Humans, Wildlife, and Economic Growth in the Kavango Zambezi Transfrontier Conservation Area (KAZA-GROW) 2021-2023

A TRANSBOUNDARY DIAGNOSTIC ANALYSIS OF THE KWANDO RIVER SYSTEM

A Key Strategic Resource for the Kavango Zambezi Transfrontier Conservation Area

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Sustainable Groundwater Development and Management for Humans, Wildlife, and Economic Growth in the Kavango Zambezi Transfrontier Conservation Area

KAZA-GROW

A TRANSBOUNDARY DIAGNOSTIC ANALYSIS OF THE KWANDO RIVER SYSTEM – A Key Strategic Resource for the Kavango Zambezi Transfrontier Conservation Area

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Cover photo: Peace Parks Foundation has distributed treadle pumps to local communities living in the Simalaha Community Conservancy in Zambia. This has improved food production and security and provided an extra income as excess produce is sold in the market.

EXECUTIVE SUMMARY

Freshwater underpins the strategic value of the Kavango Zambezi Transfrontier Conservation Area (KAZA TFCA), the largest terrestrial transfrontier conservation area globally and a key eco-tourism destination in Southern Africa. It covers 520,000 km² and is home to 2.7 million people. Specifically, and as part of the natural freshwater cycle, groundwater resources are central to ecosystem functioning and resilience, with hydraulic connectivity across the landscape from headwaters to discharge zones, as well as human health and livelihoods in the KAZA TFCA. While groundwater is often under-prioritized in management, enhancing its management at local to transboundary levels can significantly support the long-term sustainability and resilience of the region.

KAZA TFCA is undergoing a significant change in population growth (average of 2.4% annually), land-use changes, infrastructure development, and increasing climate variability, putting increasing strain on its natural resources with repercussions on ecosystems, biodiversity, water security, and human health and livelihoods, especially for the more than third of the population estimated to live below the poverty line.

The Transboundary Diagnostic Analysis (TDA) documented in this report was initiated to enhance the knowledge base of the water resources, particularly groundwater, and related environmental, socioeconomic and legal, policy, and institutional aspects of the Kwando River system (KRS) as a pilot for the KAZA TFCA. This particular area was selected due to its relatively pristine character and critical importance for maintaining interconnected terrestrial and aquatic inland ecosystems across the landscape and the services it provides to the local population, biodiversity, and tourists. The objectives of the TDA were:

- Supporting and enhancing the collation, sharing, and dissemination of data as well as the joint knowledge development around groundwater resources and transboundary aquifers in the KRS as a strategic resource for the KAZA TFCA
- Supporting and enhancing policy co-development around groundwater development, use, management, and protection in the KRS and wider KAZA TFCA
- Strengthening cooperation across the KAZA TFCA Partner States and River Basin Organizations in terms of groundwater management for sustainable and resilient development

Structured into ten chapters and populated with information obtained through extensive research and stakeholder engagement, the report is an inclusive joint effort that underscores the key role of groundwater and the criticality of incorporating considerations of this resource into development and conservation frameworks in the KRS as part of the wider KAZA TFCA. While the biophysical knowledge base is still rather limited and fragmented, the TDA provides a solid basis for an overarching conceptual hydrogeological model of the subsurface systems and the role of groundwater in supporting the water security of local communities. The report includes chapters on physiography, socioeconomics, water resources, transboundary aquifers, ecosystems and environmental risks, and legal, policy, and institutional frameworks. Ultimately, the report lays a foundation on which transboundary cooperation across the KRS will be enhanced.

The conclusions provide an outline of the key knowledge base as well as scope out requirements to improve management of this resource and integrate it into broader, including transboundary, freshwater resources, ecosystem and conservation management, and cooperation structures.

1. The KAZA TFCA is a flagship transfrontier conservation area in Southern Africa. This is not only due to its size – being the biggest on the continent and globally – and its unique biome, but also

because of the advanced cooperation mechanisms in place. The KAZA TFCA Ministerial Committee at its apex and the KAZA TFCA Secretariat drives and coordinates the daily activities associated with the planning and development of the KAZA TFCA. This is with support from local and Partner States (Angola, Botswana, Namibia, Zambia, and Zimbabwe) entities, National Governments, and River Basin Organizations (OKACOM and ZAMCOM) as well as international donors, with a common long-term vision of prosperity and sustainability for the region.

2. Since TFCAs are focused on critical landscapes and ecological systems – not necessarily aligned with river basins – their remit related to river basin and aquifer system management is less prominent. However, water resources coming under increasing stress, in turn, indicates the clear need for, and the synergy between, TFCA, RBO, and Partner State cooperation.
3. The groundwater resources, the subsurface hydrogeological and surface morphological setting and dynamics, along with the climate, of the KAZA TFCA, are to a large extent controlling the natural environment, e.g., concerning the soil systems, vegetation, topography, catchment dynamics, and characteristics of ecosystems.
4. The Kwando River Basin, which is presently in a relatively pristine condition, is groundwater-driven, supporting perennial and relatively steady river flows downstream. Compared to the Okavango River system, the Kwando River is less seasonal given the maintained level of flow throughout the year, being less prone to larger floods and drought, and hence more climate-resilient.
5. To maintain the Kwando River Basin and associated conservation and wildlife dispersal areas healthy and climate resilience going forward, better groundwater management and understanding are required along with a better assessment of human and climate change impacts over the medium term.
6. The KAZA TFCA counts on five identified transboundary aquifers (TBAs), while only two of them are presently associated with a certain level of knowledge, including the Nata Karoo TBA, located within the KRS and possibly shared between the five Partner States. It cannot be ruled out that other TBAs exist, e.g., that the Nata Karoo consists of several distinct TBAs. It is also possible that a larger more regional aquifer system that ties upland headwaters and recharge areas in Angola to downstream discharge areas is present.
7. It is important to protect areas in the KAZA TFCA that are upstream of critical ecological sites, aquatic ecosystems, and potential Groundwater Dependent Ecosystems (GDEs), like wetlands and inland deltas. This is the case for both the Okavango and Kwando Rivers, which have significant deltas or flood plains downstream. This includes recognizing and possibly designating Ramsar sites in key upstream groundwater recharge areas maintaining pertinent upstream-downstream linkages, even with areas that lie outside of the KAZA TFCA, such as the Angolan highlands.
8. Groundwater will likely play a larger role in the KAZA TFCA, as populations grow, and urbanization and economic activities expand. This implies larger pressure on existing water and land resources for wellbeing, livelihoods, and economic growth, and climate change exerts larger variability in freshwater resource availability, implying larger demands for water during droughts (inevitably from groundwater). However, the legal, policy, and institutional frameworks are presently not robust enough to support the development and management of the envisaged demand on the resource (in-situ and ex-situ – i.e., for ecosystem services and abstraction for human needs) in the KAZA TFCAs, where conservation itself is an important water 'user'.
9. The KAZA TFCA represents a strong candidate for developing a Transfrontier Groundwater Management Framework relevant to the TFCA and possibly the Southern African Development Community (SADC) more broadly. Pre-scoping of such framework among the Partner States and relevant stakeholders as part of the TDA initiated a process towards consolidating such framework.

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ACRONYMS AND ABBREVIATIONS

ADMADE	Administrative Management Design
AEM	Airborne Electromagnetics
AMCOW	African Ministers' Council on Water
AWP	Artificial water point
BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
BUPUSA	Buzi, Pungwe, and Save River Basins
CAMPFIRE	Communal Areas Management Programme for Indigenous Resources
CBNRM	Community Based Natural Resource Management
CBO	Community-based organization
CEB	Cuvelai-Etosha Bsin
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CoM	Council of Ministers
CVES	Continuous Vertical Electrical Sounding
DEM	Digital Elevation Model
DEPI	Drought Exceedance Probability index
DWS	Department of Water and Sanitation
EUS	Epizootic Ulcerative Syndrome
e-flow	Environmental flow
ENSO	El Niño/Southern Oscillation Index
GCM	Global Climate Model
GDE	Groundwater-dependent ecosystem
GDP	Gross Domestic Product
GEF	Global Environment Facility
GGRETA	Governance of Groundwater Resources in Transboundary Aquifers
GIP	Groundwater Information Portal
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GLTFCA	Great Limpopo TFCA
GMA	Game Management Area
GoA	Government of Angola
GoB	Government of Botswana
GoN	Government of Namibia
GoZam	Government of Zambia

GoZim	Government of Zimbabwe
GRIPP	Groundwater Solutions Initiative for Policy and Practice
GWPZ	Groundwater Potential Zone2
HWC	Human-Wildlife Conflict
ICP	International Cooperation Partner
IDP	Integrated Development Plan
IDs	identification numbers
IGRAC	International Groundwater Resources Assessment Centre
IPCC	Intergovernmental Panel on Climate Change
IRDNC	Integrated Rural Development and Nature Conservation
IW:LEARN	International Waters Learning Exchange and Resource Network
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
JSAP	Joint Strategic Action Plan
KAZA	Kavango Zambezi
KAZA-GROW	The project: Sustainable Groundwater Development and Management for Humans, Wildlife, and Economic Growth in the Kavango Zambezi Transfrontier Conservation Area
KfW	Kreditanstalt für Wiederaufbau Bankengruppe = Credit Institute for Reconstruction (formally, today, simply KfW)
KJAG	Kwando Joint Action Group
KRB	Kwando River Basin
KRS	Kwando River system
KRWDA	Kwando River Wildlife Dispersal Area
LGC	LIMCOM Groundwater Committee
LIMCOM	Limpopo Watercourse Commission
MAP	Mean annual precipitation
MAR	Mean annual runoff
mbgl	Meter below ground level
MCCM	Multi-Country Cooperation Mechanism
MCDM	Multi-criteria Decision Making
MEFT	Ministry of Environment, Forestry and Tourism
MIDP	Master Integrated Development Plan
MoU	Memorandum of Understanding
MOZ	Makgadikgadi-Okavango-Zambezi
MUS	Multiple Use Water Services

NACSO	Namibian Association of Community Based Natural Resource Management (CBNRM) Support Organizations
NASC	National Stakeholders Committee
NGO	Non-Governmental Organization
NGOWP	National Geographic Okavango Wilderness Project
NP	National Park
OKACOM	Permanent Okavango River Basin Water Commission
ORASECOM	Orange-Senqu River Commission
ORB	Okavango River Basin
ORZ	Okavango Rift Zone
Peace Parks	Peace Parks Foundation
PSC	Project Steering Committee
RBO	River basin organization
RIMS	Ramotswa Information Management System
RESILIM	Resilience in the Limpopo Program
RISDP	Regional Indicative Strategic Development Plan
RSAP	Regional Strategic Action Plan
SADC	Southern African Development Community
SANParks	South African National Parks
SAP	Strategic Action Programme
SAREP	Southern Africa Regional Environmental Program
SMME	Small, Medium and Micro Enterprise
SRTM	Shuttle Radar Topography Mission
SWP	Sustainable Water Partnership
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Management
TBA	Transboundary Aquifer
TBNRM	Transboundary Natural Resources Management
TDA	Transboundary Diagnostic Analysis
TEM	Transient Electromagnetic
TFCA	Transfrontier Conservation Area
TGMF	Transfrontier Groundwater Management Framework
TNC	The Nature Conservancy
TWAP	Transboundary Waters Assessment Programme
UNECE	United Nations Economic Commission for Europe

UNESCO-IHP	United Nations Educational, Scientific and Cultural Organization – Intergovernmental Hydrological Programme
USAID	United States Agency for International Development
WASH	Water, Sanitation and Hygiene
WDA	Wildlife Dispersal Area
WMA	Wildlife Management Area
WBT	Wild Bird Trust
WWF	World Wide Fund for Nature
ZAMCOM	Zambezi Watercourse Commission
ZAMSEC	Zambezi Watercourse Secretariat
ZAMTEC	Zambezi Watercourse Technical Committee
ZAMWIS	Zambezi Water Resources Information System
ZimParks	Zimbabwe Parks and Wildlife Management Authority

1 INTRODUCTION

This report serves as the Transboundary Diagnostic Analysis (TDA) for the ***Sustainable Groundwater Development and Management for Humans, Wildlife, and Economic Growth in the Kavango Zambezi Transfrontier Conservation Area*** **(KAZA TFCA)** project – shortly denoted **KAZA-GROW.** The KAZA-GROW flagship project (**Grant Agreement No. RWP-G13-IWMI**) is a project implemented and led by the International Water Management Institute (IWMI) in partnership with the KAZA TFCA Secretariat and Peace Parks Foundation (Peace Parks) and funded by the United States Agency for International Development (USAID) under the Resilient Waters Program and the CGIAR (Consultative Group on International Agricultural Research) Research Program on Water, Land and Ecosystems (WLE) (IWMI, 2021a). The project runs over two years from January 18, 2021, to February 15, 2023.

1.1 Background

Transboundary groundwater

There is growing attention to the role of groundwater in supporting ecosystems and building resilience against climatic change. Studies show that groundwater can sustain ecosystems and livelihoods and support communities against the harsh realities of increasing climate variability (Guppy et al. 2018, CGIAR 2017). The historic focus on surface water management is now shifting to more integrated water resources management that also accounts for this invisible yet significant resource.

At transboundary levels, it has similarly been concluded that while significant strides in terms of transboundary aquifer (TBA) cooperation in Africa have been achieved over the last 20 years (Nijsten 2018), transboundary management frameworks and agreements for shared aquifers are not as prolific as for surface water (typically rivers and lakes) (UNECE 2021). Furthermore, transboundary groundwater management is typically less addressed and less associated with actual regulations than domestic groundwater management (Murcia 2020). This may result in over-abstraction and negative impacts on aquifer productivity and linked surface water ecosystems.

For example, in the Mapungubwe National Park, which forms part of the Greater Mapungubwe TFCA in the Southern African Development Community (SADC), groundwater over-abstraction for agricultural uses along the Limpopo River has been observed with consequences for river flow (SANParks 2019). Coupled with water demands from mining activities, groundwater has been especially vulnerable, compromising its role in sustaining baseflows and groundwater-dependent ecosystems (GDEs) (SANParks 2019).

Focus and priority for the TFCAs are principally on conservation and ecotourism, with a traditionally less specific focus on freshwater resources. However, with increasing climate pressures and socioeconomic development, water is becoming a constraining factor for conservation and maintaining the values provided to society by these transboundary landscapes and associated ecosystems. This development calls for greater integration around freshwater across countries and existing international cooperation frameworks, typically through established international river basin organizations (RBOs) and in coordination with the TFCAs. This approach retains the clear mandates as originally set out for these bodies while requiring strong coordination between them in terms of water management and conservation imperatives. Synergies are however overriding, as overall objectives for both TFCAs and RBOs are sustainability and socio-economic development. Geographically, bringing RBOs in supporting water resources management in TFCAs critically ensures the integrated water resources management across hydrologically relevant units. Since TFCAs are focused on critical landscapes and ecological systems – not necessarily aligned with rivers or lakes - their remit related to river basins and aquifer system management is less prominent, indicating the obvious synergy through TFCA, RBO, and Partner State cooperation.

However, despite the agreed consensus on the increasing role of groundwater in transboundary settings and the need to protect shared systems, progress towards harmonized legal and policy frameworks has been slow (Devlaeminck 2020), and by implication also in TFCA contexts. As a result, there is a need to co-develop the knowledge base, capacity and decision support tools, policy guidelines, as well as management and cooperation frameworks around groundwater at the most appropriate integrated scales from local to transboundary for the TFCAs.

The KAZA-GROW project

The KAZA-GROW project was conceptualized in partnership with the KAZA TFCA Secretariat, Peace Parks Foundation, and endorsed by ZAMCOM, to prioritize the management and precautious development of water, and in particular groundwater resources, in the Kavango Zambezi Transfrontier Conservation Area (KAZA TFCA[1]) in SADC (Figure 1.1). The overarching goal of the KAZA-GROW project is: *To support water security and resilience in the KAZA TFCA, shared between the five Partner States Angola, Botswana, Namibia, Zambia, and Zimbabwe, through the sustainable development and management of groundwater resources*.

Relatively little is known about the five identified TBAs in the KAZA TFCA (Figure 1.1) (Altchenko and Villholth 2013) and their existing and potential role in terms of supporting water security and resilience in the area (TWAP 2016). Some knowledge exists for the Eastern Kalahari Karoo Basin TBA, shared between Botswana and Zimbabwe, for which a study was commissioned in 2020 by the SADC Groundwater Management Institute (SADC-GMI).[2] Of relevance to this TDA, the Nata Karoo Sub-basin TBA shared between Angola, Botswana, Namibia, and Zambia is located in the center of the KAZA TFCA and intersects the boundaries of the Kwando River Basin (KRB), Kwando River Wildlife Dispersal Area (KWRDA) and the Chobe-Zambezi Floodplain WDA (Figure 1.2). However, its exact extent is not known (Section 6.2.1). As clear from Figure 1.1, it likely straddles the Okavango River and the Zambezi River Basins.

1.2 The Kavango Zambezi Transfrontier Conservation Area

The Kavango Zambezi Transfrontier Conservation Area (KAZA TFCA) (Figure 1.2 and Figure 1.2), was formally established in 2011 through a multilateral treaty with a vision to establish a world-class transfrontier conservation and tourism destination area in the Okavango and Zambezi River Basin regions of the Partner States Angola, Botswana, Namibia, Zambia and Zimbabwe within the context of sustainable development.[3] Broadly, the KAZA TFCA aims to secure natural resources for the good of people, economic growth, and the intrinsic value of nature. It is the largest terrestrial TFCA globally, covering 520,000 km^2 and counting on unique natural systems, interlinked supporting water systems and immense biodiversity. All Partner States sharing the TFCA are experiencing significant population growth, with a population of around 2.7 million (KAZA TFCA 2014) and an average annual population growth rate of 2.4% across the focus area (Section 4.1.1). Climate change trends indicate a warmer and drier climate in the region with larger variability in water availability and higher risks of severe floods and longer droughts. While expansive protected areas persist, approx. 71% of the KAZA TFCA (Stoldt et al. 2020), and a large impetus of the TFCA is to strengthen the connectivity between individual conservation areas to reestablish and/or conserve large-scale ecological processes and integrity and wildlife mobility across the region. It is also clear that the KAZA TFCA is under growing

[1] The Transfrontier Conservation Area (TFCA) paradigm emerged in Southern Africa with the first Peace Park in 1990. A TFCA is defined as an area, or component of a large ecological region, that straddles the boundaries of two or more countries, encompassing one or more protected areas as well as multiple resource use areas (EC, 2015).

[2] https://sadc-gmi.org/projects/water-resources-management-research-in-the-eastern-kalahari-karoo-basin-transboundary-aquifer/

[3] https://www.kavangozambezi.org/en/about/about-kaza

threats from broad drivers. These include climate change, population growth, and infrastructure development, requiring close cooperation between the Partner States and strong coordinated governance measures and structures.

Figure 1.1 Map of transboundary aquifers (blue) and transfrontier conservation areas (green) in SADC. The KAZA TFCA is the large green area in central SADC cutting across Angola, Botswana, Namibia, Zambia, and Zimbabwe (Peace Parks 2021).

Challenges of water insecurity and general poverty, especially among rural communities, extreme climate events (droughts and floods), inadequate water supply and other public services, growing human-wildlife and land-use conflicts, land degradation, water contamination, over-fishing and poaching, and large-scale economic activities, like commercial agriculture and mining, call for more pro-active natural and water resources management, e.g. through overionization of integrated water resources managed principles, and transboundary cooperation to ensure the resilience of communities, wildlife and the ecosystems on which they rely.

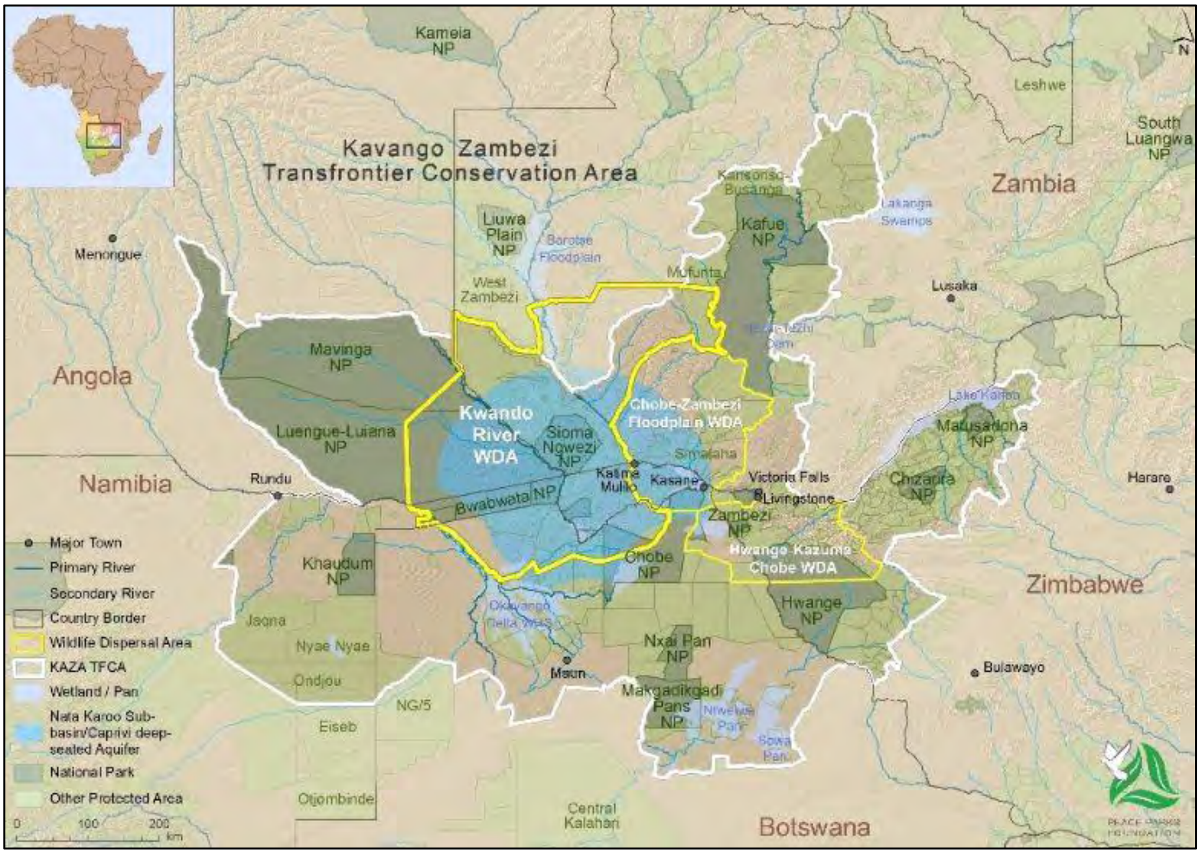

Figure 1.2 The KAZA TFCA and the Kwando River Wildlife Dispersal Area (KRWDA) (the area marked in yellow in the western part). The Nata Karoo transboundary aquifer, the relevant TBA for the KRB and the KRWDA, is marked in blue, while the exact delineation is uncertain (Peace Parks, 2021).

Rural communities are mostly reliant on water from rivers and shallow groundwater resources for their domestic and small-scale livelihood uses, with few formal reticulation systems in place outside major settlements. While surface waters constitute critical interconnected river/riparian, wetland, and internal drainage/delta systems, (prominently the iconic Okavango Delta) across the region, groundwater and transboundary aquifers (TBAs) increasingly play a role in supplying reliable, climate-resilient, and widely available water to dispersed communities and wildlife. They also critically underpin natural ecosystems, like rivers, wetlands, and terrestrial vegetation. Addressing the needs and existing gaps in the management of groundwater resources is an increasingly acknowledged key to supporting biodiversity, economic development, and resilience to climate change in the KAZA TFCA (KAZA TFCA 2019a).

