riparian vegetation at EF sites 1, 4 and 5 were all in a C/D ecological category (Table 5.14) because much of the wet and dry banks had been cleared to make way for cultivated fields. This reduced the abundance of the woody and non-woody indigenous plants but did not drastically alter the natural species composition. There were still many indigenous plants present and relatively few exotics.

There was a larger abundance of indigenous plants at EF sites 2 and 3 because the extent of clearing for cultivated fields was far less. A species list is shown in Appendix B.

Table 5.14 Ecological status of riparian vegetation

EF Site	Riparian vegetation score	Ecological category
1	59%	C/D
2	70%	C
3	85%	B
4	59%	C/D
5	59%	C/D

5.3.3.1 Aquatic plants

Relevant at EF sites 1, 3 and 5.

Aquatic plants were submerged in the channel and are probably not heavily utilized. Love charms are made from *Hydrstachys* (PlantZAfrica 2004) but how many of these are made and sold is not known. They were found growing on the submerged rocks at EF sites 1, 3 and 5. None were seen growing on the rocks at EFlows site 2 and there were no submerged rocks at EFlows site 4.

The main anthropogenic driver of indicator status was:

- High turbidity from gold-mining upstream, which reduces light penetration into the water that reduces photosynthesis, growth and reproduction (Bornette and Puijalon 2011). The main source of turbidity is large-scale commercial mining on the banks of the Honde valley.

Assuming that the 2022 quantity (in terms of abundance) of the indicator was 100%, the estimated quantity as a relative percentage to 2022 in:

- 1900 was:
 - 100% at EF sites 1 and 5, because the abundance of aquatic plants has not changed from baseline; small amounts of the plant are harvested.
 - 120% at EFlows site 3, because there was less artisanal gold-mining, the population was lower, so the water was less turbid and plant productivity and abundance were higher.
- 1960 was:
 - 100% at EF sites 1 and 5, because the abundance of aquatic plants has not changed from baseline; small amounts of the plant are harvested.
 - 115% at EFlows site 3, because artisanal gold-mining had increased but was still low, so the water was less turbid and plant productivity and abundance were higher.
- 2000 was:
 - 100% at EF sites 1 and 5, because the abundance of aquatic plants has not changed from baseline; small amounts of the plant are harvested.
 - 110% at EFlows site 3, because commercial mining had begun and artisanal mining had increased, so turbidity had increased further.

5.3.3.2 *Emergent grasses*

Relevant at all EF sites.

Emergent grasses are short and were seen growing on the side of, and in the channel at, all the EF sites. Some of these may be used socially, to make domestic items such as baskets, hats, mats and so on, but their use is probably less than larger grasses and reeds that will make stronger and larger products.

The three main anthropogenic drivers of indicator status are:

- Clearing of river banks to make way for cultivated fields.
- Grazing by livestock.
- Mining of sand and stone from the river banks.

Assuming that the 2022 quantity (in terms of abundance) of the indicator was 100%, the estimated quantity as a relative percentage to 2022 in:

- 1900 was 120%, because the population was lower so there was less cultivation, livestock grazing and mining.
- 1960 was 110%, because the population was lower so there was less cultivation, livestock grazing and mining.
- 2000 was 100%, because there have been no changes in the land-use around the sites since 2000, and it is assumed therefore that livestock and mining have also been constant since then, same as baseline.

5.3.3.3 *Floodplain reeds*

Relevant at all EF sites.

Floodplain reeds grow on the floodplain sands and are cleared to make way for cultivated fields. They are also used to make a variety of domestic items such as baskets, mats, hats etc..

The four main anthropogenic drivers of indicator status are:

- Clearing of the floodplain to make way for cultivated fields.
- Grazing by livestock.
- Mining of sand and stone from the river banks.
- Harvesting of reeds for domestic use.

Assuming that the 2022 quantity (in terms of abundance) of the indicator was 100%, the estimated quantity as a relative percentage to 2022 in:

- 1900 was 140%, because the population was lower so there was less cultivation, livestock grazing, mining and harvesting.
- 1960 was 120%, because the population was lower so there was less cultivation, livestock grazing, mining and harvesting.

- 2000 was 100%, because there have been no changes in the land-use around the sites since 2000, and it is assumed therefore that livestock and mining have also been constant since then, same as baseline.

5.3.3.4 *River bank trees*

Relevant at all EF sites.

Trees grow on the river bank. The width of the riparian zone would have been much wider prior to being cleared to make way for cultivated fields, and the harvesting of wood to make coal and for timber.

The two main anthropogenic drivers of indicator status are:

- Clearing of river banks for cultivated fields.
- Felling of trees.

Assuming that the 2022 quantity (in terms of abundance) of the indicator was 100%, the estimated quantity as a relative percentage to 2022 in:

- 1900 was 160%, because the population was lower so there was less cultivation, livestock grazing, mining and harvesting.
- 1960 was 140%, because the population was lower so there was less cultivation, livestock grazing, mining and harvesting.
- 2000 was 100%, because there have been no changes in the land-use around the sites since 2000, and it is assumed therefore that livestock and mining have also been constant since then, same as baseline.

5.3.3.5 *Exotic shrubs*

Relevant at EF sites 1, 2 and 3.

Like other invasive plants, once established, exotic shrubs will continue to spread especially when a disturbance creates a gap in the canopy cover. The plant is spread by animals that eat the fruits so can spread in an upstream and downstream direction (Bionet 2022). It is very difficult to control because it spreads quickly, grows to form dense monotype stands and is not grazed by livestock because it is poisonous (theSpruce 2022). It was found growing on the Pungwe River and not on the tributaries.

The two main anthropogenic drivers of indicator status are:

- The planting of exotic shrubs in gardens.
- The planting of exotic shrubs to harvest leaves for medicinal purposes.

Assuming that the 2022 quantity (in terms of abundance) of the indicator was 100%, the estimated quantity as a relative percentage to 2022 in:

- 1900 was 10%, after being introduced probably in the later 1800s when this shrub was spread to other countries from South America.
- 1960 was 40%, slowly increasing in abundance as use and cultivation, and therefore spread take place.
- 2000 was 80%, slowly increasing in abundance as use and cultivation, and therefore spread take place.

5.3.4 Macroinvertebrates

The Zambian Scoring System (ZISS) biomonitoring method (Lowe *et al.* 2013) was used to guide the determination of the BES 2022 for the aquatic macroinvertebrates. The ZISS method is essentially an adaptation of the South African Scoring System version 5 (SASS5) (Dickens and Graham 2002), which is a widely used approach for the assessment of macroinvertebrate communities in South African rivers (Dallas 2007). Whereas SASS5 was developed for temperate river ecosystems across South Africa, ZISS was developed specifically for assessing aquatic macroinvertebrates in afro-tropical river ecosystems. Thus, the ZISS method was considered more appropriate for application to the Pungwe River and its tributaries sampled during this assessment.