The collective ability to harness and sustain the benefits of groundwater in the KAZA TFCA is dependent on the understanding, proper development, protection, and management of the resource, as well as transboundary cooperation. The critical aspects include understanding groundwater quantity, dynamics, and quality in time and space, aquifer mapping and conceptual modeling, and the role of groundwater in sustaining perennial flows in the Kwando and other rivers and GDEs. Of common interest is the acquisition of joint baseline knowledge of the Nata Karoo TBA. A current lack of knowledge leaves both human and wildlife populations increasingly vulnerable to the impacts of climate change and biodiversity loss but also to missed opportunities of leveraging fresh groundwater resources sustainably to tackle and adapt to the prescient challenges that face the KAZA TFCA.

SADC and TFCAs in the region increasingly work with international institutions spanning global issues of conservation, biodiversity, and water resources, including groundwater, like the European

Commission, the United Nations Economic Commission for Europe (UNECE), United Nations Educational, Scientific and Cultural Organization – Intergovernmental Hydrological Programme (UNESCO-IHP), Ramsar, World Wide Fund for Nature (WWF), Groundwater Solutions Initiative for Policy and Practice (GRIPP), as well as a host of international donor organizations. Bringing these partnerships to bear on the goal of KAZA-GROW and future work in the field will be important.

1.3 Focus area: The Kwando River system

The geographic focus of this TDA is referred to as the Kwando River system (KRS), which is defined as the combined areas of the Kwando River Basin (KRB) and the Kwando River Wildlife Dispersal Area (KRWDA), an area of approx. 190,000 km^2 in the northwestern part of the KAZA TFCA[4]. This area is shared between Angola, Botswana, Namibia, and Zambia and extends into the Angolan highlands (Figure 1.3) beyond the KAZA TFCA, requiring the integrated assessment of the hydrological aspects of the area. Several case studies are further drawn upon from adjacent regions that include for example the Chobe-Zambezi floodplain wildlife dispersal area (WDA) (Figure 1.2) and within the KAZA TFCA to highlight key issues and enhance regional interpretation.

At the heart of the KAZA TFCA is the KRWDA (approx. 106,000 km^2), its geographical coverage highlighted in yellow in Figure 1.2. A wildlife dispersal area, of which there are six in the KAZA TFCA (KAZA TFCA 2014), is defined as an area adjacent to or surrounding protected areas, wildlife conservancies, or sanctuaries into which wild animals move during some period of the year or use for feeding, laying and storing eggs, breading, rearing or feeding their young.[5] As such, these areas present buffers or critical ecological and wildlife movement linkages or corridors between protected areas across the landscape. The WDAs are an integral part of the mosaic of various land uses and are hence important to land use planning to reduce and/or stop the risks associated with habitat loss, degradation, and fragmentation while seizing opportunities for strengthening co-existence. The KRWDA spans four Partner States, Angola and Zambia to the north while encompassing the western Zambezi of Namibia and the most northerly fringe of Botswana to the south. The southern border runs approximately along with the interface between the Okavango and Zambezi River basins. The outline of the Kwando River Basin (KRB) (approx. 123,000 km^2) is shown in blue in Figure 1.3. Given that the KAZA TFCA only intersects the lower part of the KRB, it is important to highlight that the TDA coverage extends beyond the KAZA TFCA to encompass the upper catchment areas of the KRB to enable the integrated assessment of the upstream-downstream linkages of the basin.

The entire KRS lies within the Zambezi River Basin. It covers important protected areas, including parts of the Luengue-Luiana and Mavinga National Parks (NPs) in Angola, part of the Chobe NP in Botswana, the Bwabwata NP, the Mudumu and Nkasa Rupara NPs in Namibia, and the Sioma Ngwezi NP and the West Zambezi Game Management Area (GMA) in Zambia (Figure 1.3). A series of ongoing environmental issues are highlighted in a situation analysis of the KRWDA in the KAZA TFCA Master Integrated Development Plan (MIDP) (2014). These include poaching, commercial timber operations, human-wildlife conflict (HWC), excessive bush and vegetation burning, restricted movement along veterinary fences, lack of accurate and detailed land use information, and limited transboundary infrastructure (KAZA TFCA 2017).

The recent Kwando River Basin Report Card refers to the basin as largely undeveloped (WWF 2020a) and currently in moderate health (WWF unpubl.a). The relatively intact basin provides a good opportunity to select and work towards protecting key biodiversity areas that are currently threatened by human-wildlife conflicts and competition for productive uses (WWF 2020a). The relative pristine

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[4] Note, Kwando is spelled Cuando in Portuguese. In this report we primarily use the English spelling.

[5] https://www.lawinsider.com/dictionary/dispersal-area

character of the basin also supports an undisturbed hydrological system that may provide ecosystem support in both upstream and downstream regions of the basin.

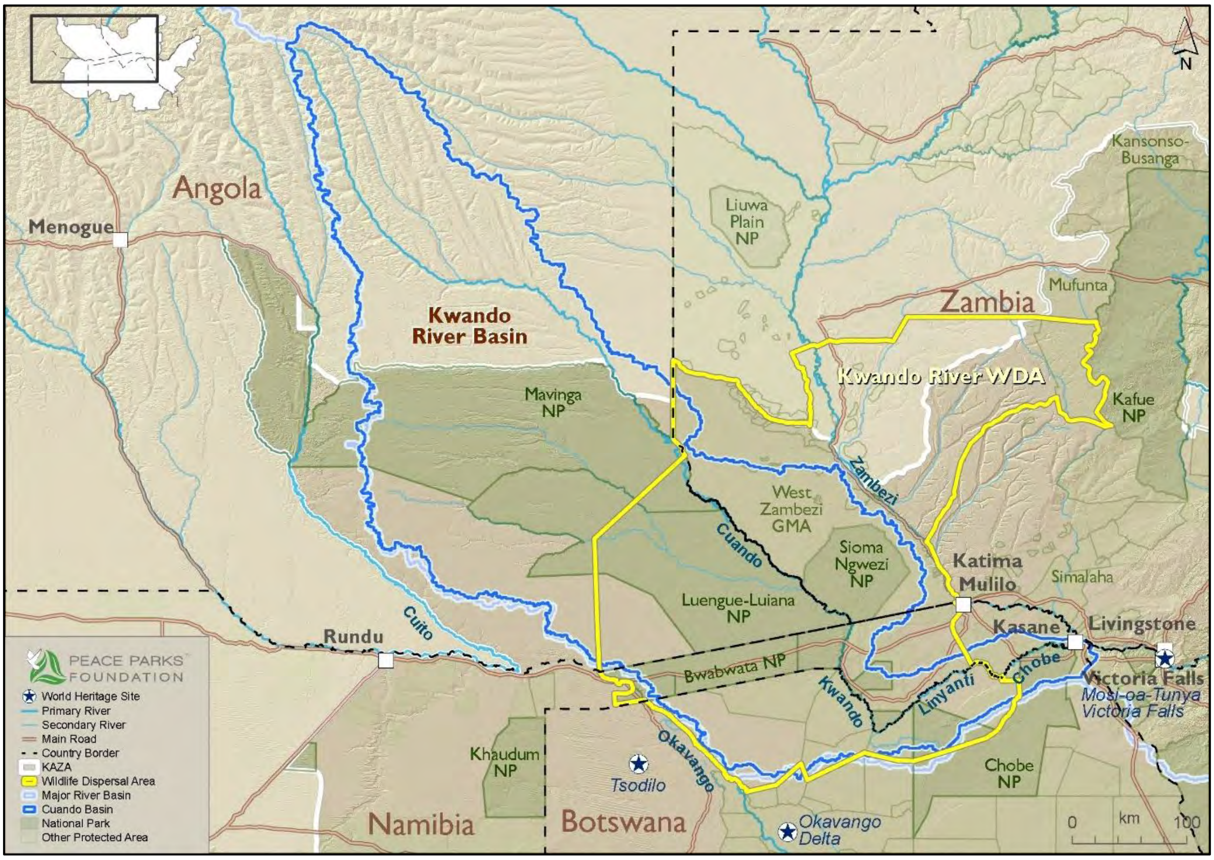


Figure 1.3 The project focus area of the Kwando River system (KRS), which includes the Kwando River Basin (KRB) and its intersection with the Kwando River Wildlife Dispersal Area (KRWDA) in the northwestern corner of the KAZA TFCA (Peace Parks 2021).

2 THE TRANSBOUNDARY DIAGNOSTIC ANALYSIS

2.1 Objectives

The transboundary diagnostic analysis (TDA) enhances the knowledge base of the water resources, particularly groundwater, and related environmental, socioeconomic and legal, policy, and institutional aspects of the Kwando River system (KRS) as a pilot for the KAZA TFCA. This focus was identified, prioritized, and specified as part of the KAZA-GROW inception phase (IWMI, 2021b). The objectives of the TDA were:

- Supporting and enhancing the collation, sharing, and dissemination of data as well as the joint knowledge development around groundwater resources and transboundary aquifers in the KRS as a strategic resource for the KAZA TFCA.
- Supporting and enhancing policy co-development around groundwater development, use, management, and protection in the KRS and wider KAZA TFCA.
- Strengthening cooperation across KAZA TFCA Partner States and River Basin Organizations in terms of groundwater management for sustainable and resilient development.

2.2 Partners and stakeholders

2.2.1 Project partners

KAZA TFCA

On 18 August 2011 at the SADC Summit in Luanda, Angola, the Presidents of the Republics of Angola, Botswana, Namibia, Zambia, and Zimbabwe signed a treaty, which formally and legally established the Kavango Zambezi Transfrontier Conservation Area (KAZA TFCA). This treaty was built on a long anterior process and an interim agreement in the form of a Memorandum of Understanding (MoU) between the Partner States signed on December 07, 2006. The goal of the KAZA TFCA is to sustainably manage the Kavango Zambezi ecosystem, its heritage, and its cultural resources, based on the best conservation and tourism models for the socioeconomic wellbeing of the communities and other stakeholders in and around the ecoregion through harmonization of policies and practices.[6]

The KAZA TFCA, through its various structures (Section 8.3.2) represents the interest of the five Partner States in terms of the development and management of the TFCA. The KAZA TFCA Secretariat plays a crucial role in supporting and facilitating the implementation of the projects outlined in the KAZA TFCA MIDP (KAZA TFCA 2014). The secretariat provides support in the following areas, among others:

- Securing financing
- Promoting transboundary cooperation and communication
- Encouraging partnerships with existing structures
- Integrating climate change planning into project design
- Promoting good quality monitoring and evaluation

Peace Parks Foundation

Peace Parks Foundation, or Peace Parks, has since 1977 pioneered and facilitated the formation of TFCAs in southern Africa and developed relevant human resources, thereby supporting the conservation of biodiversity, sustainable economic development, and regional peace and stability in the region. PPF has gained over 20 years of experience, working with ten countries in the southern African region, and as a facilitator and implementer enjoys good relations with stakeholders at all levels and has a fundamental understanding of core socioeconomic and conservation challenges. Peace Parks has an excellent record of good governance. The financial resources mobilized for TFCAs have been the largest and most significant source of conservation finance in SADC over the past decade.

More specifically, Peace Parks is a key KAZA TFCA-supporting international non-governmental organization (NGO). It recognizes the importance of conserving and developing core areas, corridors and keystone species regardless of political boundaries, to secure biodiversity conservation. This in turn is the most important foundation to ensure maintained, healthy and functional ecosystems, while also acknowledging the rights of human beings to join other species in responsibly using the natural resources present in these ecosystems.[7]

International Water Management Institute

The International Water Management Institute (IWMI) is an international not-for-profit research-for-development organization focusing on the sustainable use of water and land resources in developing countries, with headquarters in Sri Lanka and regional offices across Asia, Sub-Saharan Africa, and the Middle East and Northern Africa (MENA) region. IWMI is a member of the Consultative Group on

[6] https://www.kavangozambezi.org/en/about/about-kaza
[7] https://www.peaceparks.org/what/

International Agricultural Research (CGIAR) system of international agricultural research centers. IWMI's vision is a water-secure world. IWMI's value proposition rests on its more than 30-year record of accomplishment of rigorous, relevant, and solutions-oriented water management research and its long-term and well-established field presence.

Resilient Waters Program

The KAZA-GROW project is supported by a grant from the USAID through the Resilient Waters Program. The overarching aims of the program, which runs through May 2023, are to build resilient communities and ecosystems in southern Africa, through the improved management of transboundary natural resources, increased access to safe drinking water, and improved sanitation services.

2.2.2 Stakeholders and beneficiaries

Key stakeholders and beneficiaries of the TDA include entities and organizations that are involved in the management of water resources in KAZA TFCA but are not direct project partners of the KAZA-GROW project. At the regional level, these are the two RBOs, the Permanent Okavango River Basin Water Commission (OKACOM) and the Zambezi Watercourse Commission (ZAMCOM), the SADC Water Division/Directorate for Infrastructure and Services, and its subsidiary on groundwater, the SADC-Groundwater Management Institute (SADC-GMI). At the national level, the key stakeholders are the national and sub-national authorities and entities responsible for water resources management as well as the environment, biodiversity, and tourism. The KAZA TFCA Secretariat has an MoU with OKACOM and is in the process of establishing one with ZAMCOM. These MoUs are deemed central to a formalized and close cooperation between the RBOs and the KAZA TFCA Secretariat. They facilitate in a mutually reinforcing way the development and endorsement of the TDA as well as other joint processes and initiatives.

In the context of the KAZA-GROW project, OKACOM and ZAMCOM have key complementary mandates of the river basins, parts of which overlap with the KAZA TFCA (Figure 1.1). They are not only playing a key role in coordinating activities across the respective relevant member states in their basins (OKACOM: Angola, Botswana, and Namibia, and ZAMCOM: Angola, Botswana, Namibia, Zambia, and Zimbabwe) but increasingly also in coordinating issues of trans-basin character in the context of the KAZA TFCA.

The TDA process will further strengthen and benefit from, existing regional stakeholder forums around the KRS, for example, the Kwando Joint Action Group (KJAG[8]). The KJAG is a transboundary dialogue platform that fosters water cooperation and knowledge sharing between government ministries of water, agriculture, energy, environment, and tourism. It is organized by National Administrative Steering Committees (NASCs) from these ministries. The sole mandate to convene the KJAG is held by ZAMCOM (O.C. Mwanza, pers. comm.). The KJAG is essential to informing and validating the TDA as well as aligning the KAZA-GROW project activities to other ongoing initiatives and processes and taking up and supporting the implementation of TDA recommendations.

2.3 Methodology

2.3.1 The TDA as part of an adaptive management cycle

A TDA is typically aimed at identifying the underlying and fundamental causes and effects of

[8] The KJAG was set up as a special purpose vehicle to provide a multi-stakeholder platform for two projects endorsed by ZAMCOM and implemented by WWF Zambia.

environmental and transboundary water resources issues providing the base for future assessments and interventions, the latter typically developed in the form of a Joint Strategic Action Plan (JSAP) (Pernetta and Bewers 2012, GEF 2013a&b). The TDA acts as a primary knowledge base or baseline for a particular transboundary area. However, its content and focus depend on the objectives and needs of the stakeholders involved, and importantly, it builds on a participatory process.

The overall approach to the KAZA-GROW TDA was to collate and document existing knowledge around water resources (focusing on groundwater and aquifers), ecosystems, biodiversity, socioeconomics, and legal, policy, and institutional arrangements within the KAZA TFCA, with a specific focus on the KRS. A conceptual framework is put forward that illustrates the process into which the TDA falls (Figure 2.1). This schematic allows the reader to appreciate the central role of the TDA in a larger adaptive management cycle for a transboundary area. This consists of the four key iterative steps with key accompanying principles, involving the assessment phase via the TDA; the formulating a JSAP; implementing priority actions identified in the JSAP; and monitoring the outcomes, both short-term and long-term, whilst adapting the plan accordingly (GEF 2013b). Importantly, the TDA links to other ongoing transboundary and international processes and assessments, making it a piece of a larger cooperative assessment and transboundary management framework, in our case around water resources in the KRS and the wider KAZA TFCA.

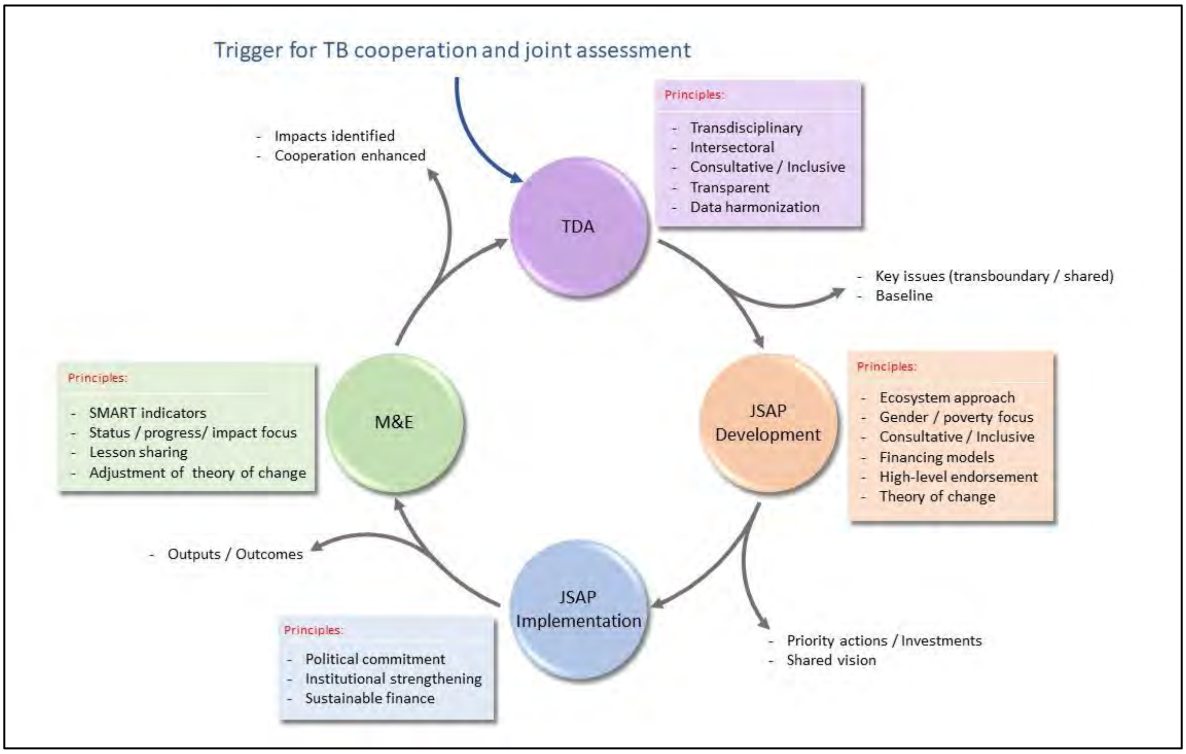


Figure 2.1. The TDA process within a larger conceptual transboundary management framework detailing the TDA/JSAP adaptive management cycle and accompanying principles.

2.3.2 Outputs and timeline of the KAZA-GROW project

The TDA forms a central output of the KAZA-GROW project, the key outputs and relative timeline of which are shown in the project flow diagram (Figure 2.2). A description of each significant project milestone and component is given below.

KAZA-GROW Inception Workshop

The successful KAZA-GROW Inception Workshops in February 2021, and subsequent synthesis in the Inception Report (IWMI 2021b), kickstarted the identification of knowledge gaps around the biophysical, socioeconomic, environmental, legal, policy, and institutional dimensions in the KAZA TFCA. It also supported the cementation of the priority focus on the KRS for the TDA. In addition, and importantly, the workshop supported the development of a stakeholder platform and process that proved invaluable for the onward TDA development, both in terms of data collection, transboundary issues identification, and setting up further consultation processes.

Data sources, database, literature review, and partner/stakeholder interviews
Post the Inception Workshop, meetings with stakeholders and partners were identified and prioritized based on anticipated data. These meetings were held in a series of interview-style open-ended virtual dialogues allowing in-depth discussions, drawing on the extensive field expertise and long-term engagements of stakeholders and partners in the region (Appendix I Summary of stakeholder engagement). This process began with a consultation with Peace Parks, in which a series of localized base maps within and around the KRS was produced to highlight key geographical and water resource features, and inter-connectedness between various protected areas[9]. With this map material as a basis, consultations were carried out with Park Managers and KAZA TFCA consultants within the Luengue-Luiana, Mudumu, and Sioma Ngwezi NPs. These consultations opened a wide-ranging network across even more stakeholders (NGOs, governmental departments, and independent consultants), a process that expanded as the project evolved.

Due to the relatively limited time and resources available under the KAZA-GROW project, the TDA was a desk study based on existing (secondary) data and information and did not include the acquisition and production of new primary data. Therefore, the process involved the production of a meta-database with links to readily available online material (Appendix II KAZA-GROW meta-database sources) and a repository of published and grey literature[10].

Appendix III (TDA materials and datasets used) lists the materials and datasets used in each section of the TDA, of which, new interpretations were brought into the report. An example of a new interpretation of existing data was the use of CHIRPS remote sensing data on precipitation, applied due to the low density of rainfall stations in the KRB (Section 3.1).

Datasets compiled in the TDA
The TDA highlights throughout that one of the major barriers to assessing the KRS lies in the limited data availability, especially around groundwater and aquifers. Therefore, an emphasis on closing the data gaps is critical in future interventions in the region. To support such a process, Appendix III lists a column of missing datasets that future studies could provide to improve the knowledge and understanding of the region.

Within the KAZA-GROW project, a mix of qualitative and quantitative data was pursued to gather and present the relevant documentation as comprehensively as possible. This was complemented by relevant inferences and extrapolations to overcome limitations and provide a preliminary assessment of regions with significant data scarcity. For example, multiple studies relate to the Okavango River Basin (ORB) due to its distinction and international significance. This is not the case for the KRB, and it was essential to draw on these comparable studies and incorporate them with the available datasets to the extent possible and relevant. Similarly, working at nested scales gave an understanding of the context, e.g., from small to larger catchments, or from upstream to downstream areas. This

[9] 'protected areas' include national parks, game/forest reserves, community conservancies and game/wildlife management areas.
[10] SharePoint literature database for the TDA: KAZA-GROW Literature

amalgamated knowledge was then used to build the conceptual hydrogeological model of the KRB with noted limitations on the level of detail and interpretation (Section 5.2.3).