This method provides an excellent index of species richness and water quality in perennial rivers with relatively natural habitats and thus provides an indication of ecological condition. The protocol allocates a predetermined score for each taxon according to its sensitivity to water quality perturbation. Sensitive taxa are allocated high weighting (maximum of 15) while taxa more common to degraded/disturbed systems receive low weightings. The aquatic macroinvertebrate data from individual samples collected at each site were grouped and summarised at family level according to the three main biotopes (i.e. Stones, Vegetation and GSM) prescribed by the ZISS biomonitoring.

ZISS scores, Average Scores Per Taxon (ASPTs)⁶ – calculated by dividing the ZISS score by the number of taxa - and total number of taxa were calculated for each of the three biotopes. Essentially, an assessment of BES for aquatic invertebrates was based on an assessment and interpretation of these data using the guidelines provided in Table 5.15.

⁶ ASPTs are particularly useful as indicators of water quality of an aquatic system, as a low score will indicate that the community is dominated by species resistant to anthropogenic perturbations such as pollution, while high scores indicate the occurrence of more sensitive and, often rare, species, that would be expected to occur in undisturbed systems.

Table 5.15 Guidelines used to determine the Present Ecological State of aquatic macroinvertebrates applied in this study.

Category	Description
A	<i>Unimpaired</i>
	natural diversity of taxa, and;
	numerous sensitive taxa, and;
	abundance as expected under natural conditions, and; no taxon dominating the fauna for extended periods.
B	<i>Slightly Impaired</i>
	As above, but with fewer sensitive taxa and slightly lower diversity.
C	<i>Moderately Impaired</i>
	Moderate diversity of taxa relative to diversity expected under natural conditions, or; moderate numbers of sensitive taxa, or;
	moderate reduction in abundance of some or all taxa relative to that expected under natural conditions.
D	<i>Considerably Impaired</i>
	Low diversity of taxa relative to diversity expected under natural conditions, and; mostly tolerant taxa, and;
	considerable reduction in abundance of some or all taxa relative to that expected under natural conditions, or;
	more than one taxon dominating the fauna for extended periods.
E	<i>Severely Impaired</i>
	Very low diversity of taxa relative to diversity expected under natural conditions, and; only tolerant taxa present, or;
	severe reduction in abundance of some or all taxa relative to that expected under natural conditions, or;
	only one taxon dominating the fauna for extended periods.
F	<i>Very Severely Impaired</i>
	As above, but with Very Severe reduction in diversity and abundance.

EF Site 1

EF Site 1 on the upper Pungwe River in the eastern highlands of Zimbabwe provided a range of different flow and substrate types in August 2022 applicable to the three main biotopes relevant to the ZISS biomonitoring method. The “stones” biotope represented the most diversity in terms of flow and substrate types, including riffles and runs over large and small cobble, runs over large cobble and boulders, and a mid-channel pool with large cobbles and boulders and very slow flow. Twenty of the 27 families relevant to the ZISS assessment were found in the stones biotope, mostly belonging to the Ephemeroptera of which five different baetid mayflies were identified. Also, of the Trichoptera, four different Hydropsychidae species were found only in the stones biotope. Vegetation included mostly overhanging plants and plant roots in fast flows adjacent to the riffle. A total of 18 taxa were recorded in the vegetation (Table 5.16). Although some taxa sensitive to water quality impairment such as the Teloganodidae, and Heptagenidae were found in both the stone and vegetation biotopes, most of the sensitive taxa were found only in the stones biotope. These included the stonefly, Perlidae,

Leptophlebiidae, Pyralidae and the water penny beetle, Psephenidae. The “Gravel-Sand-Mud” biotope included mostly sand between boulders in the pool and silty slackwaters along the channel margin with slow flows. Only 11 taxa were recorded in this biotope, with an absence of sensitive taxa and dominance of the Dipteran larvae, Chironomidae which are generally hardy and pollution tolerant.

With an ASPT score of 7.60 for the stone biotope and a total ASPT score of 6.89, this site supports a high proportion of moderately to highly sensitive taxa (Table 5.16). Also no single taxon was particularly dominant. Nevertheless, the recorded number of taxa was lower than expected under natural conditions. These data suggest a slight impairment from natural and thus in terms of macroinvertebrates, the BES 2022 of the Pungwe River in the Eastern Highlands at EF Site 1 is rated as a **Category B**.

Table 5.16 ZISS results for EF Site 1 sampled in August 2022.

EF site 1: Upper Pungwe	Stones	Veg	GSM	TOTAL
ZISS	152	102	61	186
Total number of families	20	18	11	27
ASPT	7.60	5.67	5.55	6.89

EF Site 3

Despite a fast-flowing active channel characterised as a rapid over bedrock and boulders, this channel was largely inaccessible for macroinvertebrate sampling. While the secondary channel was not flowing at the time of the site visit in August 2022, isolated pools along this channel were accessible for sampling. Thus, the “Stones” biotope was limited to cobbles along the margin of the rapid and a small area of cascades and rapids over boulders and large cobbles within the active channel. Isolated pools with bedrock and small cobble in the secondary channel also contributed to the “stones” biotope at EF site 3. VIC included a small patch of aquatic fern within the cascade. VOOC included mostly stalks of *Phragmites* sp. with some grasses along the margins of pools within the secondary channel. The GSM biotope included relatively deep, sandy pools with no flow in the secondary channel, although some GSM habitat with flickering flow was present along the margins of the active channel. Although 13 taxa were recorded in both the Stones and Vegetation biotopes, the stones biotope supported a higher number of sensitive taxa thus resulting in a higher ZISS and ASPT score (Table 5.17). These included Perlidae, Leptophlebiidae, Athericidae and Dipseudopsidae. Only five families, mostly, hardy pollution sensitive taxa as indicated by the low ASPT score, were recorded in the GSM biotope at EF Site 3.

Although no single taxon was particularly dominant, the overall number of taxa and the proportion of sensitive taxa at this site is considerably lower than expected. While this may in part be due to the inaccessible nature of the site, the low ZISS and ASPT scores overall represent a system that is dominated by tolerant taxa with a diversity and abundance of sensitive taxa considerably lower than expected under natural conditions. In terms of macroinvertebrates, the BES of the Pungwe River at

EF3 is rated as a **Category D**. The high turbidity of the system and gold-mining activities along the channel upstream of this reach may account for the poor ecological integrity of the site.

Table 5.17 ZISS results for EF Site 3 sampled in August 2022.