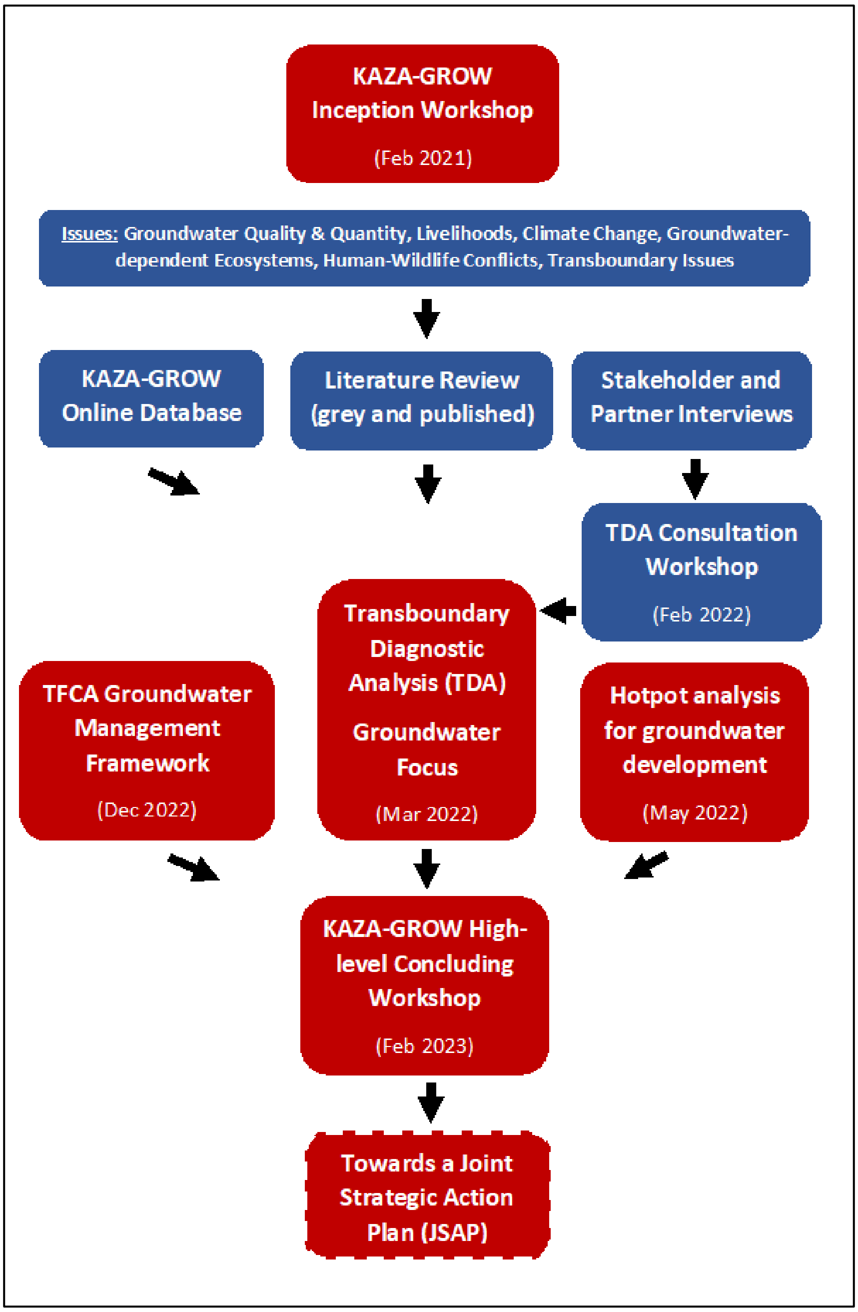


Figure 2.2 Flow diagram outlining the key outputs and activities in the KAZA-GROW project from the Inception Phase to the final High-level Concluding Workshop.

The accumulated data, maps, and shapefiles were kept in the KAZA-GROW online database.[11] At the time of this report, the long-term repository of the datasets was still to be determined. It was deemed essential that technical support at the end of the project would facilitate knowledge partners, including National Partners, International Cooperation Partners, as well as local stakeholders to have

[11] SharePoint KAZA-GROW database for the TDA: KAZA-GROW Database

access to the data. An open-source online data-sharing platform for the KAZA TFCA (like for the RIMS[12]) could be a component of a longer-term KAZA TFCA-wide knowledge management hub. This would then be linked to the pan-African Knowledge Hub of the African Ministers' Council on Water (AMCOW)[13]

The TDA stakeholder consultation workshop
The draft TDA was brought forward to key stakeholders through the TDA Stakeholder Consultation Workshop (virtual) (Figure 2.2). The invitation list was based on the KJAG of ZAMCOM, predominantly key technical representatives of the relevant ministries of the Partner States regarding water, agriculture, energy, environment, and tourism (Appendix IV Stakeholder consultation workshop attendance register).

In addition, a parallel email-based consultation process was implemented with the stakeholders who attended the KAZA-GROW Inception Workshop but were not representatives of the KJAG. This double-track consultation process was deemed necessary in terms of achieving a consensus-based TDA Report. The final TDA document was vetted with the Zambezi Watercourse Technical Committee (ZAMTEC) and the KAZA TFCA Secretariat for final endorsement.

Transfrontier Groundwater Management Framework & Hotspot analysis for groundwater development
The Transfrontier Groundwater Management Framework was conceived to strengthen the policy attention to groundwater at the KAZA TFCA level, piloted for the KRS. It builds on the TDA process and will inform future JSAP process in terms of gaps and priorities and possible enhanced and coordinated institutional frameworks for transboundary cooperation around groundwater in TFCAs, piloted for the KAZA TFCA and with generic lessons and recommendations for the SADC TFCA level.

The hotspot analysis for groundwater development involved two components: 1) assessment of areas and communities in the KRS that were particularly vulnerable to water insecurity and HWC; and 2) assessment of potential areas and options for the development of groundwater with adequate quantity and quality, based on field investigations. Combined, the two assessments support the early mapping of hotspot (potential) areas for the development of groundwater to address key vulnerabilities. This would also help inform an upcoming JSAP.

Moving towards a Joint Strategic Action Plan (JSAP)
IWMI has ample experience in cooperative TDA/JSAP work in diverse transboundary settings within the SADC region. These include the Ramotswa-Ngotwane Aquifer/River system, the Tuli Karoo-Upper Limpopo system, and the Shire River/Aquifer system (Figure 2.3). Information and outputs, including TDAs and JSAPs, on these, can be found online.[14] Each transboundary setting and TDA/JSAP process poses its own unique set of circumstances and challenges, yet overarching lessons learned are transferable to the KAZA TFCA context (UNESCO and IWMI, 2021). Lessons from TDA processes include the need to harmonize data before they can be compared (as in tables) or joined (as in maps). Furthermore, the terminology is critical, and can be sensitive, e.g., related to names of systems, names of geological formations, and units of measurements to be used. Transboundary issues and geographies can be political and sensitive. Hence, transparent and participatory processes are critical to providing open platforms for communication and sharing, building the critical trust to drive the process. These experiences are applied in the TDA process and the linking of the TDA to a potential

[12] RIMS (Ramotswa Information Management System)
https://www.un-igrac.org/resource/ramotswa-information-management-system-rims
[13] https://knowledgehub.amcow-online.org/
[14] https://conjunctivecooperation.iwmi.org/

JSAP process. It is recommended that the TDA of the KRS is succeeded by the development of a JSAP, although it does not fall under the current KAZA-GROW project.

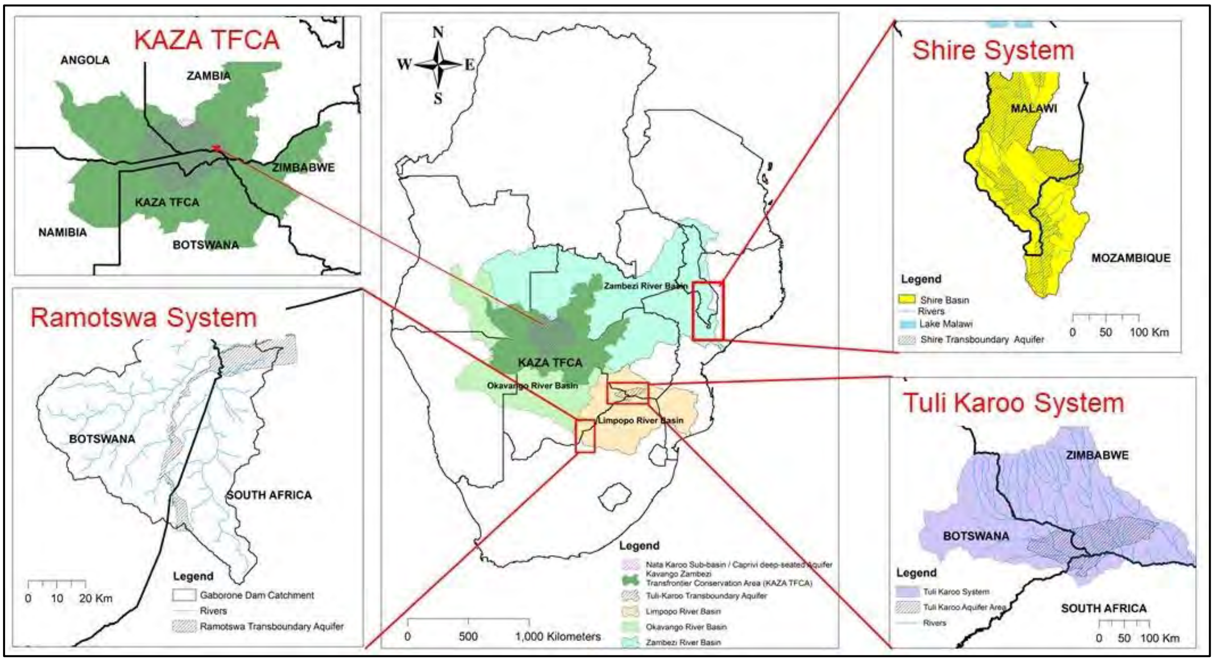


Figure 2.3 Transboundary water systems in SADC with key projects led by IWMI, encompassing critical TDA and JSAP processes.

3 PHYSIOGRAPHY

3.1 Climate - present and historic

Trends across the major river basins within the KAZA TFCA, from 1950 to 2005, point towards decreasing annual precipitation and an increased number of relatively dry years across the Kwando, neighboring Okavango, and western Zambezi basins[15] (Gaughan and Waylen 2012). Hoerling et al. (2006) report a similar drying trend over southern Africa, for a similar period, in response to rising temperatures in the Indian Ocean. The rainfall data below (Figure 3.1) is based on the Willmotte Matsuura and Willmott (2007) dataset, a global gridded monthly time series of modeled rainfall. The time series shows a much greater similarity in the annual precipitation between the Okavango and Kwando Basin, whereas the sum for the western Zambezi Basin appears to follow the same pattern but with consistently larger sums. The similar trends show that the three basins are likely to be subject to similar climatic regimes but the difference in volumes may be explained by the greater surface area covered by the Zambezi (Figure 3.1). Furthermore, the likelihood of either the El Niño or La Niña phenomenon is indicated during each hydrological year (Oct to Sep). The El Niño/Southern Oscillation Index (ENSO) is a global climate phenomenon caused by changes in Pacific Ocean Sea Surface Temperatures with large impacts on global inter-annual rainfall variability. A prevailing negative index, typical of La Niña conditions (white arrows), can lead to increased rainfall over southern Africa, while less rainfall is typically associated with El Niño years (black arrows) (Nicholson and Selato 2000). Gaughan and Waylen (2012) highlight a stronger association with the occurrence of El Niño and 'dry' years in more westerly regions that include the Okavango and Kwando River Basins.

[15] Interchangeable use of both catchment and river basin in the text refers to the land surface area drained by a particular river.

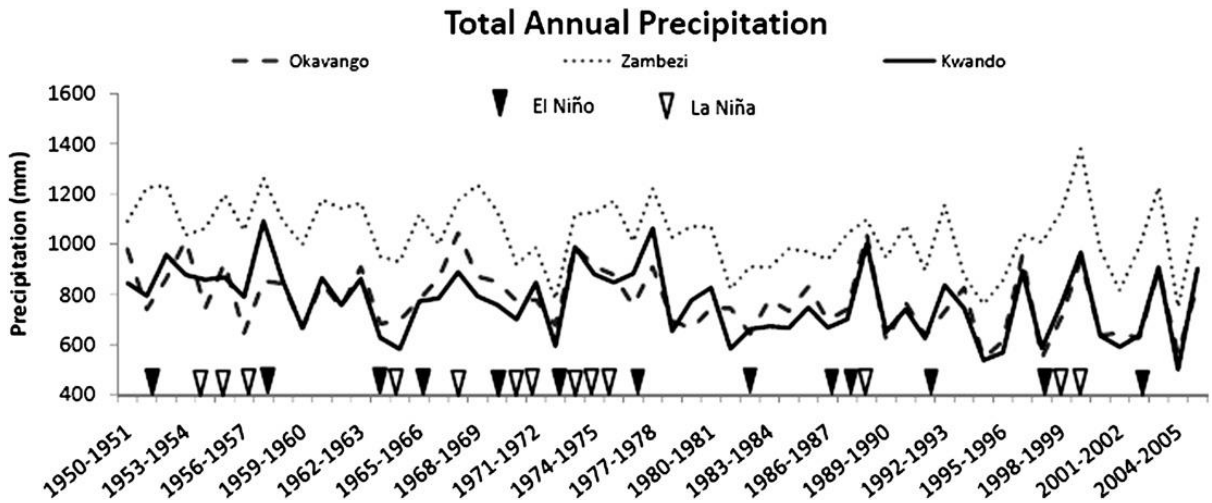


Figure 3.1 Annual precipitation across the Okavango, western Zambezi, and Kwando River Basins between 1950-2005. The likelihood of either the El Niño or La Niña phenomenon is indicated during each hydrological year (Oct to Sep) (Gaughan and Waylen 2012).

The occurrence of weather stations throughout the KAZA TFCA is sporadic and of low density. The positioning of known weather stations can be found on the SASSCAL WeatherNet website[16], which covers Zambia, Botswana, Angola, and Namibia. These are available for downloading and visualizing using Google Earth. The consistency and density of data across timescales at each station are very variable, and it is not possible to undertake a comprehensive analysis across stations. All available climate records within the KRS (13 in total) are available in the KAZA-GROW database.[11] There is a single precipitation gauge located within the Angolan section of the KRB at Mavinga (1959-73), recording monthly rainfall sums. Again, this record is inconsistent and unsuitable for analysis, making a basin-wide analysis based on observations infeasible.

Alternatively, remote sensing data were employed to collect rainfall time series from 1981-2020. The CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) dataset contains modeled precipitation based on infrared Cold Cloud Duration observations assimilated with gauge observations (Funk et al. 2015). This charts a similar pattern for the annual sums of KRB and wider KAZA TFCA (Figure 3.2). Notably, the annual rainfall in the KAZA TFCA is consistently lower than that estimated for the KRB. This can be explained by the large areas of low-lying plains in the southernmost regions of the KAZA TFCA that experience little rainfall. In contrast to Figure 3.1, the temporal trends from this dataset show a gradual long-term increase in precipitation. This may be explained by more recent records showing recent consecutive wet years with high seasonal volumes in the period after the previous time series ends (2005), particularly in the years 2007-14. However, it is also observed visually from Figure 3.2 that the trend since 2011 is decreasing.

The climatic setting of the KRB is split broadly between the upper and lower sections of the basin based on the Koppen-Geiger climate classification (Peel et al. 2007). The upper is indicated as dry winter humid subtropical and the lower as arid-hot steppe. The source regions of the Kwando River are located within the Angolan highlands, and most of the precipitation occurs during the austral summer season between October to April (Jury 2010). There is a significant gradient of median rainfall, ranging from approx. 1200 mm/year in the Angolan highlands to 400 mm/year across both the lower

[16] http://www.sasscalweathernet.org/

Kwando and Okavango Basins (Gaughan and Weylen 2012). Generally speaking as the trend of annual rainfall tends to decrease further south and away from the highlands, the climatic setting changes within the KAZA region from semi-humid to semi-arid (Bäumle et al. 2018). These trends are characterized by the weather station at Katima Mulilo (17°30'S, 24°16'E, 946 masl) located on the banks of the Zambezi River at the border between Namibia and Zambia. This station records average rainfall values of 514 mm/year (1987-2000). Between 1958 and 1981, an average potential evapotranspiration level of 2507 mm/year occurred, where the extremes range differentiate between 150 to 300 mm per month, in June and October (data not shown). It is assumed that low levels of groundwater recharge occur under average rainfall conditions in this region because of the high levels of evaporation throughout the year (Margane et al. 2005).

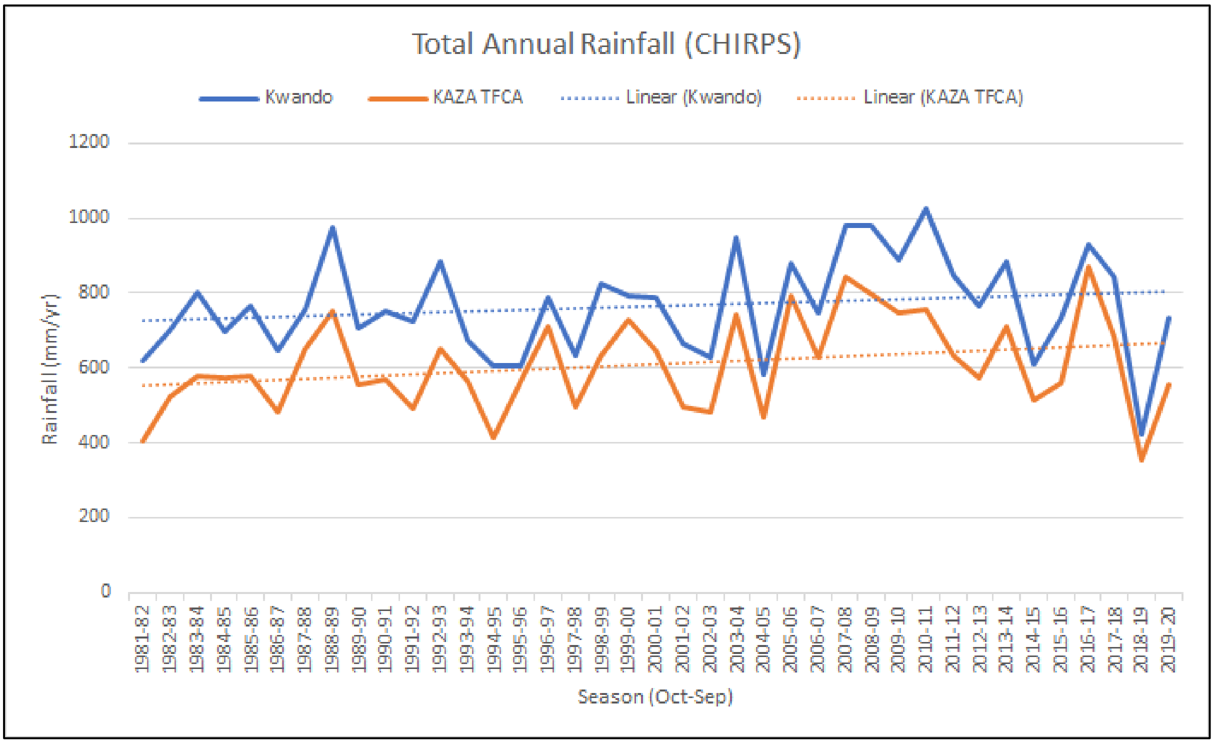


Figure 3.2 Annual precipitation time series data modeled using the global CHIRPS dataset 1981-2020. Hydrological year from Oct to Sep.

For the KRB and using the CHIRPS precipitation dataset, the distribution of annual rainfall for three hydrological years (Oct-Sep) is shown in Figure 3.3. These represent spatial variability in rainfall across examples of high, low, and annual totals. In 2016-17 (931 mm), there are high levels of rainfall across all areas of the catchment, whereas, in 2019-20 (733 mm), there is a tendency for the precipitation to fall higher in the basin in line with greater altitudes over the Angolan highlands. In 2018-19 (423 mm) there is relatively low rainfall across the entire basin, although a significant fraction of rainfall (values estimated up to 1100 mm/year) are occurring in the uppermost reaches.

3.2 Climate change projections

Over southern Africa, temperatures have been increasing at double the rate of global temperatures over the last five decades, with forecasts estimating that there may be a six-degree average temperature rise by the end of the century over western and central areas unless substantial headway is made towards climate mitigation (Archer et al. 2018). Recent outcomes from the IPCC report (2021b) present changes for the mid-21st century, concurrent with global warming of at least 2°C. These include observed decreases in mean precipitation, observed increases in heavy precipitation and pluvial flooding, observed and projected increases in aridity, and agricultural and ecological droughts.

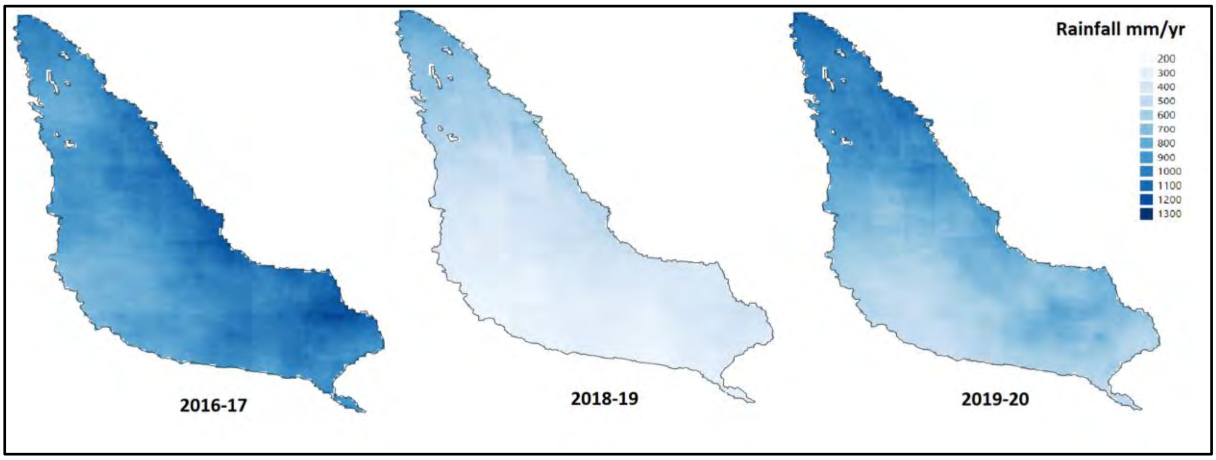


Figure 3.3 CHIRPS dataset showing rainfall distribution across the KRB in the hydrological years 2016-17, 2018-19, and 2019-20 with total rainfall of 931 mm, 423 mm, and 733 mm, respectively.

A recent assessment by World Wide Fund for Nature (WWF) aggregated climate projections for the KAZA TFCA region for the period 2040-2060 based on the representative concentration pathway (RCP 8.5[17]) referred to as the 'business-as-usual' emission scenario, which best represents more recent trends (WWF 2020b). The present and projected average temperatures across each month are given in Figure 3.4, presenting an overall increase of 3°C in mean annual temperatures. Similarly, Kaaya et al. (2020) undertook climate projections related to the Zambezi River Basin. These produced temperature increases ranging from 2.08 to 2.97°C in the years 2046-2065 compared to the average historical records from 1961-1990. The maximum increases are predicted over the western and southern regions of the basin (Kaaya et al. 2020).

The same models predict a 4.6% decrease in annual precipitation by the middle of the century for the entire KAZA TFCA region with Angola being one of the most affected areas, not just in the KAZA TFCA, but across the entire southern Africa region (Archer et al. 2018, WWF 2020b). On a more localized scale, similar predictions were made for individual protected areas within the KAZA TFCA (Table 3.1).

[17] https://sedac.ciesin.columbia.edu/ddc/ar5_scenario_process/RCPs.html

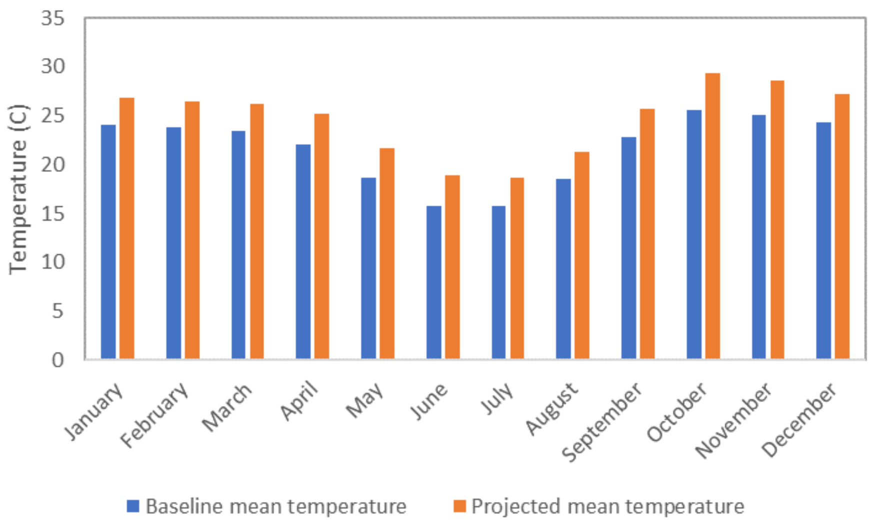


Figure 3.4 Comparison between baseline (1960-1990) and projected (2040-2060) mean monthly temperatures across the KAZA TFCA landscape, based on two global climate models (WorldClim Version2[18] and CMIP5[19]) (WWF 2020b).

Table 3.1 Summary of projected changes in mean annual temperature and precipitation relative to historic values for protected areas in proximity to or within the boundaries of the KRS based on climate modeling (WorldClim Version2 and CMIP5) (modified from WWF 2020b).

	Temperature (°C)			Precipitation (mm)		
Protected Area	Historic annual avg.	Projected annual avg.	% change	Historic annual avg.	Projected annual avg.	% change
Sioma Ngwezi NP	21.8	24.8	13.8	673.6	636.4	-5.5
Luengue-Luiana NP	21.6	24.8	13.8	642.0	593.3	-7.6
Chobe NP	22.1	25.2	13.6	520.0	493.6	-5.1
Nkasa Rupara NP	22.0	25.1	13.9	522.6	503.9	-5.6
Mudumu NP	21.9	24.9	13.8	571.6	539.7	-5.6
Mavinga NP	21.1	24.3	14.9	775.6	719.5	-7.2

The strategic plan for ZAMCOM (2018-2040) provides insight into the impacts of climate change on hydrology (ZAMCOM 2019). These include studies that estimate reduced runoff (26-40% by 2050), greater evaporation, and increased crop water requirements for rainfed and irrigated crops. (Box 1). It is qualitatively discussed how seasonal patterns in rainfall are predicted to change with shorter more intense rainfall events, delayed onset of the rainy season, and an increase in the frequency and severity of both floods and droughts (ZAMCOM 2019).

[18] www.worldclim.org/version2
[19] https://esgf-node.llnl.gov/projects/cmip5/

Box 1. Modelling future water availability in the Zambezi River Basin

A quantitative approach to modelling the Zambezi River Basin was undertaken by Beck and Bernauer (2011) considering climate change and water use changes resulting from projected changes in population, urbanization, irrigated agriculture, and industrial developments by 2050. The rainfall-runoff model was calibrated using precipitation, evapotranspiration, and river discharge data. No groundwater processes are accounted for, while groundwater contributions with respect to anticipated water usage are included but only as a replacement to surface water in water shortage periods and not as a perennial resource. Only the use of a fully calibrated 3D integrated model would be able to account for available groundwater storage in the region.

Mean annual flows at the outlet of each sub-basin are modelled under three different scenarios (Table 3.2). The first scenario (1) explores the effects of modest population growth and some minor industrial expansion without climate change impacts. The second scenario (2) serves to examine the implications of a ‘‘middle-of-the-road’’ demand expansion in which the distribution of water demand across sectors remains comparable to the present day, combined with moderate climatic changes. In the third scenario (3), water demand is driven by the expansion of irrigated agriculture combined with strong changes in climatic conditions (Typified by 15% overall reductions in precipitation across the various countries within the Zambezi River Basin as predicated by global climate models). The results are stark and show a strong vulnerability towards the Kwando (Cuando Chobe) River in both scenarios 2 and 3 as both indicate a 100% decrease in total runoff. Beck and Bernauer (2011) indicate a more pronounced impact from water use increase than from climate change, which suggests that the eight countries in the Zambezi River Basin have some control over future outcomes, but also highlights the importance of transboundary cooperation. Given the uncertainties around modelling, it is difficult to predict future scenarios under climate change, but these results and earlier climate models do indicate extreme climate change projections in the next few decades that undoubtedly leave the region very vulnerable and increasingly reliant on diminishing or more variable water resources.

Table 3.2 Mean annual flow (m^3/s) as modelled for the Zambezi sub-basins for three different predicted climate and water use scenarios for the year 2050. The Cuando-Chobe (8) refers to the KRB. Surface waters that cross into the KRWDA originate from sub-basins in the headwaters of the Zambezi River (numbers 9, 10 ,11 ,12 and 13) (Beck and Bernauer 2011).

Sub-basin	Mean annual flow (m^3/s)			
	Year 2000	Scenario (1)	Scenario (2)	Scenario (3)
1. Delta	2597	2457	2162	1383
2. Tete	1729	1682	1464	834
3. Shire	445	354	307	165
4. Mupata	1248	1188	818	23
5. Luangwa	489	485	431	250
6. Kariba	929	898	598	0
7. Kafue	273	248	187	62
8. Cuando Chobe	32	31	0	0
9. Barotse	1007	1002	720	149
10. Luanginga	58	58	34	0
11. Lungue Bungo	263	263	235	152
12. Upper Zambezi sub-basin	253	252	186	0
13. Kabompo	82	82	70	8

3.3 River basin layout and topography

Figure 3.5 shows an aerial view of a regional Digital Elevation Model (DEM) that encompasses the Okavango, Kwando, and western Zambezi River basins. The source of each river lies outside of the KAZA TFCA and flows into the north and western parts of the TFCA. The source of the Kwando River originates in the southwestern Angolan highlands in regions up to 1890 meters above mean sea level (mamsl) with the lower reaches at approx. 900 mamsl in the Linyanti-Chobe floodplains. The DEM shows how the incising tributaries in the northerly parts of the KRB coalesce to form the Kwando River, which has a total catchment area of 122,886 km^2. Gaughan and Weylen (2012) highlight the linkage between precipitation and hydrological dynamics and extremes within the river basins. The precipitation mostly occurs upstream in the Angolan highlands although significant spatial variation is possible throughout the basin (Figure 3.3). The upstream phenomena directly impact the magnitude and timing of discharge downstream and the water resources available to human and wildlife populations within the KAZA TFCA and specifically the KRWDA.

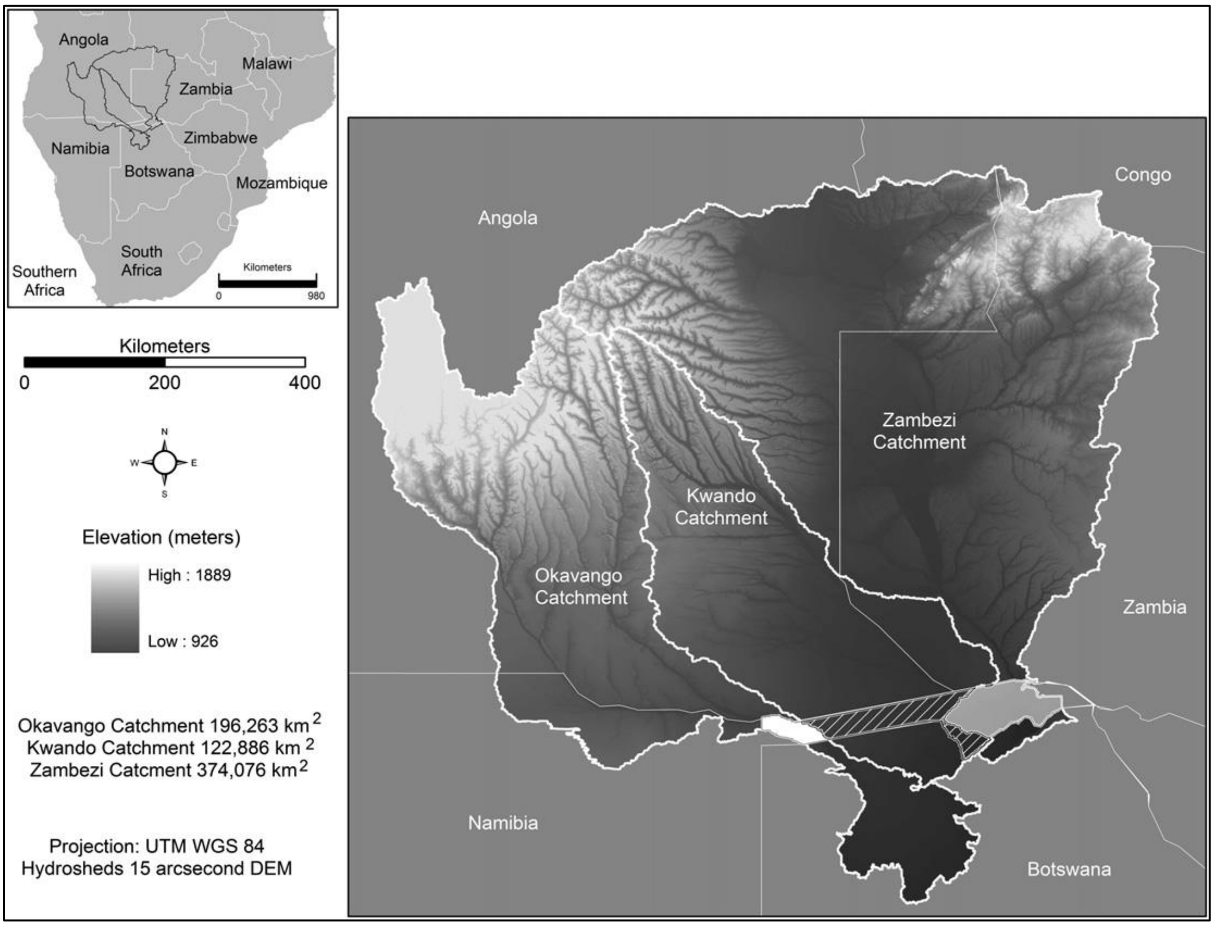


Figure 3.5 Digital Elevation Model (DEM) displaying altitude and catchment area across the Okavango, Kwando, and western Zambezi River Basins (Lehner et al. 2006 in Gaughan and Waylen 2012).

3.4 Land cover and use

Large areas of the KAZA TFCA are covered by sparse/open bushlands/shrubs (pink area in Figure 3.6), whilst green and dark green areas represent closed bushlands and sparse forest/woodland, respectively, present in central areas of the KRWDA, especially within the Sioma Ngwezi NP and the West Zambezi GMA.

In Figure 3.7, a complementary land use map shows the distribution of dryland/subsistence cultivation across the same area. This land use is virtually absent in the Angolan part of the KRS. Within the KRWDA, some subsistence farming is located on the eastern banks of the Kwando River in the West Zambezi GMA and further downstream in the Namibian part of the river section. Here, the farming is centered around the town of Sikwanyi. In areas north of Katima Mulilo, in Zambia, subsistence farming follows the approximate outline of the tributary channels. This trend continues outside of the KAZA TFCA and is centered around the Barotse Floodplain. Additionally, a stretch is highlighted along the Angola/Namibia border along the lengths of the Cubango River, mostly on the Namibian side. There is no indication of commercial (including irrigated) cultivation within the KRS on the map, though there is information on various initiatives in the upper Angolan parts, e.g., a failed largescale rice farm in Longa (Mendelsohn and Martins 2018).

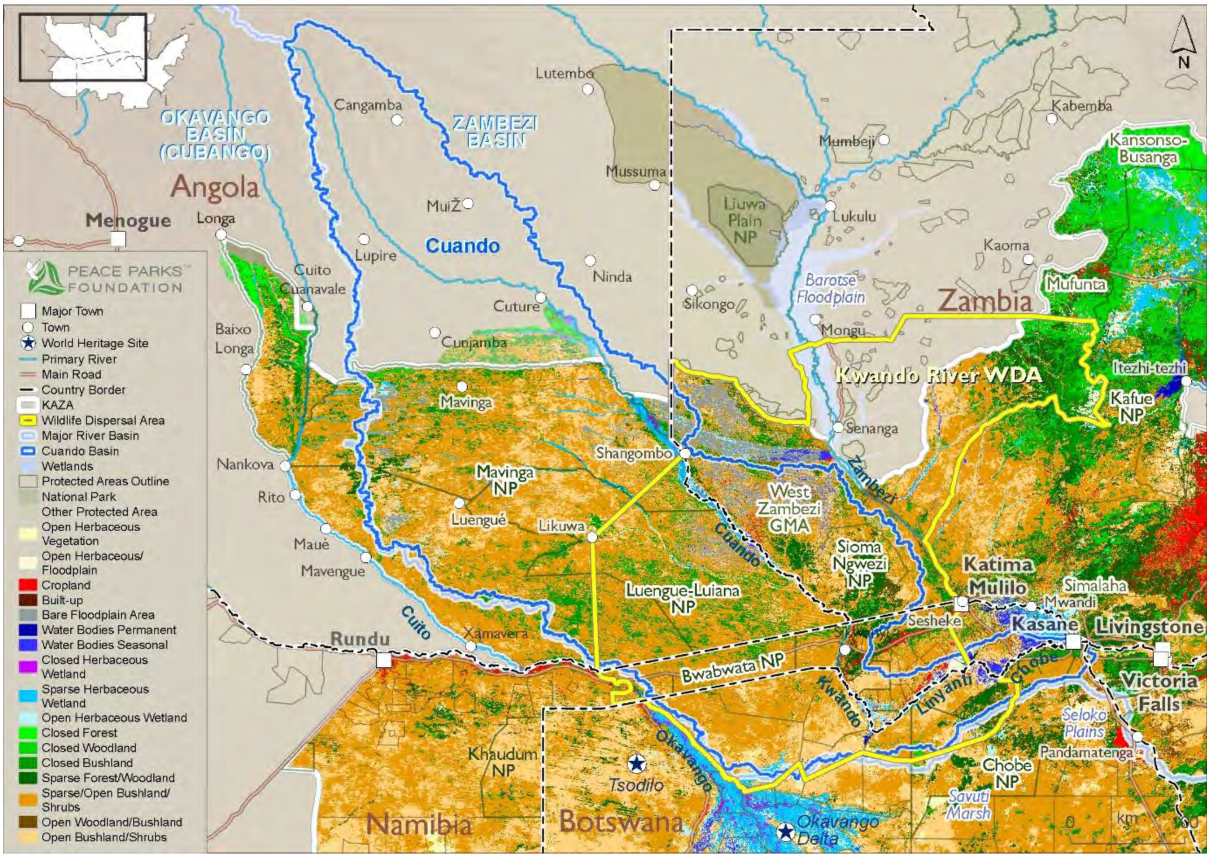


Figure 3.6 Land cover map showing vegetation types across the northwestern parts of the KAZA TFCA. Data not included for the northern part of the KRWDA or upper KRB that lie outside of the KAZA TFCA (Peace Parks and partners[20] 2021).

[20] KAZA Secretariat, WWF, Peace Parks, Wageningen University, GeoTerraImage, and KfW.

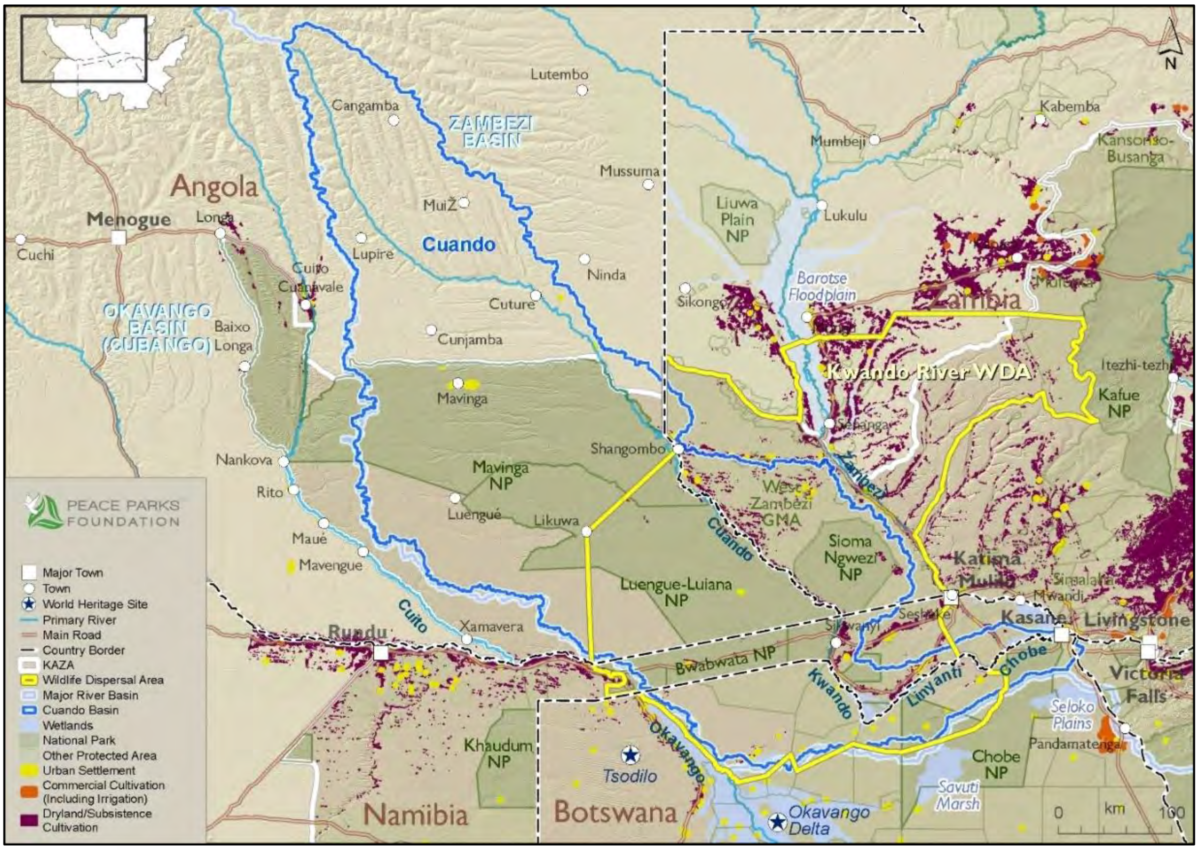


Figure 3.7 Land use map showing the distribution of urban settlements, commercial cultivation, and dryland/subsistence cultivation across the northwestern parts of the KAZA TFCA. Data not included for the northern part of the KRWDA or upper KRB that lie outside of the KAZA TFCA (Peace Parks and various partners[17] 2021).

3.5 Geology

3.5.1 Geological history

The southeastern corner of Angola is dominated by the Kalahari Group. These sediments were deposited 65 Ma ago in the late Cretaceous within a large basin that stretches 2,200 km from South Africa to the Democratic Republic of Congo. There are minor exposures from the underlying Calonda Formation in the upper reaches of the KRB (Mendelsohn and Martins 2018) that date from the earlier Cretaceous period, 113-93 Ma ago (Robles-Cruz et al. 2012).

Further downstream, in the Zambezi Region, the physiography of the Kwando River is more closely linked to the regional tectonic setting and geological structures in the underlying earlier Precambrian crystalline basement rock. The geological map (Figure 3.8) reveals a series of NE-SW trending faults that represent the furthest extension of the southwestern part of the East African Rift zone (Modisi 2000). This area consists of a series of basins that both the Okavango and Kwando rivers flow into along a 250 km (NW-SE) wide and 1700 km (NE-SW) long zone, which is known as the Okavango Rift Zone (ORZ) (Figure 3.9). The orientation of these faults in Figure 3.8 is pre-determined by the subduction of the Kalahari craton (SE) beneath the Congo craton (NW) during the Neoproterozoic, forming the established directional trend in the previous Damara orogenic belt (Kinabo et al. 2007).

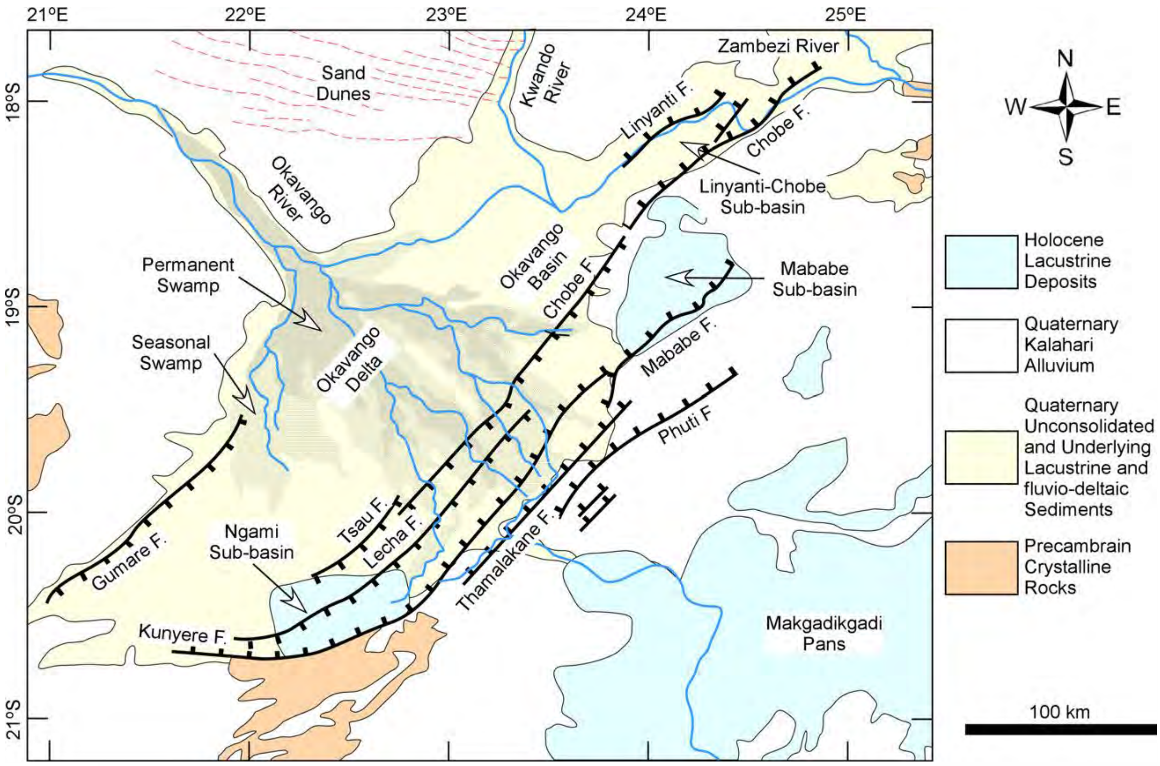


Figure 3.8 Regional geological map highlighting lithology and structural features across the Okavango Rift Zone (ORZ, Figure 3.9) (Bufford et al. 2012).

The ORZ forms part of the larger Makgadikgadi-Okavango-Zambezi (MOZ) Basin, which has manifested as the result of large-scale NE-SW downwardly troughing of basement complexes and the younger Karoo Supergroup. The darker regions in Figure 3.10, produced via Shuttle Radar Topographic Mission-30 (Kinabo et al. 2007), show the regional depressions in topography alongside rivers and major rift faults; these areas are downthrown in relation to the faults. These topographic lows are then filled by incoming sediment that produces large alluvial fans from Quaternary Kalahari alluvium and Holocene lacustrine deposits that support both the Okavango and Linyanti wetland areas (Haddon and McCarthy 2005, Ringrose et al. 2005) (Figure 3.10 and Figure 3.11).