EF site 3: Pungwe on the N1 bridge	Stones	Veg	GSM	TOTAL
ZISS	76	66	22	119
Total number of families	13	13	5	21
ASPT	5.85	5.08	4.40	5.67

EF Site 4

The Nhandungue River at EF Site 4 is characterized as a low gradient, gravel and sand bed river fringed with dense stands of reeds. Thus, there was no ‘stone’ habitat available for sampling at this site and biotopes were limited to vegetation and GSM. Despite the limited availability of habitat, a total of 32 families applicable to the ZISS assessment were recorded at EF site 4 in August 2022, with the majority of taxa present (i.e., 28 families) in the Vegetation biotope (

Table 5.18). Vegetation at this site included mostly *Phragmites* sp. along the channel margins in very slow flow with grasses and alien macrophytes (mostly *Myriophyllum aquaticum*) providing habitat both in slackwaters and shallow runs, thus representing both VIC and VOOC. The GSM biotope was represented by shallow sand and gravel runs, and sandy slackwaters along the channel margin. Despite a relatively high number of taxa recorded at this site, very few sensitive taxa were present. Sensitive taxa were found almost exclusively in the vegetation and included, the odonate, Calopterygidae, the lepidopteran, Pyralidae, more than two species of baetidae, and Leptophlebiidae. Moderately sensitive taxa were also limited to the vegetation and included the water mite (*Hydracarina*) and elmids beetles. With the exception of the Cordulidae found in the GSM, this biotope was dominated by taxa tolerant of pollution as indicated by the low ASPT score. Certain taxa, particularly those belonging to the Hemiptera were moderately abundant, with relatively large numbers of chironomids in the vegetation biotope. Although the ZISS and ASPT scores would be compromised by the limited diversity of habitat available at this site, these indices are lower than would be expected under natural conditions. The macroinvertebrate community is therefore rated as a **Category B/C**, indicative of a system that is slightly to moderately impaired with a moderate number of sensitive taxa but a relatively high proportion of tolerant taxa and a disproportionately high abundance of chironomids, relative to natural.

Table 5.18 ZISS results for EF Site 4 sampled in August 2022.

EF site 4: Nhandungue River @ Casa Banana	Stones	Veg	GSM	TOTAL
ZISS	Not sampled	155	73	170
Total number of families	Not sampled	28	17	32
ASPT	Not sampled	5.54	4.29	5.31

EF Site 5

EF Site 5 on the Nhandare River near Gorongosa Village is characterized by a diversity of available biotopes for aquatic macroinvertebrates, including stones both in and out of current (i.e. SIC and SOOC), vegetation both in and out of current (i.e. VIC and VOOC) and some patches of gravel in bedrock pockets representing the GSM biotope. A total of 21 families applicable to the ZISS assessment method, were recorded at EF Site 5 in August 2022 (Table 5.19). The stones biotope represents the highest number of taxa (i.e. 17 families) while only four taxa were found in the GSM.

Pollution sensitive taxa included the highly sensitive water specs (Prosopistomatidae), Perlidae, Heptageniidae, Tricorythidae, Glossosomatidae, Psephenidae and Athericidae, mostly in the stones. Nevertheless, under natural conditions a higher proportion of sensitive taxa would be expected, considering the diversity of flow and substratum types at this site. In particular, a greater diversity of both Baetidae and Heptagenidae would be expected at this site under unimpaired conditions. Nevertheless, no taxa were particularly dominant with a moderate to high proportion of sensitive taxa overall and thus the site is rated as a **Category B** from an aquatic macroinvertebrate community perspective.

Table 5.19 ZISS results for EF Site 5 sampled in August 2022

EF site 5: Nhandare River near Gorongosa Village	Stones	Veg	GSM	TOTAL
ZISS	122	61	23	145
Total number of families	17	10	4	21
ASPT	7.18	6.10	5.75	6.90

5.3.4.1 *Baseline status and trends*

Ecological status based on the macroinvertebrate community is unknown but based on a qualitative assessment of habitat, it is likely to be a **Category D**; i.e., a community dominated by hardy pollution tolerant taxa with a low overall diversity.

The main drivers of long-term change in the macroinvertebrate communities are:

- Intensification of agricultural activities with population increases that have resulting in an increase in sedimentation and thus a deterioration in habitat quality
- Introduction of pesticides and herbicides that result water quality deterioration and the loss of sensitive macroinvertebrate taxa.
- The introduction and intensification of detergents for washing of cloths that result in an increase in nutrient concentrations and thus a shift in trophic status. This results in an increase in productivity of the system with an associated loss of habitat, shift in food supply and thus a change in macroinvertebrate community structure.
- The introduction of gold-mining along the river banks which has led to an increase in turbidity and hence a reduction in light penetration. Increased sediments affect habitat quality directly

and affect the periphytic algal community structure that may result in the reduction in food quality for many macroinvertebrate grazers.

- Some increase in organic pollution as the population in settlements has increased without adequate sanitation

It is difficult to estimate historical changes in community structure of macroinvertebrates in the Pungwe River as there are no data available to guide such an assessment. Nevertheless, a broad desktop evaluation of changes in population densities, extent and intensity of land-use change and the introduction of certain chemical products to the area, can be used to infer the historical changes over time. Table 5.20 to Table 5.23 provide an estimation of historical trends for macroinvertebrates.

Table 5.20 Estimated historical trends as a percentage of baseline for macroinvertebrate indicators at EF Site 1 (2022 = 100%).

Indicator	2000	1960	1900	Explanation
Species Richness	102	112	115	Land use intensity, use of pesticides/herbicides and detergents has increased significantly since 2000
Perlidae	110	130	130	Perlidae are particularly sensitive to water quality pollution so abundance would have decreased over time
Simuliidae	102	110	110	Simuliidae generally hardy so probably not affected by water quality changes. Found in the riffles and runs which are not significantly affected by sedimentation
Chironomidae	95	90	90	Chironomids are generally hardy and pollution tolerant so may have increased in abundance over time
Ceratopogonidae	98	95	95	Favour fine sediments so would have increased in slower flowing habitats where boulders and cobbles have become embedded in fines

Table 5.21 Estimated historical trends as a percentage of baseline for macroinvertebrate indicators at EF Site 3 (2022 = 100%).