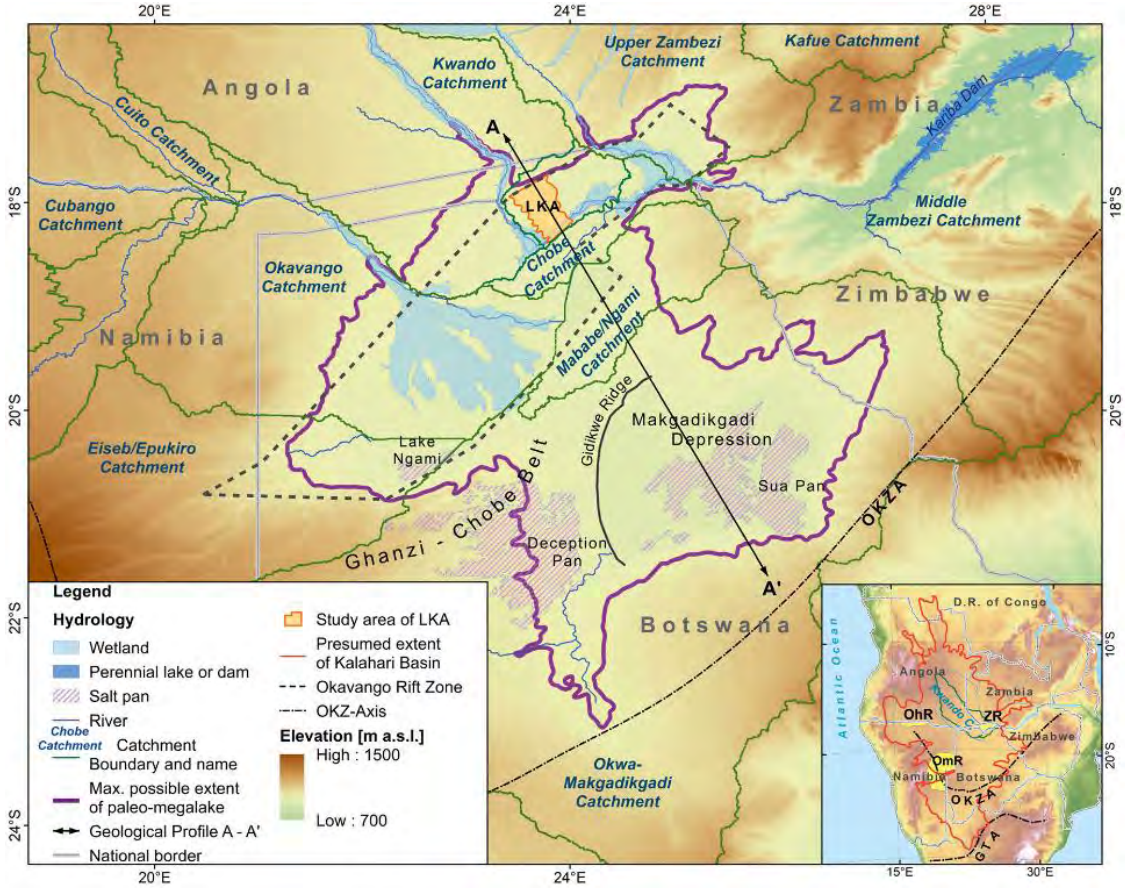


Figure 3.9 Map showing the regional geological structures including the Okavango Rift Zone (ORZ) within the Makgadikgadi-Okavango-Zambezi (MOZ) Basin (Bäumle et al. 2018). Cross-section of the region is shown in Figure 3.12.

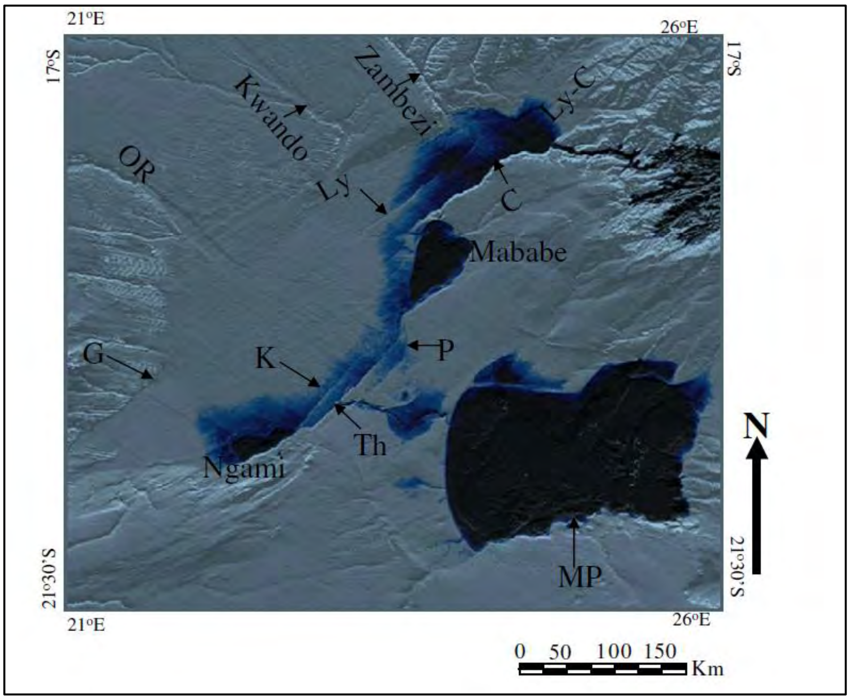


Figure 3.10 Shuttle Radar Topographic Mission-30 (SRTM-30) image showing topographic depressions across the MOZ and occurrence in relation to regional tectonic faulting. Ngami = Lake Ngami, Ly-C = Linyanti-Chobe depocentre, Th = Thamalakane Fault, K = Kunyere Fault, P = Phuti Fault, C = Chobe Fault, OR = Okavango River, Madabe sub-Basin, MP = Makgadikgadi Pan (Kinabo et al. 2007).

The extent of this sedimentation pattern can be measured using airborne magnetic data. Figure 3.11 shows the thickness of the Kalahari sediments at over 400 m in the Okavango Rift Zone. There is a sharp contrast and dramatic reduction in thickness across the NE-SW trending Thamalakane Fault (compare Figure 3.10 and Figure 3.11) with depths decreasing to 200 m. This highlights how the faults have created topographic differences that have led to the accumulation of sediments. Overall, the neo-tectonic activity along these faults has had a great influence on the drainage and sedimentation patterns of both the lower Kwando and Okavango Rivers (Moore and Larkin 2001).

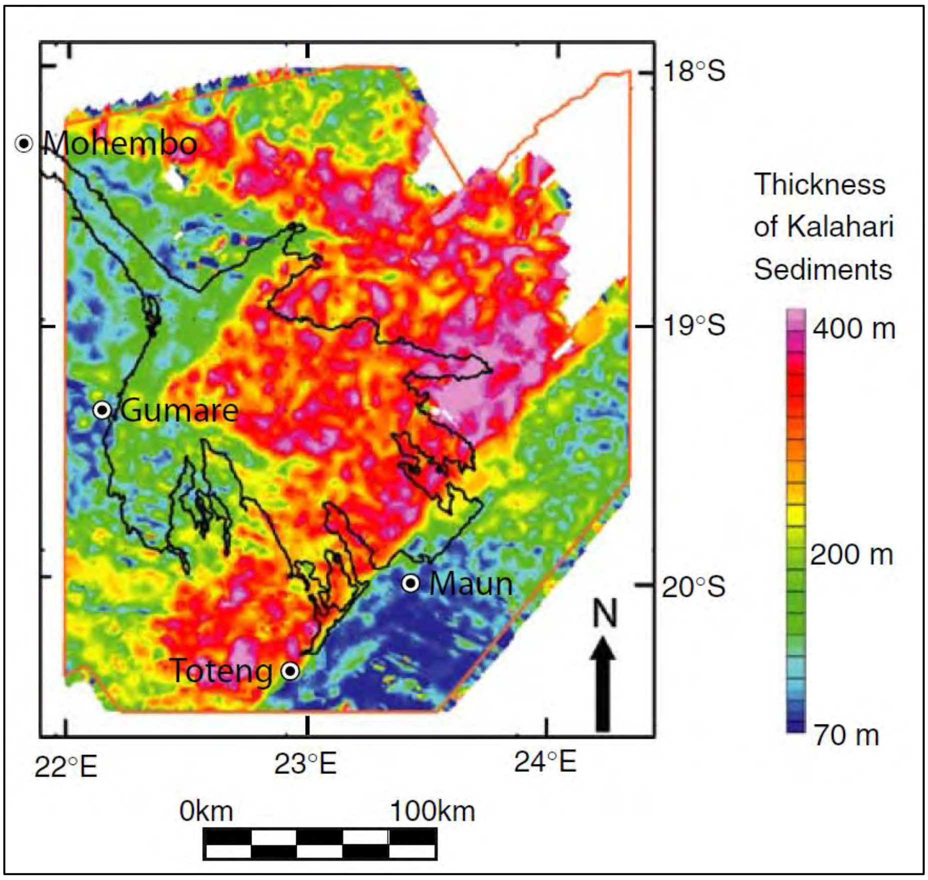


Figure 3.11 Airborne magnetic data showing the range in thickness of Kalahari sediments within the Okavango Delta and surrounding ORZ (Milzow et al. 2009).

3.5.2 Stratigraphy

Given the regional extent and substantial thickness of the Kalahari Group sediments, this group is considered the main water-bearing formation across the region (Christelis and Struckmeier 2001). A summary of the overall stratigraphy is drawn from knowledge of the Zambezi Region in northeast Namibia (Table 3.3) and a cross-section that covers the MOZ (Figure 3.12).

In summary, the main stratigraphic units can be simplified, with the youngest first (Milzow et al. 2009), and the absolute ages summarized in Table 3.3:

1) Kalahari Group sediments
2) Karoo Supergroup (and post-Karoo), are a series of sedimentary and volcanic Carboniferous to Jurassic sequences intruded by dolerite sills.
3) Damara orogenic belt - Neoproterozoic siliciclastic and carbonate sequences

Table 3.3 Summary of the stratigraphy within the eastern Zambezi Region of northeastern Namibia with the nature of the contacts described between the stratigraphic units (Margane et al. 2005, as modified from Christelis and Struckmeier 2001).

Group	Formation	Age	Age (MY)
Kalahari		Recent – Tertiary/? Upper Cretaceous	0-65 (135)
Disconformity (65-130 MY)			
Karoo	Rundu Fm./Kalkrand Fm. (Basalt) Etjo Fm. (Sst) Omingonde Fm.	Jurassic – Permian	135-300
Erosion (300-500 MY)			
Damara	Mulden Group Otavi Group Nosib Group	Namibian – Early Cambrian	500-1000
Pre-Damara	Gamsberg Suite Abbabis Complex Grootfontein Complex Hohenwarte Complex	Cambrian – Precambrian	

In addition, Figure 3.12 shows a schematic representation of these stratigraphic units in a cross-section across the MOZ. The Pre-Karoo Basement corresponds to the Damara and Pre-Damara. It shows the series of horst-graben structures across the region.

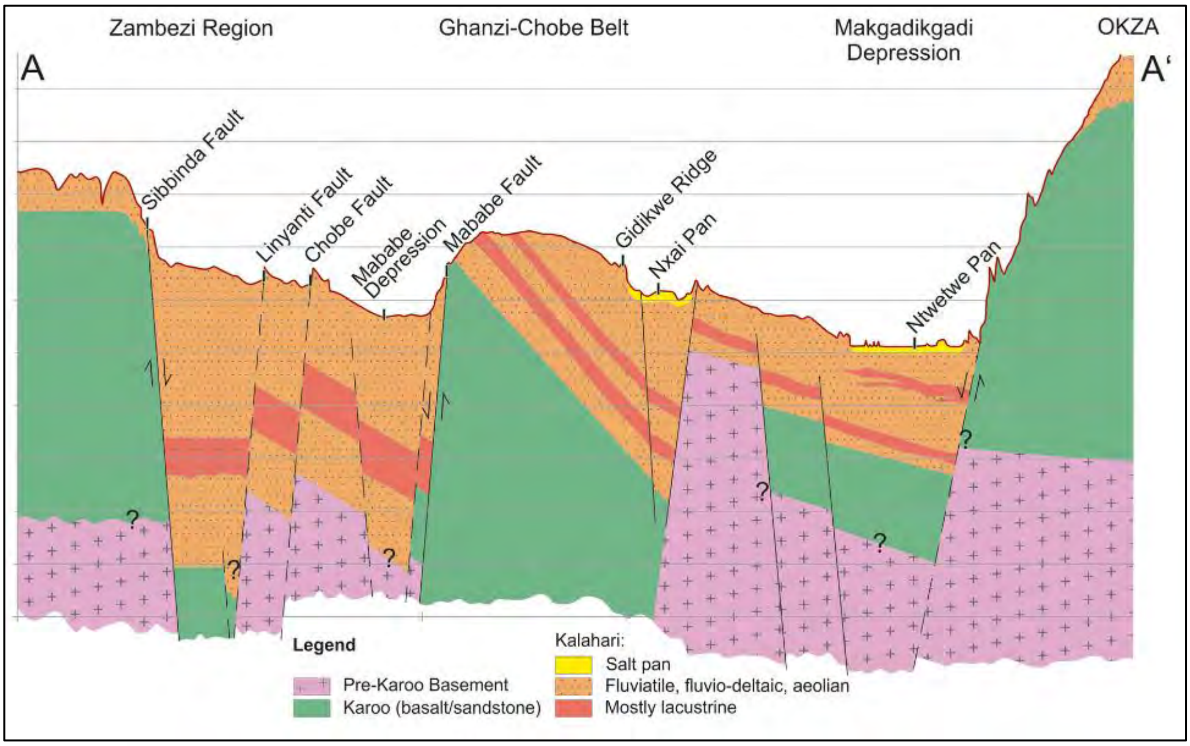


Figure 3.12 Schematic cross-section across the MOZ that covers the ORZ. The lower part of the KRB is located between the Sibbinda Fault and the Chobe Fault. The location of the cross-section is indicated in Figure 3.9 (Bäumle et al. 2018).

The depositional settings of the Kalahari Group represent a predominantly fluvial environment in the late Cretaceous and early Tertiary with the uppermost unconsolidated sediments being reworked in an aeolian environment from the Pliocene to the Quaternary (Haddon and McCarthy 2005). There are significant local variations, but the overall Kalahari Group litho-stratigraphy follows the sequence of basal conglomerates and gravels at the bottom, followed by clay beds, then sandstones and unconsolidated sands. The Kalahari Group is common across the KAZA TFCA, and therefore each Partner State has defined different names for the Kalahari formations. Figure 3.13 shows the comparison of nomenclature across the KAZA TFCA. It is necessary to understand how these names alter across borders to harmonize the description of shared aquifers and enhance multi-partner communication and transboundary cooperation.

3.6 Soils

According to J. Mendelsohn (pers. comm.) (Appendix I), there are two critical characteristics of the soils in the KRB:

1) The soils of the region are generally poor and low yielding in terms of crop production. The soils of the upper KRB are typically acidic, and fertilizers are often required for attaining adequate crop yields.
2) Secondly, Mendelsohn and Martins (2018) describe the sandy, permeable soil in the upper basin as capable of absorbing and attenuating rainwater, acting as a 'sponge' that slowly releases water back into the major rivers and potentially recharging aquifers within the region.

Figure 3.14 shows that the upper parts of the KRB (part of the Angolan highlands) are dominated by Ferralic Arenosols (Qf). The middle part of the basin is covered by Eutric Gleysols (Ge), while the lower parts are covered by Cambic Arenosols (Qc). Within the region, the riverbeds across the lower parts of the Kwando, Zambezi, and Okavango, including the deltaic regions, are dominated by Eutric Fluvisols (Je) (Eutric = having a 50% or more base saturation). Other notable groups covering the KRB/ KRWDA include Humic Podzols (Ph). Each of these soil types is briefly described below.

- **Arenosols** (medium textured Quartzic-sands) in southeastern Angola are leached and typically porous. The mineral and organic content and thus the fertility and quality of the soils are typically poor. The difference between the Ferralic and Albic Arenosols is characterized by the relative abundances of iron and sodium in their respective mineral assemblages. The leaching of the Ferralic Arenosols is responsible for generating acidic headwaters in the KRB (Mendelshon and Martins 2018) (Section 5.1.3).
- **Fluvisols** are composed of the alluvial sediments that flow along the riverbeds and then deposit in the floodplains of the major rivers. Hence their occurrence in the lower segments of the rivers. The fluvisols in the lower floodplains are generally acidic and affected by the deposition of the upstream materials (Mendelsohn and Martins 2018).
- **Gleysols** are usually moist throughout the year with clear redox horizons, the uppermost layers rich in organic material provide greater fertility and are often found in wetland areas. In the gleyic layer, water-saturated iron is reduced and depletes the red coloration leaving a grey layer behind, the depth which acts as a proxy for groundwater levels. They typically occur in unconsolidated sediments that originate from fluvial, marine, or lacustrine depositional settings. Gleysols are often poorly drained or waterlogged because of a high groundwater table or because a constraining layer impedes infiltration/recharge of rainwater.
- **Podzols** generally derive from either quartz-rich sand or sandstone. Podzols have a strongly bleached horizon and are typically acidic and not very fertile. **Humic Podzols** have a spodic B horizon that is strongly acid with high amounts of leached humic substances, iron, and aluminum.

South Africa (Smit, 1977) (Thomas, 1981)*	Southern Namibia (SACS, 1980)	Northern Namibia (SACS, 1980) (Miller, 1992)*	Northeastern Namibia (SACS, 1980)	Zimbabwe (Maufe, 1939)	DRC (Cahen & Lepersonne, 1952, 1954) (Claeys, 1947)*	Angola (Pachero, 1976)	Zambia (Money, 1972)	Botswana (Passarge, 1904)	Botswana (Du Plessis, 1993)
Lonely Fm* (diatomaceous limestone) ***Goeboe Goeboe Fm**** (pan sediments) ***Obobogorop Fm**** (gravels)						***Série Superior*** (unconsolidated sand, duricrusts, pan sediments	***Zambezi Fm*** (limestone and clays on pan floors, duricrusts)	***Alluvialle Bildungen*** (alluvium) ***Decksand***	
Gordonia Fm (unconsolidated sand)		***Andoni Fm*** (clayey sand or sandy clay)		***Kalahari Sand*** (unconsolidated sand)	***Sable Ochres (Etage Superieur)**** (unconsolidated sand)		***Zambezi Fm*** *Mongu sand member* (unconsolidated sand)	***Kalahari Sand*** *(4 subgroups)* (unconsolidated sand)	***Gordonia Fm*** (unconsolidated sand)
Mokalanen Fm* (calcrete)			***Omatako Fm*** (ferricrete and ferruginous sandstone)	***Pipe Sandstone*** (sandstone)	***Grès Polymorphes (Etage Moyen)****		***Upper Barotse Fm*** (massive sandstones and conglomerates)	***Kalahari Kalk*** (limestone, pan deposits)	***Debe Fm*** (calcrete)
Eden Fm (sandstones)	***Weissrand Fm*** (basal conglomerate and sandy limestone)	***Olukonda Fm*** (calcareous sandstone)	***Eiseb Fm*** (silicified and calcretised sand, sandstone and limestone)	***Kalahari Chalcedony*** (silicified limestone)	(silicified sandstones, chalcedonic limestones)	***Série Inferior*** (sandstones and conglomerates, some clay)	***Middle Barotse Fm*** (bedded, ferruginous sandstones)	***Botletleschicten*** (sandstone, sandy limestone) (chalcedonic limestone) (cemented regolith)	***LSL Fm*** (gravel bed) ***Mmashoro Fm*** (sandstone and siltstone) (basal conglomerate)
Budin Fm (clay)		***Beiseb Fm*** (gritty to conglomeratic sandstone)							
Wessels Fm (basal gravels)		***Ombalantu Fm**** (siltstone, mudstone)	***Tsumkwe Fm*** (lime-cemented conglomerate and sand)				***Lower Barotse Fm*** (conglomerate)		

Figure 3.13 Comparison of nomenclature used to describe the Kalahari stratigraphy across international borders in Southern Africa, Fm = Formation. The areas within the blue boxes intersect with the boundaries of the KAZA TFCA (Haddon and McCarthy 2005).

While the exact water retaining and releasing mechanisms are still unclear in the gleysols in the middle part of the basin with extensive floodplains, they are critical for understanding the sustenance of perennial flows in the Kwando River. Water may be retained in the floodplains in shallow saturated gleysols, constrained in downward movement by impermeable layers, or water may cycle in deeper groundwater-linked systems that discharge to the river and tributaries. This will be critical to understanding hydraulic characteristics, the water flow patterns, surface-groundwater interactions, and environmental flows. Currently, there are no soil profiles in the KAZA-GROW database.[11]

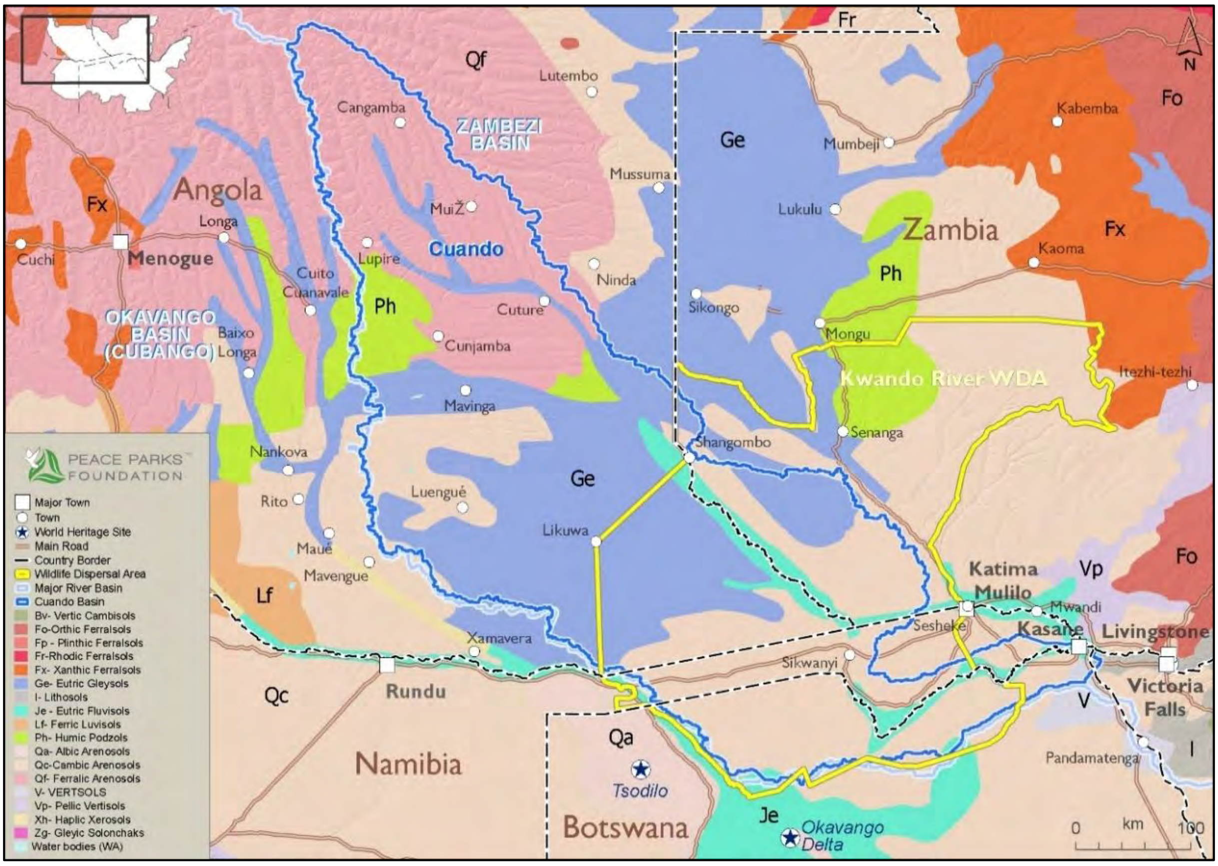


Figure 3.14 Soil map of the northwestern parts of the KAZA TFCA, including the KRB and the KRWDA (Peace Parks (2021) based on FAO-UNESCO Soil Map of the World)[21].

4 SOCIOECONOMICS

This chapter presents the demographics, socioeconomics, livelihoods, WASH provision, infrastructure, and development plans for poverty alleviation in the KRS.

4.1 Demographics

4.1.1 Country and district population

The total population of the countries that are part of the KRS is Angola (34.0 million), Botswana (2.4 million), Namibia (2.6 million), and Zambia (19.0 million) (Worldometer 2021).