Indicator	2000	1960	1900	Explanation
Species Richness	150	180	200	Besides the intensification of agriculture, the use of pesticides/herbicides and detergents, gold-mining in about 2010 has had a significant water quality and habitat quality impact.
Perlidae	200	230	250	Perlidae are particularly sensitive to water quality pollution and have been almost eliminated by increased turbidity

Indicator	2000	1960	1900	Explanation
Simuliidae	180	200	200	Simuliidae generally hardy but would have been affected by high turbidity and a likely reduction in food quality (i.e. organic material in the water column). Also, boulders and bedrock in favourable habitat are caked with fine material and so simuliids, like other taxa that use fast flowing habitats would have been reduced.
Chironomidae	100	90	90	Chironomids may have increased with a decrease in water quality over time
Shrimps (Atyidae)	115	120	120	Mostly found in marginal vegetation but also in the sandy pools but these are less affected by sedimentation
Ceratopogonidae	110	110	110	While ceratopogoniids favour fine material, although the clays that have settled on the substrate due to mining activities are not ideal.
Thiaridae (snails)	95	80	80	Increased washing of clothing in backwater pools has led to an increase in algal growth and a proliferation of this taxon in backwaters

Table 5.22 Estimated historical trends as a percentage of baseline for macroinvertebrate indicators at EF Site 4 (2022 = 100%).

Indicator	2000	1960	1900	Explanation
Species Richness	110	130	130	Water quality deterioration due mostly to use of detergents for washing in the river may have resulted in a decrease in species richness over time. But richness is limited by the lack of stone substrates
Chironomidae	100	90	90	Chironomids may have increased with a decrease in water quality over time
Shrimps (Atyidae)	110	120	120	Mostly found in marginal vegetation and may have decreased over time due to water quality deterioration
Ceratopogonidae	100	90	90	Ceratopogonidae favour fine material but this reach is naturally gravel and fine sands that is unlikely to have changed over time. Ceratopogonids are hardy and tolerant of poor water quality, so may have increased due to predominance of favourable habitat with enrichment

Table 5.23 Estimated historical trends as a percentage of baseline for macroinvertebrate indicators at EF Site 5 (2022 = 100%).

Indicator	2000	1960	1900	Explanation
Species Richness	110	115	120	Land use intensity, use of pesticides/herbicides and detergents has increased significantly since 2000. May be some organic pollution due to settlement close by.
Perlidae	120	135	140	Perlidae are particularly sensitive to water quality deterioration and also a loss of fast flowing habitat so abundance would have decreased over time due to water quality deterioration
Simuliidae	100	100	100	Simuliidae generally hardy so probably not affected by water quality changes. Found in fast flow and can proliferate below dams due to increased organic load but this does not appear to be the case
Chironomidae	100	100	100	Chironomids are generally hardy and pollution tolerant but do not seem to have proliferated at this site
Ceratopogonidae	100	100	100	Favour fine sediments but very little fine material was available for this species so does not seem to have changed over time at this site.

5.3.5 Fish

There are more than 50 species of 14 families of native freshwater fish have been recorded from the Pungwe River basin, as well as catadromous eels. In addition to these are non-native rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta* introduced in the early 1900s to the cooler waters of the upper catchment above EF site 1. Fishing pressure is likely the major decider of ecological status. All EF sites were subject to very high fishing pressure from a variety of fishing methods, the dominant being seine-nets made of mosquito netting or shade-cloth and small-mesh gillnets. Small-mesh fyke nets were also evident and dynamite fishing was reported by community members at 2 to 3 sites. Species and size composition of the fish assemblages at all sites were a reflection of the selective properties of the small-mesh nets used, comprising mostly small-bodied species or juvenile fish. None of the sites had any degree of protection from exploitation from what is an effective open-access fishery, thus complicating any estimates of a reference condition (or natural state). This said, sampling was during low flows when access and use of a variety of fishing gears is easier than during the high-flow season which may provide some refuge for fish. Desai *et al.* 2019 sampled the middle and lower reaches of the Pungwe during the high and low-flow seasons, with some of the sites inside

the Gorongosa National Park having a higher level of protection, and therefore ideal for comparison with this 2022 study.

Pungwe fish are subject to growth, recruitment and ecosystem overfishing. Growth overfishing occurs when fish are caught at a much smaller size and before maturity, recruitment overfishing when there are not enough adult fish left to replenish themselves and ecosystem overfishing results from the removal of large predatory species and replacement by smaller fish at lower trophic levels. Overfishing pressure will also see lower resilience to changes in water quality, turbidity, prey availability and other environmental stressors. Direct and indirect effects of fishing pressure suggest an ecological status of **Category E**. In the absence of fishing, the fish community is likely to reflect changes in water quality and the Category D ecological status of invertebrate prey at EF site 3.

Changes in the fish community and trophic structure will be manifest in the presence / absence and relative abundance / contribution of feeding guilds, these being detritivore, benthic herbivore, opportunistic predator, omnivore, piscivore, zoo-benthivore or zoo-planktivore. Species composition of the Pungwe ichthyofauna is dominated by zoo-benthivores (36%) and zoo-planktivores (21%) and to a lesser extent by omnivores (17%) and opportunistic predators (14%).

Changes in the fish community are expected due to:

- Growth, recruitment and ecosystem overfishing in particular that resulting in the loss of large-bodied fish and higher trophic levels.
- Increases in turbidity from small-scale and industrial gold-mining instream and on the banks, directly influence visual, selective feeding zoo-benthivores and zoo-planktivores as well as opportunistic predators and piscivores. Changes in turbidity also influence visual cues, courtship, nesting and territorial behaviour. Indirect impacts of increased turbidity include the effects of changes in algal production on herbivorous fish and invertebrates or the fish that feed upon them.
- Artisanal gold-mining is accompanied using mercury to extract gold from ore, including panned material. Small-scale or artisanal gold-mining is the largest source of mercury pollution globally (Esdaile and Chalker 2017). Aside from the health implications for the humans that consume them, mercury bioaccumulation inhibits fish growth, reproduction and neural function.
- Intensive pesticide and herbicide use by small-scale farmers was evident at each site whilst use on commercial farms occurs throughout the catchment. DDT (dichlorodiphenyltrichloroethane) remains an anti-malarial mosquito control method throughout Mozambique. Many pesticides, including DDT directly impact growth, egg and larval development and reproductive output of fish. DDT is also linked to high levels of hermaphroditism in fish and rural communities. Indirect effects include declines in invertebrate and algal food resources. Pesticides may also alter parasite - host relationships, including increases in transmission. Increased parasite loads raise fish susceptibility to waterborne diseases.

- Fertiliser and pesticide use by artisanal and commercial farmers are synonymous and probably result in elevated nutrient loads and associated eutrophication throughout the catchment.

Estimate historical changes in community structure of fish in the Pungwe River, per EF site, are provided in Table 5.24 to Table 5.27.

Table 5.24 Estimated historical trends as a percentage of baseline for fish indicators at EF Site 1 (2022 = 100%).