[21] FAO-UNESCO, Soil Map of the World, digitized by ESRI. Soil climate map, USDA-NRCS, Soil Science Division, World Soil Resources, Washington D.C.
http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/other-global-soil-maps-and-databases/en/

The districts covered in the KRS include (Figure 4.1 and Table 4.1):

- **Angola:** Bundas (Lumbala-Nguimbo), Cuito Cuanavale, Dirico, Luchazes, Luena, Mavinga, Nancova, and Rivungo
- **Botswana:** Chobe and Ngamiland East & West - Northwest
- **Namibia:** Mukwe, Kongola, Judea Lyaboloma, Linyanti, Sibbinda, Katima Mulilo Rural, Katima Mulilo Urban, Kabbe North, and Kabbe South
- **Zambia:** Itezhi-tezhi, Luampa, Mongu, Mulobezi, Nalolo, Senanga, Sesheke, Shang'ombo, Sikongo, and Sioma

The largest population centers in the KRS are (Worldometer 2021):

- **Angola:** Rivungo (33.1k) and Mavinga (27.2k)
- **Botswana:** Maun (55.8k) and Kasane (9.2k) and Gumare (8.5k)
- **Namibia:** Rundu (63.4k) and Katima Mulilo (28.4k)
  Zambia: Shangombo (100.9k), Sesheke (71.9k), and Sioma (91.9k)

Some of these towns (e.g., Kasane, Gumare, Mongu, Kitwe, and Itezhi Tezhi) are outside the KRS (Figure 4.1) but provide market and employment opportunities for people in the focus area.

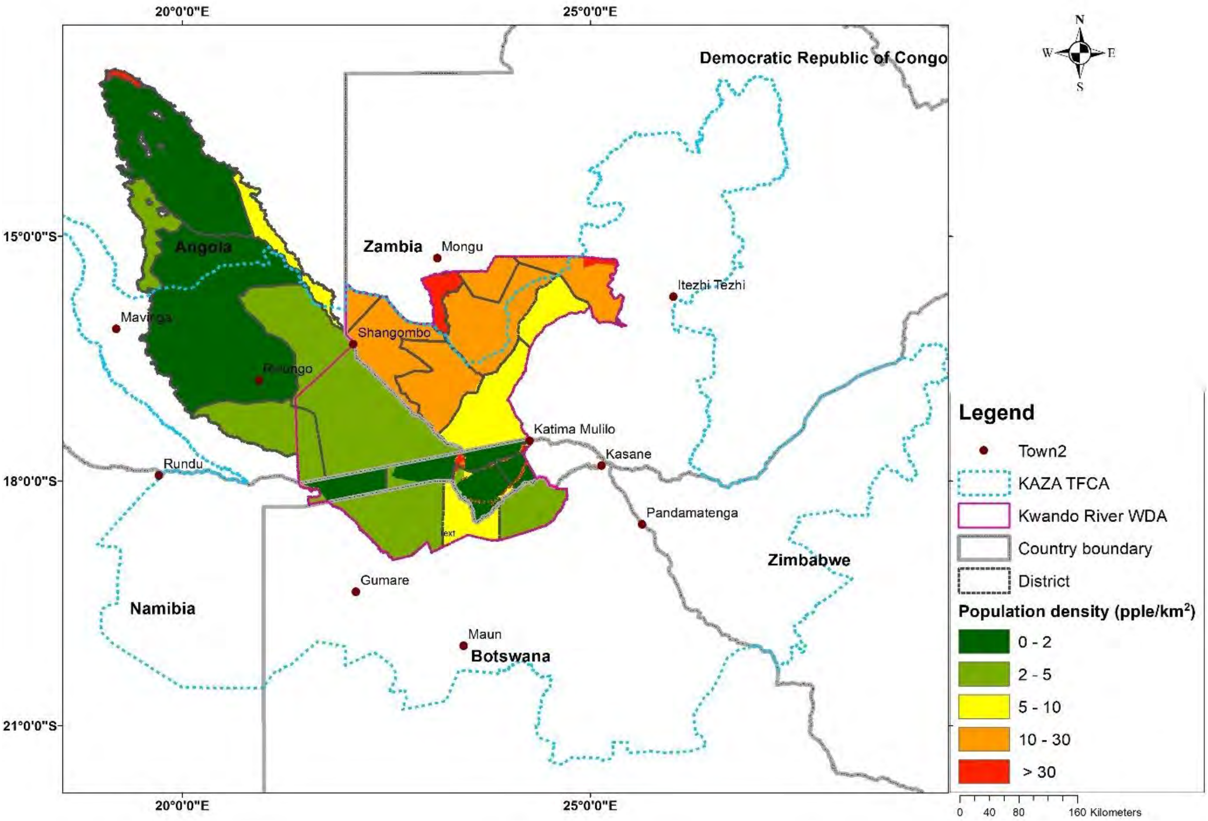


Figure 4.1 Population density per district and major towns in and around the KRS. Table 4.2 gives the names of districts.

The proportion of the area of the KRS in Angola is 55.9%, Botswana 9.6%, Namibia 7.2%, and Zambia 27.3%. Zambia has the highest population in the KRS, with 574,000 people, followed by Angola (103,000), Namibia (49,000), and Botswana (29,000). From this and Table 4.1, an estimated that 755,000 people live within the boundaries of the KRS. The KRB has remained relatively undeveloped, with a population of fewer than 200,000 people (WWF 2020a), indicating that most of the population lives in the KRWDA outside the KRB.

The population density is generally low, with an average of 6.8 people/km^2 across the area (Table 4.1). Population densities in highly urbanized areas can be high, e.g., Katima Mulilo in Namibia, with a density of 641 people/km^2 (not included in Table 4.1). There is generally high population growth in the KAZA TFCA with an average annual growth rate of 2.4% (Table 4.1). This is a strong driver of change, related to the impact of land-use change, which is incremental, but often partially irreversible. There is also increased rural-urban migration, with an above 10% annual growth rate in the urban population over the last decade (CRIDF 2019, Cain 2017).

Table 4.1 Area, population, population density, and growth rate per district in the KRS.

District	Country	Area (km^2)	District area (km^2)	Population[a]	Adjusted district population	Population density (pple/km^2)	Population growth rate (%)[b]
Bundas (Lumbala-Nguimbo)	Angola	43,800	3,921.2	83,155	7,444	1.9	3.0
Cuito Cuanavale	Angola	35,000	4,352.6	48,829	6,072	1.4	3.0
Dirico	Angola	18,300	9,490.1	18,091	9,382	1.0	3.0
Luchazes	Angola	43,000	21,118.8	17,294	8,494	0.4	3.0
Luena	Angola	42,300	511.3	427,672	5,169	10.1	3.0
Mavinga	Angola	44,000	37,127.1	32,532	27,450	0.7	3.0
Nancova	Angola	10,000	40.3	3,345	13	0.3	3.0
Rivungo	Angola	30,000	29,419.4	39,527	38,762	1.3	3.0
Chobe	Botswana	20,800	4,760.5	28,800	6,591	1.4	2.4
Ngamiland East & West (North West)	Botswana	109,130	13,400.3	180,800	22,201	1.7	2.0
Mukwe	Namibia	5,506	3,288.1	27,690	16,536	5.0	1.9
Kongola	Namibia	5,117	5,047.5	7,366	7,266	1.4	1.9
Linyanti	Namibia	1,781	3,741.9	7,328	15,396	4.1	1.9
Sibbinda	Namibia	1,831	1,534.5	11,112	9,313	6.1	1.9
Katima Mulilo Rural	Namibia	1,595	66.6	13,285	555	8.3	1.9
Katima Mulilo Urban	Namibia	4,430	1.6	28,362	10	6.4	1.9
Itezhi-tezhi	Zambia	15,709	63.9	187,704	764	11.9	5.0
Luampa	Zambia	10,722	5,768.7	68,765	36,997	6.4	1.7
Mongu	Zambia	6,360	2,784.3	223,854	98,000	35.2	1.2

Mulobezi	Zambia	12,222	3,869.2	64,152	20,309	5.2	2.6
Nalolo	Zambia	4,869	2,110.4	81,515	35,331	16.7	1.6
Senanga	Zambia	10,668	11,041.6	122,496	126,786	11.5	1.6
Sesheke	Zambia	12,178	8,496.4	71,924	50,180	5.9	2.6
Shangombo	Zambia	8,309	8,210.7	100,954	99,760	12.1	3.0
Sikongo	Zambia	8,114	1,477.5	69,373	12,632	8.5	1.3
Sioma	Zambia	7,899	7,984.4	91,927	92,921	11.6	3.0
Total/average		513,640	189,629	2,057,852	754,335	6.8	2.4

Source: World Bank (2020) and Worldometer (2021)
[a] Angola and Botswana (2020 projection), Namibia 2011, Zambia 2019. The population per district was estimated based on the area proportion method, from the portion of the area that falls in the focus area, district area, and whole district population using ArcMap based on Figure 4.1.
[b] Angola (2014-2020), Botswana (2001-2020), Zambia (2001 -2019)

4.1.2 Poverty levels

Approximately one-third of the 3 million inhabitants in the KAZA TFCA live well below the international poverty line of US$ 1.9 per person per day (CRIDF 2019, Ministry of Environment, Wildlife and Tourism 2013). At the country level, Zambia has the highest poverty level at 54.4% (2015), followed by Angola (32.3%, 2018), Namibia (17.4%, 2015), and Botswana (14.5%, (2015) (World Bank 2021, Statistics Botswana, 2015) (Table 4.2). The poverty levels in Ngamiland (22%) and Chobe (18%) are higher than the country (Botswana) average of 14.5% (Statistics Botswana 2015). The most unequal country in 2015 is Namibia with a Gini index of 59.1%, followed by Zambia (57.1%), Botswana (53.3%), and Angola (51.3%) (World Bank 2020) (Table 4.2). However, in Namibia, pensioners (12% in 2011) receive monthly payments from the government to supplement their cash income (Scovronick et al. 2007), and 33% relied on farm income in 2011 (Knoema 2022). Botswana has the highest Gross Domestic Product (GDP) per capita of US$ 7,971, followed by Namibia (US$ 5,037), Angola (US$ 2,810), and Zambia (US$ 1,305) (Table 4.2). For comparison, the SADC GDP per capita (2019) was estimated at US$ 1,599 (World Bank 2020). The high poverty rates, which are higher in the rural areas, are associated with limited livelihood options and high unemployment rates, combined with low education and skills attainment levels (World Bank 2020, CRIDF 2019).

Table 4.2 Poverty levels[a] and Gini index of the Partner States in the KAZA TFCA.

Country	Poverty level (%)[b]	Gini Index in 2015 (%)[c]	GDP per capita in 2019 (US$)[c]
Angola	32.3 (2018)	51.3	2,810
Botswana	14.5 (2015)	53.3	7,971
Namibia	17.4 (2015)	59.1	5,037
Zambia	54.4 (2015)	57.1	1,305

[a]The poverty rate was based on the population living on less than US$ 1.9 per person per day at 2011 international prices (World Bank 2020). Poverty statistics are compiled using information obtained from household income and expenditure surveys.
[b] World Bank (2020)
[c] World Bank (2021)

4.1.3 Education

Most household heads in the four countries have limited education, due to high costs and long distances to schools (Scovronick et al. 2007), which adversely affects household income and general decision-making (FAO 2014). According to the Department of Environmental Affairs and Centre for Applied Research (2010), over half (52%) of the household heads have never attended schooling in the Botswana portion of the KAZA TFCA. Lack of formal education was reported to be common in most parts of Ngamiland District, which resulted in insufficient knowledge about government support opportunities and lower participation in productive activities meant to improve the livelihoods of the household members (Ministry of Environment, Wildlife and Tourism 2013). The most commonly completed level of education by adults in Sioma Ngwezi was grade 7, while in Central Caprivi and Bukalo-Masida, it was grades 10 or 12 (Scovronick et al. 2007). The reasons for low education levels are poor performance at primary school and junior school, and few senior secondary schools (e.g., there is one senior secondary school servicing Letlhakane and Maun and two new (only opened in 2012) senior secondary schools and higher learning institutions opened in Nata and Shakawe (FAO, 2014). The literacy rate (> 15 years of age) in Angola was 46% and Namibia was 81% (Knoema 2022). Shortages of schools and teachers and a lack of basic teaching and learning materials forced the education system to turn away tens of thousands of registered students (Women's Commission for Refugee Women and Children 2003). In Angola, Women's Commission for Refugee Women and Children (2003) and in Botswana, Knoema (2022) reported that girls were less likely to go to school because of a) fears about their safety, especially if they travel a long distance; b) cultural preferences for boys' education; and c) a lack of female teachers.

4.1.4 Health

Household health is low in the focus area due to high incidences of diseases such as bilharzia, malaria, diarrhea, cholera, typhoid, tuberculosis, measles, and HIV, and due to inadequate access to health care (Scovronick et al. 2007).

4.2 Transport infrastructure and water and energy services

4.2.1 Angola

In Angola, 6 out of the 18 Angolan provinces fall into the KRB in southeastern Angola. The six provinces are Huambo, Huíla, Bié, Cunene, Moxico, and Cuando Cubango, the latter being the only province that lies entirely within the basin. There are tarred roads linking different portions of the area in Angola (Figure 4.2). Angola has made a significant effort to rebuild its dilapidated road network during the first post-civil war years. Benmaamar et al. (2020) reported that Angola's infrastructure public expenditure is at par with the average expenditure of lower and medium-income countries (4.0% of GDP for 2011) and is nearly twice more than Sub-Saharan African countries (2.5% of GDP). Half of the population is located further than 2 km from any road, resulting in poor access to agriculture production to main markets and poor access to social services (health care centers and schools). There is an airport located outside the focus area at Menongue. There is generally low coverage of electricity (about 9.9%), while water supply was about 25% in 2012 (Knoema 2022).

4.2.2 Botswana

In Botswana part of the focus area, infrastructure is linked by tarred roads of an acceptable standard. These are roads that lead to key tourism hotspot areas and are also service transit routes that link to major towns (Kasane, Nata, Letlhakane, Maun, Gumare, and Shakawe) outside the focus area. The primary road network covers most settlements and towns. Grid electricity, telecommunication, and water supply are almost universally available in villages and towns. At the country level, the proportion of the population with access to electricity (2015) was 64.5% (World Bank 2020).

Many tourism facilities and activities are located within the Okavango Delta, the Linyanti area, and the Chobe riverfront. There are two international airports outside the focus area (Maun and Kasane) and numerous airstrips in the area. These are mainly used to support tourism and mining activities (Ministry of Environment, Wildlife, and Tourism, 2013).

4.2.3 Namibia

The Namibian area of the KRS is relatively small, yet centrally located. It is linked by tarred roads to the other KAZA TCFA countries and larger settlements (Figure 4.2). The majority of towns and communities can be accessed by a network of quality gravel trunk, main, and district road networks including tarred roads. The focus area is linked by road and air to Angola, Zambia, Zimbabwe, Botswana, and South Africa. Approximately 200 km of the Rundu-Divundu road on the Trans-Caprivi highway in Kavango East require light rehabilitation. Namibia has invested heavily in the modernization and expansion of its telecommunications to service the rural areas as well (Embassy of the Republic of Namibia 2022). Namibia produces electricity from hydro and thermal energy sources. Electricity and water supply coverage is relatively moderate in most areas (Scovronick et al. 2007).

4.2.4 Zambia

The Zambian part of the focus area is linked by tarred roads to the other KAZA TCFA countries, industrial areas, and settlements (Figure 4.2). Three of the roads (Senanga-Sesheke, Kabombo-Chavuma, and Kalulushi-Lufwanyama) that form part of the Trans-African Highways stretch from Cape Town to the DRC’s Katanga Province and onwards to Kinshasa are being funded by Development Bank of Southern Africa (DBSA 2022). The Senanga-Sesheke road forms part of a strategically important regional link as a shorter route (Western Corridor) from the copper-producing region of Zambia around Kitwe up to the DRC in the north, Botswana and Namibia to the south, and Angola to the west. The development and rehabilitation of these three roads in the Western Corridor fit into the wider corridor network program for the SADC region, which will open up regional markets. The electricity and water supply are poor, especially in rural areas (e.g., Sioma Ngwezi), while in towns (e.g., Katima Mulilo, Shesheke, and Sioma), there is high coverage (Scovronick et al. 2007).

Figure 4.2 Main roads, districts, and national parks in the KAZA TFCA (Peace Parks 2021).

4.3 Economics and livelihoods

4.3.1 Main livelihoods in the KAZA TFCA

The concept of the KAZA TFCA is founded on the idea that wildlife and nature-based tourism are going to create a local economy that is going to grow and uplift everyone, not only those involved in tourism (CRIDF 2019, Cain 2017).

In the KAZA TFCA, the livelihood strategies of most inhabitants (more than 70%, mostly rural) depend on natural resources (e.g., forestry and forestry products), subsistence and commercial farming, livestock, fisheries, and tourism-related activities (Scovronick et al. 2007, CRIDF 2019). Residents in towns function in a cash economy, the majority engaged in informal trade and services, and public services (CRIDF 2019, USAID 2016). Cash also forms much of the income of peri-urban residents and rural residents who live close to major trunk roads where they produce and sell vegetables, charcoal, and wildlife /game meat. The gender perspective was noted in the different livelihood activities, for example, men typically produce charcoal and hunt and harvest and sell honey and game meat, while women are involved in the collection of firewood for cooking at home, crop production, and collection of water for household use, i.e., less income-generating activities (CRIDF 2019, OKACOM 2011a). Rural households derive little income from employment and business and highly depend on agriculture and natural resources for their livelihoods (Scovronick et al. 2007). Human-Wildlife Conflicts (HWCs) in the form of human and livestock attacks and destruction of crops are prevalent, especially in local communities, affecting livelihoods incomes. HWCs might affect tourism as most animals that attack humans and destroy crops have high tourism attractions. Further discussion on HWCs is provided in Section 7.2.1.

The main economic sectors within the KAZA TFCA are wildlife-based tourism, agriculture, and mining (Ministry of Environment, Wildlife and Tourism 2013). Wildlife-based tourism is the main economic driver of the area, with numerous tourism enterprises in the form of hotels/lodges and safari camps in several protected areas (Figure 4.2). More than 300,000 tourists visit these areas annually (Spenceley 2010). Nature-based tourism (photographic, trophy hunting, etc.) now contributes about as much to the GDP of southern Africa as agriculture, forestry, and fisheries combined.[22] Reasons for border crossing included visiting relatives, employment and shopping (i.e., Zambians entering Namibia), and tourism (Scovronick et al. 2007). The KAZA visa (KAZA UNIVISA[23]) allows people to travel freely between the countries (at present Zambia and Zimbabwe[24]) stimulating tourism and free flow of goods and services among the five KAZA TFCA countries and has been gauged as a success in terms of tourism.[25]

In terms of agriculture, the KAZA TFCA comprises both commercial and small-scale or subsistence farming. Commercial farms in the Pandamatenga area (Figure 3.7) supply most of Botswana with sorghum, sunflower, and horticultural produce (Ministry of Environment, Wildlife, and Tourism, 2013). The area contains Botswana's only large area with fertile black cotton soils and relatively high average rainfall (FAO 2014). Furthermore, subsistence farmers specialize in flood recession farming (Molapo farming) along the rivers in the Okavango Delta, especially the Boteti River and in the Chobe Enclave bordering the Zambezi Region in Namibia. Subsistence farming is prevalent in all KAZA TFCA countries, with a particularly good potential for expansion to more commercial small-scale farming (rainfed or irrigated) in the Angolan part of the KRB. Large-scale commercial agriculture is not deemed feasible, due to relatively poor soils and lack of markets and infrastructure (Mendelsohn and Martins 2018). Commercial and smallholder livestock farming is also prevalent in the KAZA TFCA with ongoing issues of wildlife-livestock health (Section 7.3) and HWC's. Other nature-based economic sectors of relevance in the KAZA TFCA are traditional and commercial fishery and forestry (KAZA TFCA 2014).

Mining includes the diamond mines of Letlhakane, Damtshaa, and Karoe, copper mines of Dukwi and Toteng, and the soda ash mine in Sowa in Botswana. Mining exploration is continuing, and other potential oil and mineral deposits have been discovered in the North West (Ngamiland) District (Ministry of Environment, Wildlife, and Tourism 2013) and northeastern Namibia. The discovery of these mineral and fossil fuel resources has resulted in a heated debate in the media around sustainability[26]and could have severe consequences on water, including groundwater, resources, and ecosystems, as well as tourism income.

4.4 Water and sanitation provision

Increasing population and urbanization in the KAZA TCFA lead to increased demand for services related to water supply, sanitation, and hygiene (WASH). This could result in increased water scarcity and pollution if not properly managed or regulated, especially in urban areas (OKACOM 2011a).

[22] http://www.wcs-ahead.org/workinggrps_kaza.html

[23] The Kaza UniVisa is a visa that is available to 65 nations and allows visitors to Zambia and Zimbabwe to cross the borders, of these two countries, as many times as they like over a period of 30 days. As of 2017 the governments print 50,000 unified visas for foreign visitors to their countries. It also allows for day trips into Botswana to view attractions such as the Chobe National Park, provided you return to Zimbabwe or Zambia that same day (https://wildandisle.com/what-is-a-kaza-univisa/).

[24] https://victoriafalls24.com/blog/2020/01/20/botswana-and-namibia-join-the-kaza-univisa/

[25]https://www.sadc.int/files/5315/9781/9415/Zambia_SADC_Success_Stories_Stimulating_Tourism_with_a_Univisa.pdf

[26] For example: https://www.kfw-entwicklungsbank.de/International-financing/KfW-Development-Bank/Our-topics/Biodiversity/KAZA/

Unfortunately, there is a data gap in WASH statistics for the various countries in the KAZA TFCA. Sanitation in rural areas of the focus area is still very low, while the coverage in urban areas is higher, with a third of the population still facing water supply challenges (Scovronick et al. 2007).

4.4.1 Water access

The majority of rural households obtain their water from open sources in the form of rivers, streams, and shallow wells. Over the years, different modes of access have been promoted including communal standpipes, protected shallow wells, boreholes, bulk water supply to settlements, industry, and direct abstraction for agriculture (Knoema 2022). In Namibia, CRIDF worked with communities to develop water supplies close to their homes and away from the rivers that typically are areas conducive to HWC's. Under the umbrella term 'water for livelihoods', CRIDF conducted feasibility studies for water supply provision in Namibia, Zimbabwe, and Zambia, and subsequently constructed boreholes for communities in Namibia (CRIDF 2019) (Box 2).

Box 2. Water for livelihoods in parts of the Kwando River system

Through 'water for livelihoods' projects, CRIDF realized that the projects may be unsustainable unless remote communities could find economically rewarding uses for the water supplies, such as use in the tourism sector and supplying agricultural produce to hotels, restaurants and other businesses in the area. The approach emphasized the importance of multiple water uses (van Koppen et al. 2020) in rural communities to co-support domestic use and livelihood strategies.

As part of this approach, CRIDF and the KAZA TFCA Secretariat built climate resilient groundwater infrastructure, such as water points for portable uses and livestock watering in the KAZA TFCA portion of Namibia. This infrastructure was separated to avoid possible contamination of the portable water by livestock. These water points also included solar-powered pumps, storage tanks, and garden irrigation systems. The infrastructure was located within communal conservancies, where local communities have taken on the ownership and long-term management of their natural resources through CBNRM. This project showed the importance of active participation by local communities. As another example, in Maun, Botswana, CRIDF supported pro-poor outcomes by ensuring that local communities and smallholder farmer collectives are included in value chains along with larger farmers. This pilot demonstrated how local producers can participate in tourism-driven value chains without placing strain on the natural resources of conservation areas. These experiences need to be evaluated for further out-scaling to other communities.

Source: CRIDF (2019)

4.4.2 Sanitation access

Throughout the ORB, there is a trend toward increasing urbanization associated with population growth, partially driven by a lack of alternative livelihood options (Mendelsohn and Martins 2018). Although the population in the basin is predominantly rural, Angola has an urban population of about 40%, Botswana 30%, and Namibia 20% (USAID, 2016). Urban areas enjoy better sanitation access than rural areas.