Indicator	2000	1960	1900	Explanation
Community structure, species composition	100	110	120	Dominant fish at this shallow site were small-bodied zoo-benthivores including the rock catlets <i>Chiloglanis</i> sp. and easter sand catlet <i>Zaireichthys monomotapa</i> of 28-56 mm in length. Local fishers interviewed reported catching omnivorous Mozambique tilapia <i>Oreochromis mossambicus</i> , opportunistic predator sharptooth catfish <i>Clarias gariepinus</i> , “bottlefish” of 25 cm, Mormyridae probably slender stonebasher <i>Hippopotamyus ansorgii</i> and tiny spiky catfish <i>Chiloglanis</i> sp. both zoo-benthivores. They also referred to Solomon fish (Hunga) as being snakelike which may be an anguillid eel, in this part of the catchment, most likely <i>Anguilla mossambica</i> , an opportunistic predator. Pesticide use likely the overriding pressure but fishing also significant. The dominant fishing method used by the local community was shade-cloth seine in or just below the upstream weir. Pesticide use, especially DDT & pyrethroids was already extensive in the 1960s but has increased from 2000 to the present day. Fertilisers, detergent use and wastewater inflow are likely to have increased nutrient levels. Species composition and community structure, dominated by zoo-benthivores likely to be similar but biomass much lower than historical levels. <i>A. mossambica</i> are susceptible to poor water quality but still appear to occur at this site.
Zoo-benthivore	110	120	140	Decline in invertebrate prey due to pesticide use and poor water quality. Reproduction and growth of the catlets <i>Zaireichthys</i> spp. and <i>Chiloglanis</i> spp. impacted by pesticide contaminants and poor water quality.
Zoo-planktivore	110	120	140	Decline in invertebrate prey due to pesticide use and poor water quality. Zoo-planktivores at this site mostly cyprinid <i>Enteromius</i> spp., growth and reproduction susceptible to pesticides, DDT but also due to high heavy-metal loads, the latter not measured here.
Omnivore	100	120	150	Omnivores at this site mostly Cichlidae <i>Oreochromis mossambicus</i> which are versatile, tolerant and often opportunistic under poor water-quality conditions but the target of most fishing here.

Indicator	2000	1960	1900	Explanation
Opportunistic predator	110	140	150	Represented by <i>Clarias gariepinus</i> and <i>Anguilla mossambica</i> , the latter susceptible to poor water quality but still appear to occur at this site.
Benthic herbivore	110	140	150	Only <i>Labeo cylindricus</i> expected at this site, may be impacted by changes in algal, macrophyte growth arising from herbicides and pesticide removal of invertebrate grazers.
Piscivore	100	90	80	No indigenous piscivores at this site but <i>Salmo trutta</i> and <i>Oncorhynchus mykiss</i> farmed and introduced to the catchment upstream, flyfishing one of the area's tourist drawcards. Suggests water quality upstream of EF Site 1 may be better.
Detritivore	100	100	100	No records of detritivores at this site. <i>Labeo altivelis</i> is the only detritivore in the Pungwe system and restricted to the middle and lower reaches.

Table 5.25 Estimated historical trends as a percentage of baseline for fish indicators at EF Site 3 (2022 = 100%).

Indicator	2000	1960	1900	Explanation
Community structure, species composition	120	200	200	Overfishing the dominant pressure. This is exacerbated and recovery inhibited by increased turbidity and pollutants from mining and agriculture. Large-mesh seine and fyke nets as well as traps increased in use in the 1980s but were mostly replaced by gillnets by 2000. As catches deteriorated, gillnet mesh-sizes got smaller and mosquito-net or shade-cloth seines are ubiquitous in the present day. Growth and recruitment overfishing are indicated by the low numbers of large-bodied species and adult fish. Visual, selective feeding zoo-benthivores, zoo-planktivores and piscivores are in low numbers or absent. Low invertebrate biomass has likely contributed to low zoo-benthivore and zoo-planktivore densities as well. Pesticide contamination is likely to have impacted growth, development and susceptibility to parasites and pathogens across all taxa. Fish community at this site dominated by benthic-herbivores, detritivores and opportunistic predators.
Zoo-benthivore	120	250	250	Increased turbidity inhibits visual foraging, decline in invertebrate prey from pesticide and detergent use, mining pollutants.
Zoo-planktivore	120	250	250	Increased turbidity inhibits visual foraging, decline in invertebrate prey from pesticide and detergent use, mining pollutants. High turbidity also likely to negatively affect filter feeding fish.
Omnivore	200	250	250	Low contribution of omnivores (mostly Cichlidae), at this site likely due to fishing as they're versatile, tolerant and often opportunistic under poor water-quality.

Indicator	2000	1960	1900	Explanation
Opportunistic predator	150	200	250	The two at this site are <i>Clarias gariepinus</i> which is well adapted to drought, tolerant of poor water and high fishing pressure quality and <i>Anguilla marmorata</i> which is intolerant of all these pressures. It is however, the most resilient of the four Anguillid eels in the Pungwe and also an affinity for muds. Depressed body-shape of <i>Clarias</i> suited to mud and floodplain habitats, anguilliform body-shape to bedrock and boulders.
Benthic herbivore	110	150	200	Represented by <i>Labeo cylindricus</i> and <i>L. molybdinus</i> , their cylindrical body shape an adaptation to bedrock and boulders. Likely to have been at higher biomass at lower turbidity and greater algal, macrophyte growth. These are medium size fish susceptible to fishing but reproduction of these and other cyprinids also likely to already have been impacted by DDT and other pesticides in the 1960s.
Piscivore	120	150	150	No or few piscivores at this site, probably a function of turbidity, tigerfish <i>Hydrocynus vittatus</i> being a visual predator and electric catfish <i>Malapterurus shirensis</i> also preferring still waters.
Detritivore	110	150	250	<i>Labeo altivelis</i> is the only detritivore in the catchment but can equally be grouped as a benthic-herbivore. It's a large-bodied fish and intensively fished throughout its range, including for "caviar". Also, likely to already have been impacted by DDT and other pesticides in the 1960s.

Table 5.26 Estimated historical trends as a percentage of baseline for fish indicators at EF Site 4 (2022 = 100%).