In Angola, access to sanitation services is limited. There are no wastewater treatment facilities in the urban areas and solid waste is often dumped in the river (OKACOM 2011). While basic access to drinking water in urban areas reaches 70% (90% for sanitation), in rural areas it averages under 37%

(Knoema 2022) (27% for sanitation). For the population below the median wealth level and for the poorest, water access falls to 30% and 15%, respectively (these figures are 33% and 9%, respectively, for sanitation). Drinking water coverage has seen little improvement in the past decade (partly due to population growth and rural-to-urban migration), and 6 million people continue to practice open defecation. However, there is reduced reliance on open defecation and decreasing rates of water-borne disease in the focus area (Knoema 2022), despite the leading cause of death among children under five in Angola being diarrheal disease. The rate of stunting in children under 5 years at the country level is 37.6%, with some provinces peaking well above 40% (Serrat-Capdevila et al. 2020).

In Botswana, there is a relatively new sewage treatment plant in Maun that was designed in 1993 but currently experiences regular breakdowns and may be reaching its capacity (OKACOM, 2011). Other wastewater treatment facilities in Botswana include a 100 m^3/day plant at Boro Farm, a constructed wetland facility at Thuso Rehabilitation Center, and a new sewer network and treatment plant at Gumare (Masamba 2009). Within the Okavango Delta, each camp or lodge has its own wastewater disposal facility, such as a septic tank. There is concern that localized water pollution and eutrophication are occurring in the wetlands around tourist facilities (OKACOM 2011). In Namibia, approx. 82% of the rural population have no access to sanitation services and the majority use open defecation, although some have access to pit latrines and septic tanks. Only 15% of the inhabitants of Rundu are connected to a central sewer system (OKACOM 2011).

The USAID Southern Africa Regional Environmental Program (SAREP) increased access to safe drinking water supply and sanitation. In collaboration with SADC and OKACOM, SAREP provided communities surrounding the Okavango River with easier access to clean water, reduced contamination, and improved sustainable environmental management (USAID 2016). For example, the number of people in the KAZA TFCA with improved access to drinking water and sanitation due to SAREP was 30,535 and 35,510 people, respectively. In Caiundo in Angola, to the west of the KAZA TFCA, 5,260 people realized improved water supplies (USAID 2016). In the KAZA TFCA, more than 5,000 school children benefited from improved sanitation services as a result of the WASH management program (USAID 2016).

According to WHO and UNICEF (2017), at the country level, 31% of households in Zambia accessed improved sanitation facilities, 12% accessed limited sanitation facilities, and 41% accessed unimproved sanitation facilities (Ministry of Water Development, Sanitation and Environmental Protection 2019). In 2015, it was estimated that 15% (25% in rural areas) practiced open defecation, which was defined as the disposal of human faces in fields, forests, bushes, open bodies of water, beaches, or other open spaces (WHO and UNICEF 2017, Ministry of Water Development, Sanitation and Environmental Protection 2019).

In summary, with projected increases in population and urbanization, local sanitation might fall short or deteriorate further due to overloading, threatening potable supplies of water, the environment, and public health (OKACOM 2011).

4.4.3 Water use for portable water supply, irrigation, livestock, and wildlife

For the KRS, no separate consistent data for water use by sector are available. To give some indications, the water uses per country and by different sectors in the ORB were used as a proxy and are shown in Table 4.3 (FAO 2014). The total water use in the three countries was 132.9 million m^3 per year, with the highest water use in Namibia (68.4 million m^3 per year), followed by Angola (51.9 million m^3 per year) and Botswana (12.7 million m^3 per year) (FAO 2014). It is seen that irrigation is the largest water user in Angola and Namibia, while in Botswana, it is settlements. No, or limited, quantitative information is available to assess water abstraction from large irrigation schemes.

Livestock is the second-largest water user. Tourism water use is very low, from an abstraction point of view, but high non-consumptive use, such as tourist boats for leisure and fishing is present. In some areas, e.g., the Zambezi-Chobe Floodplain WDA, water quality, riverbanks, and fish stocks are believed to be affected by noise, wave, propeller, and fuel pollution associated with mass boat tourism (KAZA TFCA 2014). It is seen from Table 4.3, that groundwater, estimated as the difference between 'estimated total water use' and 'estimated river water use', is high in Namibia and Botswana, and less in Angola (30.1, 8.7, and 4.1 million m^3/year, respectively, or 44%, 68%, and 7.9%, respectively). On average for the region, it is 34%. The figures provide an estimate of the average per person use for all the countries of 10 L/day. Since these data derive from public water supply and the figure is relatively low, it confirms that many, most populations, rely on open natural sources to cover their water needs.

Table 4.3 Annual water use by sector and country in the Okavango River Basin used as a proxy for the focus area (in 1,000 m^3/year) Figures in parenthesis indicate water use per person (in m^3/year).

Sector water use	Angola	Botswana	Namibia	Basin
Irrigation	34,835.4 (1.1598)	620.0 (263.605)	43,100.0 (16.9618)	78,555.4 (2.0802)
Livestock	13,163.8 (0.4005)	4,900.0 (2.0833)	14,500.0 (5.7064)	32,563.8 (0.8623)
Settlements	3,935.2 (0.1197)	6,850.0 (2.9124)	8,220.0 (3.2349)	19,005.2 (0.5033)
Mining	0.0 (0.0)	-	0.0 (0.0)	0.0 (0.0)
Tourism	0.2 (0.0)	280.0 (11.9048)	2,530.0 (0.9957)	2,810.2 (0.0744)
Other (e.g., aquaculture)	0.1 (0.0)	-	-	0.1 (0.0)
Total water use	51,934.7 (1.5800)	12,650.0 (537.8401)	68,350.0 (26.8989)	132,934.7 (3.5202)
River water use	47,825.4 (1.4550)	3,994.0 (169.8129)	38,270.0 (15.0610)	90,089.4 (2.3857)

Source: FAO (2014). The table refers to water abstractions from public supply and excludes self-supply by local people and environmental water use (e.g., human use from natural sources and wildlife water use).

4.5 Future development plans

4.5.1 Livelihood improvement and KAZA TFCA poverty reduction plans

Livelihood improvement and poverty reduction of local communities through tourism-related activities became an objective of the KAZA TFCA for the first time in its Master Integrated Development Plan (MIDP) 2015-2020 (KAZA TFCA 2014). Evidence-based pilot projects are planned to persuade investors to support the expansion of these livelihood improvement initiatives across the KAZA region (CRIDF 2017). The MIDP advocates for (KAZA TFCA 2014):

1. Conservation agriculture that, with a resultant increase in yields and reduced production costs, are economically attractive.
2. Improvements in local food security through the introduction of new crop varieties, including chilies, cassava, maize, sorghum, millet, cowpeas, soya beans, groundnuts, and rice.
3. Market linkages have the potential to boost community income and contribute to more environmentally friendly sourcing. With support from the private sector, small-scale producers

could supply the tourism industry, especially lodges, which currently source most food and other products from outside the KAZA TFCA region (CRIDF 2019).

4. Further support for Community Based Natural Resource Management (CBNRM), which is widespread throughout the KAZA TFCA, has helped ensure development at the lowest levels. This includes community conservancies and community forests.
5. Programs supporting value addition for non-timber forest products, fish, livestock, game, timber, and agricultural products. Value addition significantly boosts the economic value of products, but such programs require skills training, branding, and policies that promote open borders for the movement and trade of agreed products. Also, the environmental footprints of these activities need to be carefully considered.
6. The development of cultural tourism. The KAZA TFCA has a wealth of cultures whose customs, dress, festivals, and music could be packaged and promoted to the tourism sector. Small, Medium, and Micro Enterprise (SMME) development has the potential to increase indirect tourism opportunities for local communities. Products and services include soap and natural oils, textile, traditional cuisine, village or township guided tours, taxis, and many others. The development of successful SMME programs would require investment in financing and skills training for entrepreneurs.

Especially the natural resource-based livelihood strategies, like horticultural produce production for the tourism sector, require access to and development of water resources. In an already strained context, it would be advisable to emphasize those livelihood strategies that are less water-intensive and climate-resilient, e.g., cultural tourism, and value addition to natural resource-based production. Another livelihood option is to train local people in supporting park rangers and staff at tourist lodging. Finally, developing livelihood options for the growing urban populations is critical.

Many agricultural products in the KAZA TFCA partner states are protected by an import/export tariff or a non-tariff trade barrier in the form of a trade quota or ban. These tariffs aim to protect the KAZA countries' development goals and local industries by limiting the outflow of raw materials and unique genetic resources but do place a prohibitive financial and administrative challenge on businesses wishing to access markets beyond their country's border (CRIDF 2019).
Actions proposed to enhance local economic growth include (CRIDF 2017):

- Awareness-raising of local governments of the local economic opportunities provided by the tourism industry to stimulate alternative livelihoods through local (intra KAZA TFCA) sourcing of products
- Investment in local agricultural enterprises to ensure quality and reliability in the supply of produce to the tourism sector
- Create a regulatory environment conducive to easy transboundary trade through relaxed tariffs and barriers among the KAZA Partner States

4.6 Recommendations to improve socioeconomic conditions

From this chapter, the following recommendations to reduce poverty through livelihood approaches for local communities emerge:

- Supporting local value chains for the tourism sector through regulatory allowances for cross-border trade and sustainable infrastructure. The KAZA TFCA governing body (KAZA Joint Management Committee, Section 8.3.2) is in a good position to champion an overall effort toward such support.
- Combining climate-resilient groundwater infrastructure, conservation agriculture, and local value chains for agri-products demanded by the tourism sector. This should be done incrementally and as part of climate and water-smart strategies.

- Improved access to healthcare, infrastructure, such as roads, schools, electricity, and other basic services (e.g., telecommunications, water, and sanitation), especially in rural areas
- Piloting alternative livelihoods, especially less water-intensive, more climate-resilient, and more service-oriented ones, in growing urban areas and/or linked to the tourism sector, to build an evidence base for potential livelihoods that minimize conflicts between people and wildlife in the KAZA TFCA while reducing water and environmental footprints.

5 WATER RESOURCES

5.1 Surface water

5.1.1 River catchments

The Kwando River is the most westerly tributary within the larger Zambezi River Basin and is located east of the upper parts of the ORB, composed of the Cubango and Cuito sub-basins (Figure 5.1). These two rivers join close to the Namibian border and the waters go on to feed the inland Okavango Delta. The Western Zambezi (the given name for the area east of the upper KRB though not a strict sub-basin of the Zambezi) drains towards the Barotse Floodplain and then directly into the Zambezi River, flowing east of the Kwando River and through the KRWDA (Figure 5.1). According to Mendelsohn and Martins (2018) definition, the boundary between the upper and lower KRB is defined by the KAZA TFCA border and the beginning of Mavinga NP to the south of that boundary (Figure 5.1). The upper reaches of each of the basins, and thus their headwaters, lie outside of the KAZA TFCA boundary. Consequently, from a water resources perspective, the KAZA TFCA needs to enhance those mechanisms that ensure that a whole-of-the-basin (e.g., Kwando River) approach is incorporated into water-related strategies and management plans. This is because the upstream-downstream linkages and dynamics directly affect the quantity, quality, and timing of the surface waters that reach downstream and into the KAZA TFCA, with important consequences for ecosystems, humans, and wildlife.

The Kwando River originates in the Angolan highlands from several tributaries that include the Kembo, Cubangui, Cussivi Cueio, and Lomba (Figure 5.2). As it flows into the KAZA TFCA, other significant tributaries join the river, including the Cubia, Luengue, Utembo, and Luiana, which contribute as it moves in a southeasterly direction along the border with Zambia. From Angola, it then crosses the Zambezi Region within Namibia and aligns with the Namibian-Botswana border heading southeast. It then widens significantly as part of the Linyanti swamp region before turning sharply eastwards along the Linyanti River. The Linyanti River then goes on, to drain eastwards into Lake Lambiezi, which feeds the Chobe River and then ultimately the Zambezi River. The Kwando, the Linyanti, and the Chobe Rivers are the same river, but with different names for the different segments (Figure 5.3). The Zambezi River flows into the KRWDA after emerging from the Barotse Floodplain, then flows along the western edge of the Lower West Zambezi GMA and the Sioma Ngwezi NP and leaves the KRWDA as it meets the Namibian border (Figure 1.3 and Figure 5.5).

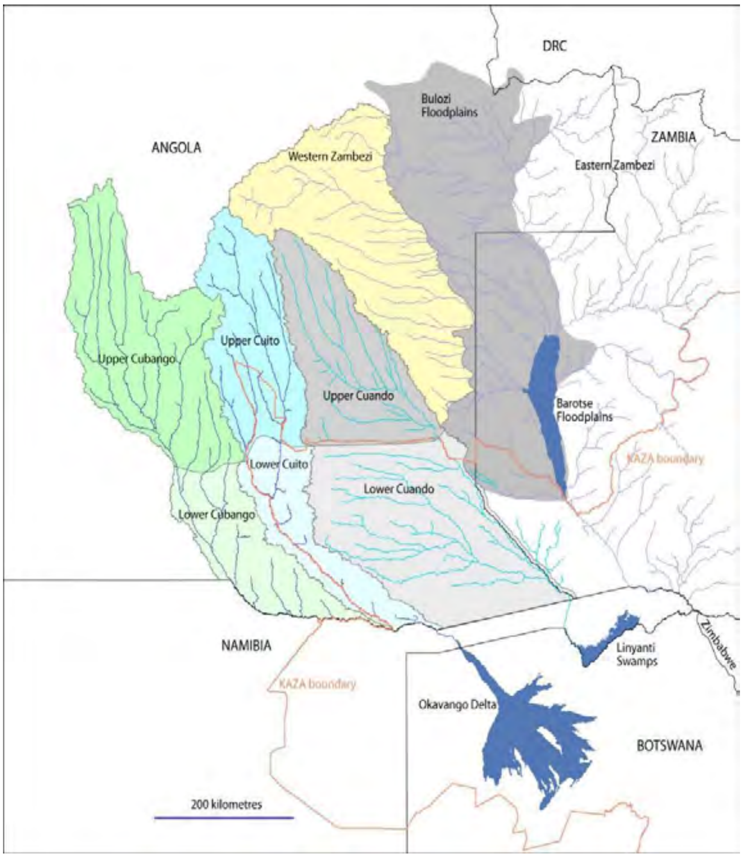


Figure 5.1 Map of river basins and upstream tributaries supplying surface waters to the KAZA TFCA from Angola and Zambia in relation to its northern and western boundaries (Mendelsohn and Martins 2018).

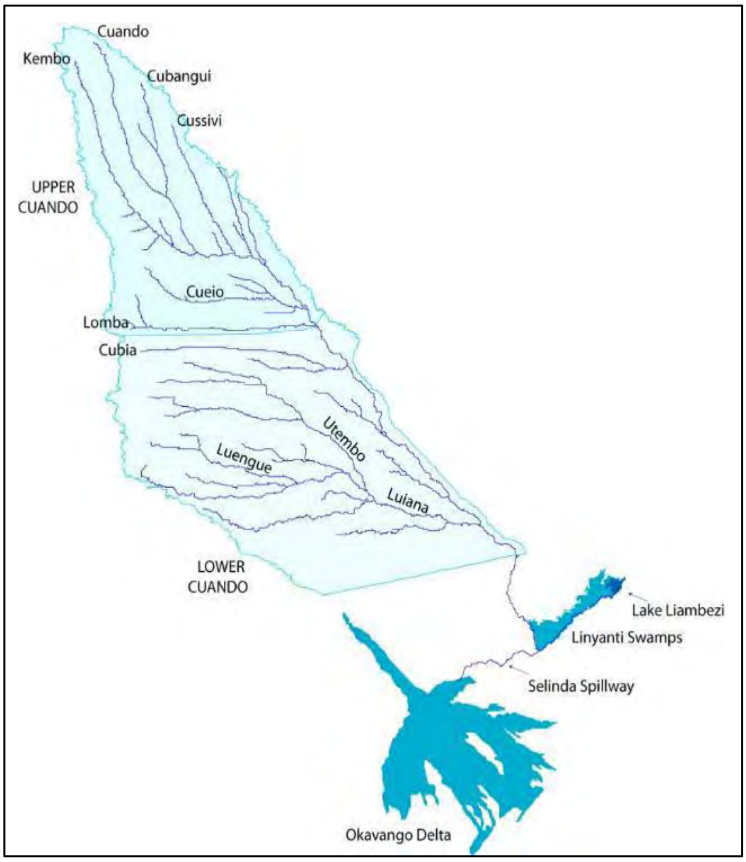


Figure 5.2 Tributary network in the KRB (Mendelsohn and Martins 2018).

Generally, the Kwando River terminates along the stretches of the Linyanti River section before it reaches Lake Liambezi (Kurugundla et al. 2010). During occasional flooding events, principally 2008/9 and 2009/10, the waters of the Kwando River reached the confluence with the Zambezi. In these cases, there was a large overflow from the Okavango via the Selinda spillway (Figure 5.2 and Figure 5.3) providing enough discharge for this seldom event to occur (Kurugundla et al. 2010). As such, and with reference to KJAG interaction during the project, there is a broad discussion about whether the Kwando should be described as a terminal / endorheic system, similar to the Okavango, ending in Lake Liambezi, or as a tributary to the Zambezi River Basin. These discussions may have consequences for long-term management depending on a unified definition of the basin, and the corresponding jurisdiction of governments and institutions.

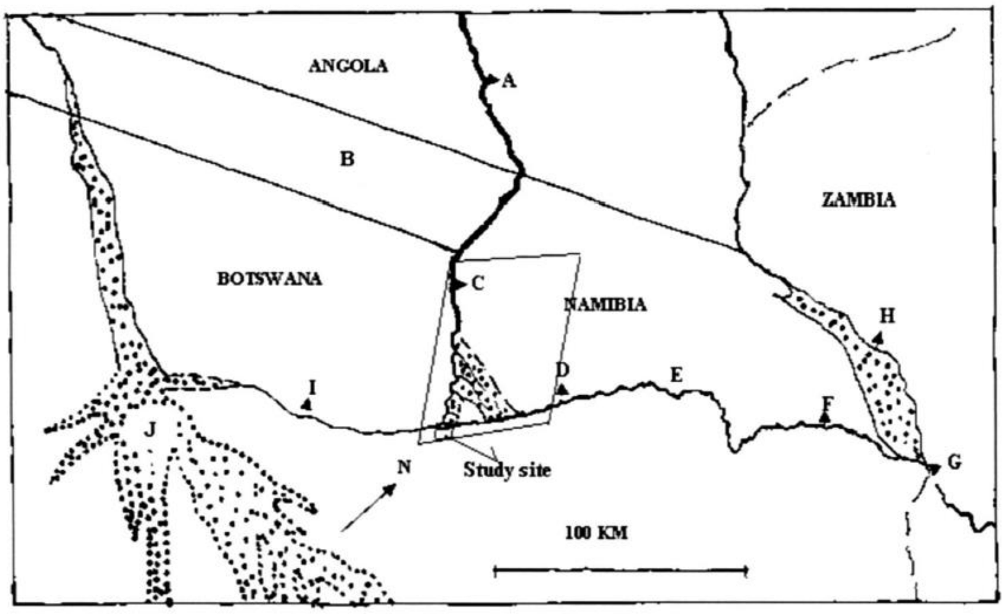


Figure 5.3 Map indicating the connectivity between surface water resources in the lower Kwando region that include: A = Kwando River (Angola); B = Zambezi Region, Namibia; C = Kwando River (Namibia-Botswana border); D = Linyanti River; E = Lake Liambezi; F = Chobe River; G = Confluence of Chobe with the Zambezi; H = Zambezi swamp, I = Selinda spillway and J = Okavango Delta (Kurugundla et al. 2010).

5.1.2 Wetlands

Wetlands are defined as distinct ecosystems that arise from shallow permanent or seasonal flooding processes and the resulting dominance of anaerobic and aerobic processes within the soils, producing some of the most diverse ecosystems on Earth (Keddy 2000). The importance of these ecosystems is recognized by the international Ramsar Convention[27]. Its mission is based on "the conservation and wise use of all wetlands through local and national actions, and international cooperation, as a contribution towards achieving sustainable development throughout the world" (Ramsar 2013). There are currently over 2,400 sites, covering 2.5 million km^2 [28], on the List of Wetlands of International Importance (the Ramsar list[29]), of which four lie within the boundaries of the KAZA TFCA (Table 5.1). None of these are transboundary (shared between one or more countries). Additionally, some significant wetlands are designated World Heritage status by following the UNESCO 1972 Convention,

[27] https://www.ramsar.org/
[28] https://www.ramsar.org/about/wetlands-of-international-importance-ramsar-sites
[29] https://en.wikipedia.org/wiki/List_of_Ramsar_Wetlands_of_International_Importance

which seeks to encourage the identification, protection, and preservation of cultural and natural heritage around the world.[30] It is important to highlight other wetland areas that lie within the KRWDA, e.g., the Barotse Floodplain, even though they are not recognized on the Ramsar list (Box 3).

Table 5.1 The four internationally recognized Ramsar sites in KAZA TFCA and their World Heritage status

Ramsar site	Country	Approximate central location	Date of designation	Area hectares (ha)	World Heritage site[a, b]
Okavango Delta System	Botswana	19°17'S 022°54'E	09/12/1996	5,537,400	Yes, 2014
Busanga Swamps[c]	Zambia	14°04'S 25°46'E[b]	02/02/2007	200,000	No
Victoria Falls National Park[c]	Zimbabwe	17°58'54"S 25°51'38"E	03/05/2013	1,750	Yes, 1989
Bwabwata-Okavango Wetland	Namibia	18°12’43”S 21°45’36”E	13/12/2013	46,964	No

[a] Year indicates the year of inscription to the World Heritage list.
[b] Tsodilo Hills (Botswana) is another World Heritage site located in the KAZA TFCA, but not a Ramsar site.
[c] Located outside KRS.

Highlights of the four Ramsar sites in the KAZA TFCA (Ramsar Sites Information Service 2021[31], KAZA TFCA, 2014) are:

1) **Okavango Delta System -** Located in northwestern Botswana (
2) Figure 5.4), it stretches northwards along the border with Namibia and includes a section of the Kwando/Linyanti River system. The surface area of the delta itself varies between 10,000-16,000 km^2 dependent on the annual inflow of water. The area is globally renowned for its unique biodiversity and remains a tourism hotspot. It was included on the World Heritage List in 2014. It provides a separate target for transboundary cooperation toward greater conservation of the Okavango landscape across Botswana, Namibia, and Angola[32]. Threats to the site include changes in land use, water abstraction, and development projects.

3) **Busanga Swamps** - Located in the Northwest Province of Zambia, the Busanga Swamps straddle both the Kasonso-Busanga Game Management Area No. 2 and the northern part of the Kafue NP. These swamps act as a groundwater recharge system and help to control floods within the Kafue River system. Threats to the site include overfishing, deforestation, agrochemicals, poaching, invasive species, and erosion.

4) **Victoria Falls National Park** - Located in Zimbabwe, the Ramsar site has a northern border with Zambia that follows the Zambezi River and covers a much smaller area than the other Ramsar sites in the KAZA TFCA. The area overlaps with the Mosi-oa-Tunya World Heritage Site, designated in 1989, and a transboundary initiative jointly owned by Zimbabwe and Zambia. Threats to the site include tourism infrastructure, poaching, waste management, deforestation, and encroachment of local people.

[30] http://whc.unesco.org/en/list/
[31] https://rsis.ramsar.org/. Here, the location of the Ramsar sites can be searched on a global map.
[32] http://whc.unesco.org/en/events/1493/

5) **Bwabwata-Okavango Wetland** - Located in the Kavango Region of northeastern Namibia, the nearest large town is Rundu. The site includes the Okavango panhandle straddling the Okavango River and borders up to the Okavango Delta System Ramsar Site to the south. The area encompasses both flooded marshes and floodplains. Threats to the site include increasing population, tourism, growth of urban areas, commercial agriculture, and large-scale water abstraction.