Indicator	2000	1960	1900	Explanation
Community structure, species composition	130	200	200	Sampling included seine, hand nets and visual observations in predominantly shallow water < 20 cm deep. Two seines were hauled across the entire length of an isolated 40 X 15 m, 3 m deep pool. All fishing by locals at this site was using shade+ cloth or mosquito seines. Species and size composition of the fish sampled reflected the selectivity of these small-mesh nets, mean body depth of all fish caught being < 11 mm. Fish included redeyed labeo <i>Labeo cylindricus</i> , linespotted barb <i>Enteromius lineomaculatus</i> , broadband barb <i>Enteromius macrotaenia</i> , threespot barb <i>Enteromius trimaculatus</i> catlets <i>Chiloglanis</i> sp, banded tilapia <i>Tilapia sparrmanii</i> and eastern happy <i>Astatotilapia calliptera</i> . Only <i>T. sparrmanii</i> were caught in the pool and all were brooding fry. This said, small fish size and assemblage composition dominated by zoo-benthivores and omnivores may have also been a function of the shallow water at low flow. High-flow sampling at a comparable sandy site (Desai <i>et al.</i> 2019), saw dominance by high densities of large-bodied piscivores <i>Hydrocynus vittatus</i> , omnivores

Indicator	2000	1960	1900	Explanation
				<i>Oreochromis mossambicus</i> and detritivore / benthic herbivore <i>Labeo altivelis</i> . This site also borders the GNP with evidence of limited control of fishing and mining further upstream. However, growth, recruitment and ecosystem overfishing are still evident. Pesticide use and small-scale mining were observed but overall high abundance of zoo-benthivores and zoo-planktivores a reflection of lower turbidity and invertebrate prey not being limiting.
Zoo-benthivore	130	200	200	<i>Enteromius macrotænia</i> and other zoo-benthivores well represented in both the high and low-flow season. Likely to have experienced a decline in invertebrate prey through pesticide use but mining induced turbidity much lower than elsewhere in the catchment.
Zoo-planktivore	130	200	200	Linespotted barb <i>Enteromius lineomaculatus</i> , freshwater pipefish <i>Microphis fluviatilis</i> and other zoo-planktivores well represented in both the high and low-flow season. Likely to have experienced a decline in invertebrate prey through pesticide use but mining induced turbidity much lower than elsewhere in the catchment.
Omnivore	120	130	130	Omnivores well represented by the Cichlidae, Mozambique tilapia <i>Oreochromis mossambicus</i> , banded tilapia <i>T. sparrmannii</i> and eastern happy <i>Astotilapia calliptera</i> amongst vegetation and in isolated pools. These species also appeared to be the target of most fishing at the site.
Opportunistic predator	100	110	120	Large-bodied opportunistic predators not evident at this site, small-bodied ones, tank goby <i>Glossogobius giuris</i> , were present. This species is equally at home in freshwater, estuaries and brackish habitats.
Benthic herbivore	100	110	120	Juvenile redeye labeo <i>Labeo cylindricus</i> were sampled during low flow and along with leaden labeo <i>L. molybdinus</i> in the high-flow season. These cylindrical fish prefer grazing over, firm rocky habitat and deeper water so expected to be in low abundance at this shallow sandy site. Susceptibility to DDT and other pesticides likely to be similar to elsewhere in the catchment.
Piscivore	120	140	200	Low turbidity, high prey abundance and deeper water see large-bodied piscivores tigerfish <i>Hydrocynus vittatus</i> occurring during the high-flow season. Fishing is likely to be the greatest pressure at this site and population status a reflection of overfishing throughout the Pungwe.
Detritivore	120	140	200	Large adult manyame labeo <i>Labeo altivelis</i> occur during high-flow, perhaps having migrated here to breed. As before, it is the only detritivore in the catchment but can equally be grouped as a benthic-herbivore. It is a large-bodied fish and intensively fished throughout its range, also likely to already have been impacted by DDT and other pesticides in the 1960s.

Table 5.27 Estimated historical trends as a percentage of baseline for fish indicators at EF Site 5 (2022 = 100%).

Indicator	2000	1960	1900	Explanation
Species Richness	120	200	250	Boulders, bedrock and cover provided by the attached waterplant <i>Hydrostachys polymorpha</i> are the main features responsible for the discrete fish community at this site. Most fish were caught over sand in and around boulders and bedrock covered with <i>H. polymorpha</i> . These included the zoo-benthivores slender stonebasher <i>Hippopotamyrus ansorgii</i> , spotted sand catlet <i>Leptoglanis rotundiceps</i> , omnivore <i>T. sparrmanii</i> and zoo-planktivorous <i>Enteromius</i> spp. Also associated with this habitat are the piscivorous electric catfish <i>Malapterurus shirensis</i> , zoo-planktivores robbers <i>Brycinus imberi</i> and <i>Micralestes acutidens</i> , barred minnow <i>Opsaridium zambezense</i> , omnivorous redbreast tilapia <i>Coptodon rendalli</i> and large-bodied zoo-benthivore large-scale yellowfish <i>Labeobarbus marequensis</i> . Fishing pressure is high, mostly with small mosquito-net and shade-cloth seines but this was also the only site where line-fishing (for small catfish) was mentioned by the local community. Farming, pesticide, herbicide and detergent use is once again as high as elsewhere in the catchment. Herbicide use may have reduced the near 100% cover provided by <i>H. polymorpha</i> in other reaches of this tributary.
Zoo-benthivore	120	140	160	Zoo-benthivores and zoo-planktivores dominant but likely at lower densities due to a decline in invertebrate prey through pesticide use, herbicide use and loss of <i>H. polymorpha</i> cover.
Zoo-planktivore	120	140	160	Zoo-benthivores and zoo-planktivores dominant but likely at lower densities due to a decline in invertebrate prey through pesticide use, herbicide use and loss of <i>H. polymorpha</i> cover.
Omnivore	120	140	180	Omnivorous cichlids tolerant of reduced water quality but have likely experienced decline due to overfishing and the impact of pesticides on reproduction and growth.
Opportunistic predator	120	200	250	Little evidence of any opportunistic predators e.g. <i>C. gariepinus</i> at this site and interviews with community members saw no mention of any Anguillidae, <i>A. mossambicus</i> expected to be here. The latter is susceptible to pollutants. All Anguillidae are subject to high fishing pressure in Mozambique, predominantly for glass eels to supply aquaculture, profit has removed taboos associated with eating snakelike and “scaleless” eels.
Benthic herbivore	110	110	110	Although cylindrical body-shape an adaptation to bed-rock and boulder habitats, neither <i>L. cylindricus</i> nor <i>L. molybdinus</i> were recorded at this site or by Desai et al. in other reaches of this tributary.
Piscivore	110	120	120	Piscivores represented solely by the electric catfish <i>Malapterurus shirensis</i> which seems to be associated with still waters and cover provided by <i>H. polymorpha</i> . Abundance may have declined with loss of <i>H. polymorpha</i> cover.

Indicator	2000	1960	1900	Explanation
Detritvore	120	200	200	Large adult <i>Labeo altivelis</i> probably migrate into this tributary to spawn during the high flow season. However, this fish was not recorded at EF Site 5 or downstream in the tributary in the high-flow season by Desai <i>et al.</i> 2019. As before, it is a large-bodied fish and intensively fished throughout its range, also likely to already have been impacted by DDT and other pesticides in the 1960 and continued use in the present day

5.4 ECOLOGICAL: ESTUARY

A detailed analysis of the estuary and marine environment indicators will be conducted after the field trip (23-29 October 2022) and completion of the numerical modelling of these two domains as the assessments will be strongly influenced by change in the hydrology and resultant shifts in the salinity regime of the system.

5.5 SOCIO-ECONOMICS: POPULATION AND ECONOMY

5.5.1 Population

In the Pungwe Basin, population distribution is influenced by land use and accessibility to water and roads whereby communities cluster along rivers and streams and accessible pockets of arable land incised in river valleys as well as along the main transport routes. The population and settlements of the Pungwe Basin are strongly linked to the port city of Beira which is the second largest city in Mozambique and a major gateway for trade and transport of goods to the rest of the country and to the landlocked countries that border Mozambique.

Beira was established at the end of the 19th century by Companhia de Moçambique (Company of Mozambique) which at the time was a private charter company with concessions to central Mozambique under Portuguese colonial rule (Shannon 2019). Shortly after its establishment, railway, road and pipeline infrastructure were built between Beira and Zimbabwe (then Rhodesia) which saw Beira become a logistically important gateway to the sea from the British-controlled central states (Sopa and Fernandes 2018a; Shannon 2019). At the same time the district of Chimoio was created as a crossing point in communications between the Beira at the coast and the interior, also under the Companhia de Moçambique, which administered the territory until 1942 (Sopa and Fernandes 2018b). According to Sopa and Fernandes (2018a) Beira had 700 inhabitants in 1891 increasing to 3400 inhabitants in 1910, rising to 20 000 in 1928 (Figure 5.1).

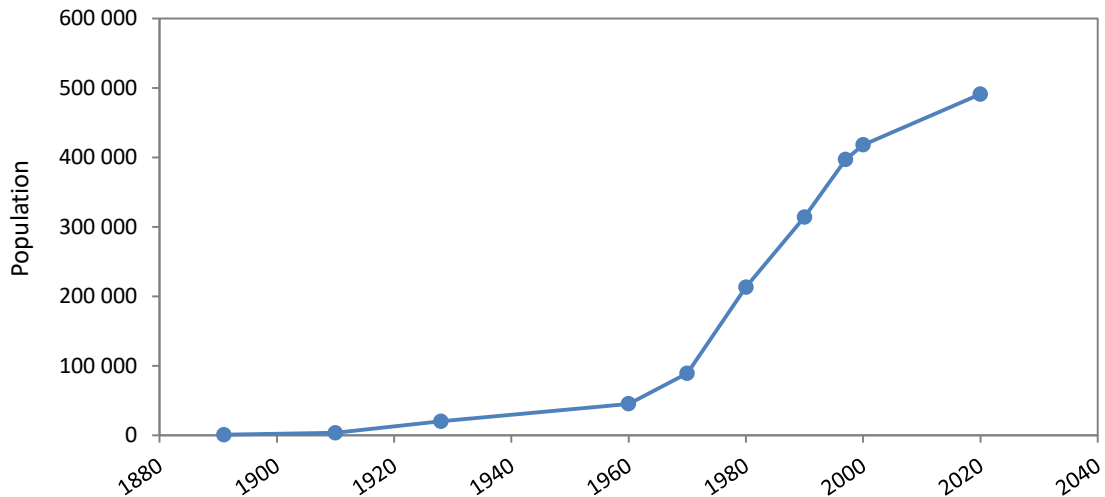


Figure 5.1 Population in Beira, Mozambique from 1891 to 2019. Source: Sopa and Fernandes, 2018a, United Nations - World Population Prospects.

During this time the rest of the basin was relatively sparsely populated with traditional homesteads made entirely from natural resources (e.g., mud, wooden poles and thatching grass). While the population increased along the main transport route that linked Beira to Zimbabwe, the rural communities in the hinterland remained small and their impact on the environment is assumed to have been minimal.

During the third quarter of the 20th century the city of Beira experienced an intense and continued population growth increasing to 45 000 inhabitants in 1960 and 89 000 by 1970 (Sopa and Fernandes 2018a). Since Mozambique gained independence in 1975 the population of Beira, and the basin as a whole, has grown rapidly, reaching 490 000 inhabitants in the city in 2020.

According to WorldPop (2020) the basin population was 1.04 million people in 2000 and was highest in SE Zones 2, 4 and 5 (Table 5.28). Since then, the population of the Pungwe Basin has grown to 1.9 million persons, an increase of 84% over the twenty-year period, an annual average growth rate of 3.1%. The average population density for the basin increased from 26 people/km² in 2000 to 48 people/km² in 2020.

Table 5.28 Population and population density of each sub-basin in the Pungwe River Basin in 2020.
Data source: WorldPop, 2020.

SE zone	Sub-basin name	Population 2000	Population density 2000 (ppl/km ²)	Population 2020	Population density 2020 (ppl/km ²)
Zone 1: Nyanga mountains	Pungwe Zimbabwe	21 449	22	33 001	33
	Honde	41 805	27	76 033	49
	Upper Pungwe	15 558	11	46 562	32
	Total Zone 1	78 812	20	155 596	39
Zone 2: Middle Pungwe	Nhazonia	69 978	20	234 643	67
	Upper Middle Pungwe	26 913	9	53 057	18
	Lower Middle Pungwe	146 476	40	258 420	70
	Total Zone 2	243 367	24	546 120	54
Zone 3: Gorongosa	Vunduzi	24 557	6	83 373	20
	Nhandugue	14 004	4	40 916	12
	Urema	52 569	7	99 215	13
	Total Zone 3	91 130	6	223 504	14
Zone 4: Lower Pungwe	Lower Pungwe	159 710	35	341 540	74
	Muda	65 507	36	153 206	84
	Total Zone 4	225 217	35	494 747	77
Zone 5: Estuary and coast	Pungwe Estuary	399 202	119	490 676	147
Pungwe Basin		1 037 728	26	1 910 643	48

Expectedly, SE Zone 4 (Estuary and coast) and SE Zone 2 (Middle Pungwe) are the most densely populated zones, as a result of Beira and Chimoio cities being located in these zones (Table 5.28). The sub-basins in Zimbabwe are the least populated because most of the mountainous terrain is uninhabitable and settlements mainly occur in incised river valleys, such as the Honde Valley, which is relatively densely populated with 49 people per km². While Zone 3 (Gorongosa) is relatively sparsely populated with just 14 people per km², the zone experienced the highest population growth between 2000 and 2020 (145%, Figure 5.2). There was also significant growth in Upper Middle Pungwe (Zone 2) and Lower Pungwe floodplains (SE Zone 4) with the population more than doubling in these zones too. This is likely due to the urbanisation of the main transport routes (the N1, N7 and N6 highways) that run through these zones where urban and peri-urban settlements have expanded in a sprawling nature along the length of these main routes. Population growth in the Nyanga Mountains (SE Zone 1) and Estuary and coast (SE Zone 5) was significantly lower.

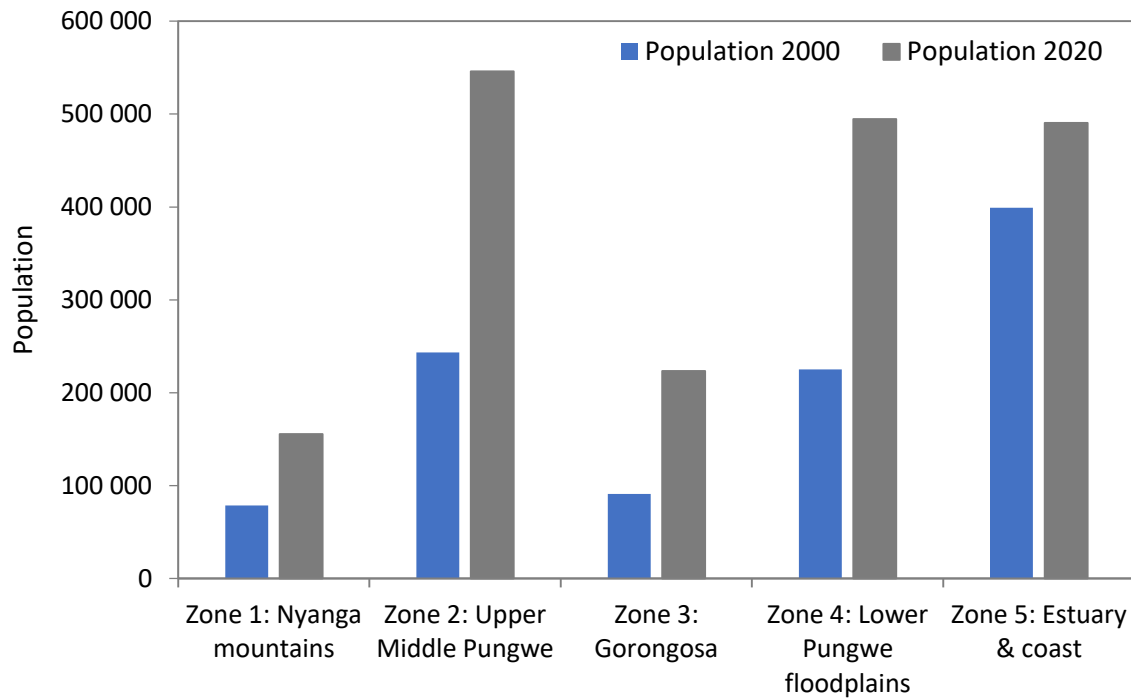


Figure 5.2 Population in each SE zone in 2000 and in 2020. Data source: WorldPop, 2020.

5.5.2 Economy

The Pungwe Basin extends across Sofala and Manica Provinces in Mozambique and Manicaland Province in Zimbabwe. In Sofala Province, the city of Beira has historically played a critical role in national and regional economies, as it provides the link to international markets through the broader Beira corridor. The Beira corridor is the main transport route (road and rail) which links parts of Zambia, Malawi, Zimbabwe and the Mozambique interior to the Indian Ocean port city of Beira. The corridor also includes an oil pipeline that runs from Beira to Zimbabwe. The main export products from the port include agricultural products such as sugar, tobacco, corn, cotton, agave fibre, and mineral resources such as chromium, iron ore, copper, lead, and coal (ANEME 2017; Shannon 2019). Fish are transported from the coast inland. Economic activity in the basin is limited by access to piped water supply and electricity, which are both largely restricted to the main urban hubs. Outside of these areas people rely heavily on instream water and other forms of energy for lighting and cooking. In rural areas this tends to be firewood. In urban areas people also rely on charcoal, batteries, kerosene and candles (BRILHO 2019).

Sofala Province contributes about 10.2% to Mozambique's GDP (US\$1.35 billion in 2017) and currently the economy is driven by the manufacturing sector (35.1%) followed by agriculture (crops and livestock, 29.9%), transport and storage (24.7%) and fishing (4.8%) (ANEME 2017). Outside of the urban areas and main transport hubs, the economy is dominated by subsistence agriculture and livestock production, which are important in terms of employment, income and food security (BRILHO 2019). Tourism is a growing industry with Gorongosa National Park being an important attraction. Approximately 50% of the provincial population is living below the poverty line and the electrification rate is 38.2%, limited to urban areas (BRILHO 2019).

Manica Province contributes approximately 3.4% to Mozambique's GDP (US\$0.5 billion in 2017) and currently the economy is driven by small scale manufacturing and agriculture (BRILHO 2019). Artisanal fishing and livestock production are also important subsectors in terms of household income and food security in the province. The capital city of Manica Province is Chimoio which is situated in Zone 2 on the southern edge of the Pungwe Basin. The city is an important stop-off between the coast and Zimbabwe, but the economy continues to be dominated by the agricultural sector. Approximately 37.2% of the provincial population is living below the poverty line and the electrification rate is just 21.5%, limited to urban areas such as Chimoio (BRILHO 2019).

Manicaland Province has a versatile economy and in 2019 contributed 9% to Zimbabwe's GDP (ZimStat 2022). The economy of Manicaland is centred around industry and agriculture. Agricultural production is dominated by fruits (bananas, peaches, mangoes, apples, lychee, and avocado), macadamia nuts, Irish potatoes, tea and coffee, and timber (Chingarande *et al.* 2020). In the Honde Valley alongside the Pungwe River in Mutasa District, bananas are the most important cash crop, as well as sugarcane and some vegetables. Commercial irrigated crops include high value crops such as avocados, macadamia nuts, tea and coffee. However, over the past decade, rainfall in the north-eastern areas of Manicaland have decreased steadily and issues of food insecurity have increased (Viceisza *et al.* 2020). Food insecurity is estimated to be 50% in the districts of Nyanga and Mutasa, some of the highest in the province (Viceisza *et al.* 2020). Household electrification rates in Manicaland province were 37% in 2012 (ZimStat 2013).

6 REFERENCES

Will be provided in the Supporting Specialist Reports.