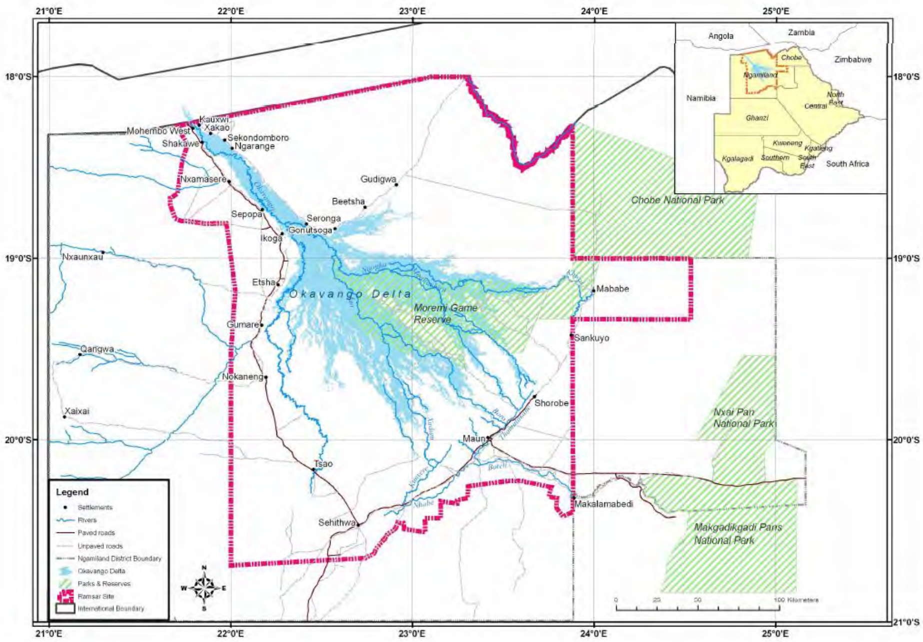


Figure 5.4 The perimeter (pink) of the Okavango Delta System Ramsar Site (Ramsar Sites Information Service 2021, Appendix II)

Box 3. Anthropogenic impacts on wetlands: The Barotse Floodplain

In the northern part of the KRWDA, along a transect of the Zambezi River, the Barotse Floodplain, Zambia, extends in a N-S direction for approximately 240 km and 34 km wide, from Lukulu to Senanga. The southern portion of the Barotse Floodplain lies within the KRWDA; the upper boundary of which stops just south of the town Mongu. Notably, no portion of the Barotse Floodplain lies within the KAZA TFCA because there is a divergence between the borders of the KAZA TFCA and the KRWDA (highlighted in orange in Figure 5.5). The total area of the KRWDA outside of the KAZA TFCA is approx. 14,000km^2, equivalent to 15% of the total surface area. It is thus important, from a water management perspective, to emphasize the importance of the collaboration between RBOs, in this case ZAMCOM, and localized conservation efforts within the KRWDA.

Water samples were taken along the length of the floodplain to assess the impact of anthropogenic activities in the surrounding areas (Nyambe et al. 2018). The results show that deforestation and agricultural practices are correlated to excessive nutrient loading and increasing sedimentation, alongside high levels of fecal coliforms close to human settlements. The pressure from these varied sources requires robust monitoring through stakeholders such as the Zambian Environmental Management Agency (Nyambe et al. 2018). This case study provides essential lessons on the risks to the integrity of all wetlands in the region that may be affected by anthropogenic activities and highlights the importance of local transboundary issues demonstrating clear upstream-downstream linkages across floodplains and river systems.

A map of surface water bodies and wetland areas in the KRS is given in Figure 5.5 with the description of each of the wetland groups provided in Table 5.2. The map shows that there are a high number of seepage areas/pans in the western part of the KRB in the border regions between Luengue-Luiana and Mavinga NPs. Similarly, there is a large swath of seepage pans extending from the West Zambezi GMA through the Sioma Ngwezi NP and on the other side of the Kwando River in the Angolan portion of the lower KRB. The map shows that the Barotse Floodplain broadly fits within wetland Group 1, whilst the

Zambezi Floodplain at Kasane is predominantly Group 2 (more permanent). The Okavango and Linyanti wetlands are identifiable under the wetland floodplain or wetland seepage/pan classification.

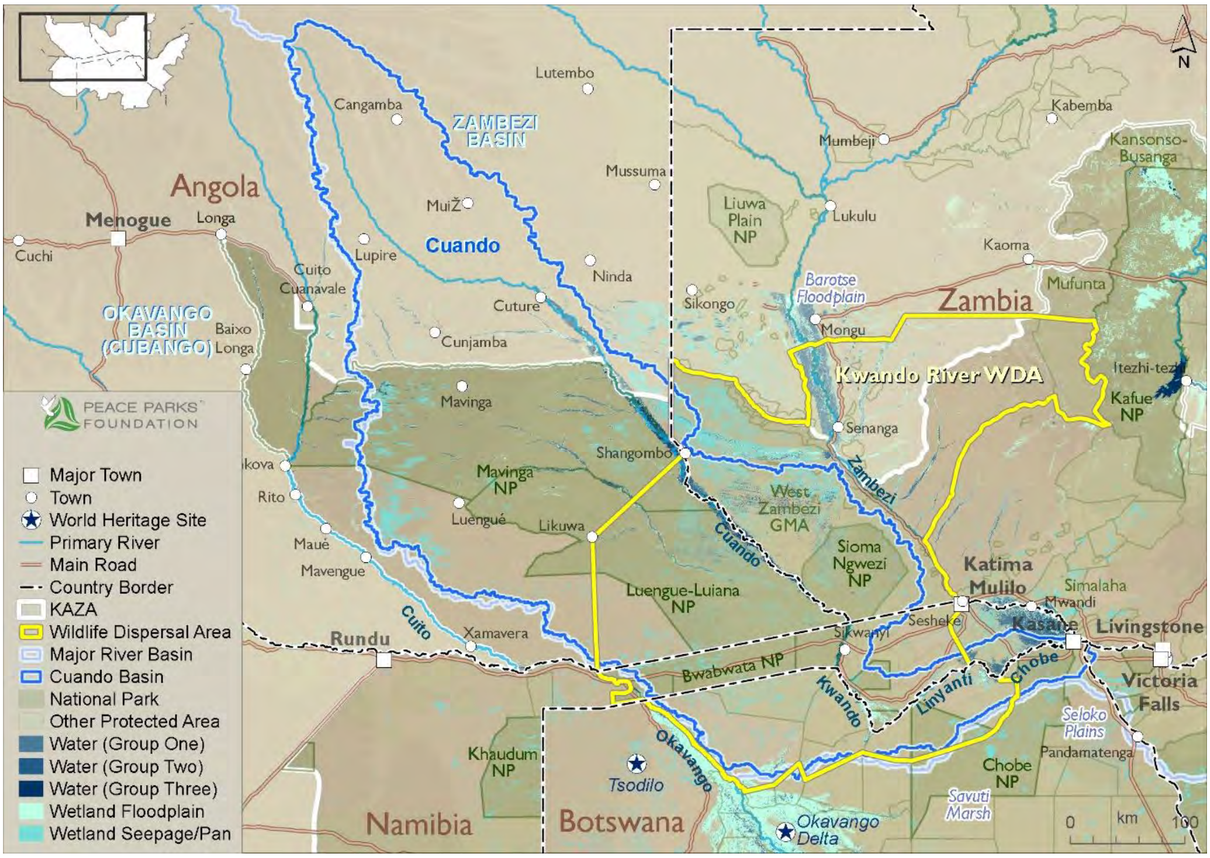


Figure 5.5 Regional map of wetland areas and types in the KRS (Table 5.2). The orange hatched area shows the KRWDA outside of the KAZA TFCA (Peace Parks, 2021).

Table 5.2 Classification and descriptions of wetland types corresponding to the legend in Figure 5.5.

Wetland Type	Description
Group 1	Open water: areas of open water that were identified on at least one of the four multi-seasonal image dates, corresponding to low seasonal flood inundation areas
Group 2	Open water: areas of open water that were identified on at least two of the four multi-seasonal image dates, corresponding to medium seasonal flood inundation areas
Group 3	Open water: areas of open water that were identified on at least three of the four multi-seasonal image dates, corresponding to high seasonal flood inundation areas
Group 4	Open water: areas of open water that were identified on all four of the four multi-seasonal image dates, corresponding to permanent water extents. (Note: not present in Figure 5.5)
Wetland Floodplain	Vegetated wetland areas that appear to be near-permanent areas on all image dates, typically associated with major floodplains
Wetland Seepage/Pan	Vegetated wetland areas that are less permanent in nature than the floodplain class (see above), which appear to be associated with riparian and seepage zone, and pan landscape features

Source: Peace Parks.

Wetlands, which are prolific in the KAZA TFCA, are vulnerable, not only because of impending climate change but also because they depend on water derived from distant highlands. These are areas that support a wide range of endemic species, play a key role in the region's tourism development, as well as help secure water access and livelihoods for local communities (EC 2015).

5.1.3 Surface water quantity and quality

Surface water quantity

The flow regimes in the three major river systems originating in the highlands of Angola (Cubango, Cuito, and the Kwando) (Figure 5.1) are shown in Figure 5.6. The Cubango and the Cuito merge to form the Okavango River just across the border from Angola to Namibia, which then goes on to drain into the Okavango Delta in Botswana. A single gauging station exists on the Kwando River, located at Kongola in the Zambezi Region, Namibia, just south of the trijunction between Angola, Namibia, and Zambia (Figure 5.26). The flow at this gauge is compared to those at similar latitudes that lie on the Cubango and Cuito rivers to the west, at Rundu (17:55:0 S, 19:45:0 E) and Dirico (17:56:0 S, 20:42:0 E), respectively, both of which lie in the Angola/Namibia border region. The discharge volumes are measured from 1981 to 2002 (Figure 5.6). The striking feature observed is the distinct seasonal patterns in both the Cubango and Cuito in contrast to the Kwando. The Cubango and the Cuito show a clear pattern with discharge peaks confirming a more well-defined response to the rainy season, falling within the same period each year (Apr-May), but with much greater peak discharges to baseflow ratios in the Cubango. In contrast, the Kwando shows a less clear annual flow pattern.

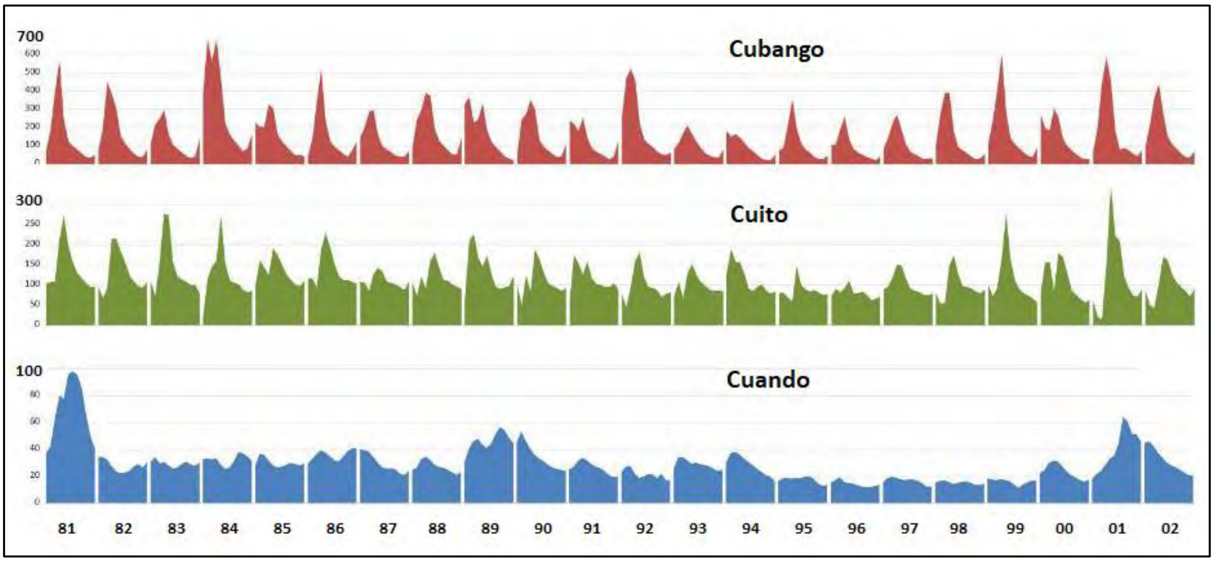


Figure 5.6 Measured daily discharge in m^3/s along Cubango (at Rundu), Cuito (at Dirico), and Kwando (at Kongola). Each year is shown from Jan to Dec from 1981 to 2002 (Mendelsohn and Martins 2018, data from Ministry of Agriculture, Namibia).

The discharge of the Kwando averages 31.9 m^3/s at the Kongola station (Bäumle et al. 2018) compared to 100 m^3/s for the Cuito, despite the basin size of the Kwando being more than double that of the Cuito. Given that the upper basins share similar overall physiographic characteristics including geomorphology, soils, and rainfall, it is likely that the characteristics within the lower reaches of each basin lead to this significant difference. The Cuito river cross-section is typically much narrower across its lower reaches, approx. 1-2 km wide, whereas the Kwando progresses across the floodplains often at breadths of 10 km or more (Mendelsohn and Martins 2018). In addition, the soils in the two lower basins are different, where gleysols predominate in the KRB (Figure 3.14). Water will flow faster in a narrower channel, whereas in a wider, more slowly moving channel, there is more time for evapotranspiration to occur, which could explain the large difference in measured discharge volumes (Mendelsohn and Martins 2018). In addition, the gleysols tend to retain water more than the arenosols that are predominant in the Cuito. Both factors could explain the less direct relationship between seasonal rainfall and downstream discharge in the Kwando River (Figure 5.6).

As a further comparative tool, a simple water balance was made for the Kwando and Cuito sub-basins. This calculation was conducted to make a broad comparison and to gain a sense of scale. Key data are:

1) The average annual rainfall and potential evapotranspiration are the same at 700 m/year, and 2,300 mm/year, respectively, in both basins.
2) The surface area of the Kwando and Cuito basins are 122,886 km^2 and 57,300 km^2, respectively.
3) The approximate average discharges of the Kwando and Cuito are 32 m^3/s and 100 m^3/s, respectively.

Even though the Cuito has a smaller surface area, the discharge value is about three times that of the Kwando. The ratios of discharge/rainfall for the Kwando and Cuito are approx. 1.2% and 7.5%, respectively. The significant difference in discharge fractions may be explained by the higher levels of actual evapotranspiration in the Kwando because of the low gradient, wider channels (Baumberg et al. 2014), and vegetated wetland environments of the lower Kwando, or, because there are greater levels of groundwater recharge to deep groundwater systems discharging outside the basin, or some combination of both.

Modeling undertaken of both the Cubango and Cuito basins reveals insights into the contrasting dynamics between the two tributaries that supply the Okavango Delta, which can be explained by a difference in geological and geomorphological settings in the basins (Baumberg et al. 2014). This may also help our understanding with respect to the hydrological dynamics within the Kwando Basin. The upper reaches of the Cubango (furthest west) are defined by crystalline rocks with poor storage capacity that form steep narrow valleys, whereas, in the upper Cuito, the hard rock formations are overlaid with thick Kalahari sediments, and a much more undulating topography formed by wider valleys. The rainwater is therefore infiltrated and retained to a higher degree in this basin through subsurface flow, and discharge to the rivers in the dry season is delayed, thus explaining greater baseflow throughout the year and less contrast in discharge volumes between wet and dry seasons (Baumberg et al. 2014). These same Kalahari beds also stretch across to the KRB. That said, the observed dynamics in the Kwando are not aligned with those of the Cuito, possibly even more evaporation and may be more dominated by groundwater.

The findings demonstrate the significant role of the subsurface in shaping the basins' physiography and discharge dynamics. The results also indicate that shallow or deep groundwater is a major contributor to river flow in these systems, and likely most significantly in the Kwando River. The delays of groundwater in the systems, i.e., the time from infiltration to appearance in the stream, may vary significantly from system to system, and within systems, and little knowledge exists on this.

To further understand the surface water dynamics and the relationship between rainfall and discharge in the KRB, datasets on annual rainfall and daily discharge from 1981-2020 are compared (Figure 5.7). There is not a clear correlation, from visual inspection, between the two, although there is a broad signal that shows the average rainfall and discharges peaking between 2007 and 2014. Similarly, there are coinciding increases in rainfall and discharge in the 1988-1989 and 1992-1993 seasons. However, there are also seasons where marked increases in rainfall are not reflected in peaks in river flows such as during 1997-98 and 2004-05. Considering that the majority of the rainfall falls in the upper basin (Figure 3.3), whilst the gauge lies in the lower basin, there are many additional factors that affect downstream discharge such as local rainfall, vegetation in the floodplains that attenuate flow, and increase evapotranspiration, rainfall intensity that may govern the distribution of rain between infiltration and evaporation, and the cumulative and delayed effect of a discharge from previous seasons. Ongoing studies carried out by WWF (Box 4) will include a Pitman model, with a view of undertaking an environmental flow (e-flow) assessment. A critical part of this will be to understand the interlinked surface water - groundwater dynamics.

Finally, it will be critical to assess the climate vulnerability of the KRS in terms of impacts of floods and droughts as well as the longer-term effects of warming. As the Kwando River historically has been flowing perennially with relatively low annual/seasonal variability, it may be more resilient to short-term climate variability and events, like floods and droughts, than other 'flashier' systems, like the Okavango River. Understanding historic and future system impacts from climate change may be different from that observed and modeled for the ORB (Section 7.1.2), and hence there is a need to better understand and predict these possible impacts to enhance adaptation strategies for the KRS.

Box 4. Complementary studies in the Kwando River Basin

Further assessments of the KRB were undertaken in a 'State of the Basin Report' (WWF unpubl.b) and 'Kwando River Basin Report Card' (WWF unpubl.a). The former presented an outline of the physical environment and the socioeconomic state, whilst the report card is used as a tool to describe ecological status, increase public awareness, and inform decision makers. In the latter, a transboundary participatory process was implemented to evaluate ecosystem health based on a set of scientifically derived indicators and thresholds. Ecosystem health encompasses the chemical, physical, and biological integrity of those systems. This definition is broadened to include the social and economic values that healthy ecosystems deliver to society, as well as the health of the management and governance systems that enable the maintenance or restoration of ecosystem health (WWF 2020a).

The Kwando River is typically classified as a tributary to the much larger Zambezi River (Pricope 2012). However, its flow regime is not only dependent on various flows from the upstream part of the basin, propagating to the Linyanti and Chobe rivers, but also 'pulses' that originate from the Zambezi River via connections that transit across the Zambezi Floodplain/Wetlands (Figure 5.8), or backwater effects directly through the Chobe River channel itself (Pricope 2012). This phenomenon has important consequences for the maintenance of the regional wetland systems and the occurrence of floods.

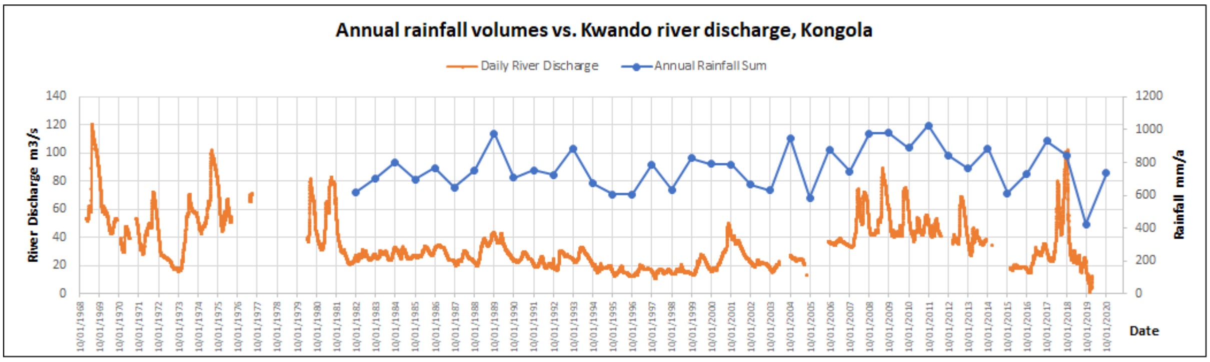


Figure 5.7 Daily discharge (left axis) of the Kwando River at the Kongola station (1968-2020) and annual precipitation (right axis) (CHIRPS dataset 1981-2020). Hydrological year from Oct to Sep. The annual rainfall sum is plotted at the end of the hydrological year.

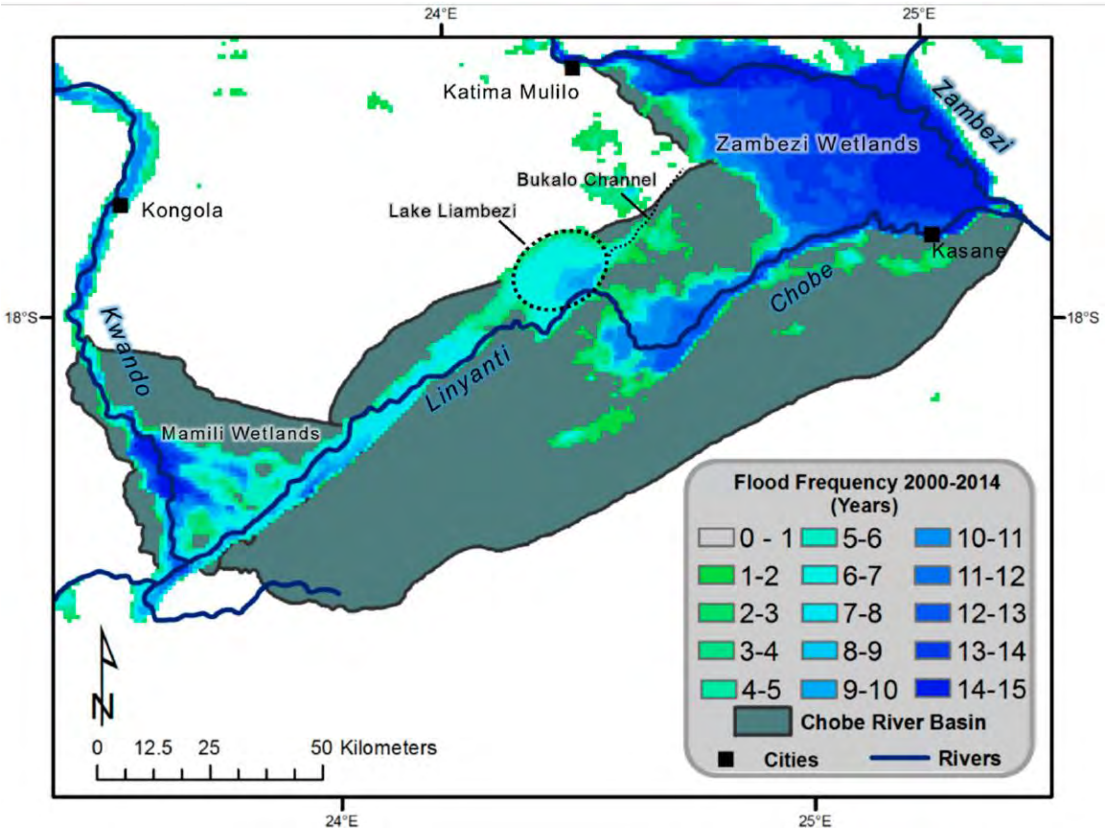


Figure 5.8 Flood frequency map showing the annual frequency of floods across areas of the Chobe River, the lower part of the KRB, between 2000-2014 (Burke et al. 2016).

This interplay is best understood through an assessment of the individual discharge patterns of the Kwando and Zambezi rivers, but also with the integrated use of remote sensing datasets. Firstly, the temporal distribution and volumes of river discharge lie in direct contrast to one another (Figure 5.9). Long-term average monthly discharge data reveal a unimodal distribution within the Zambezi that peaks in April at over 8,000 Mm^3/month. As previously discussed (Figure 5.6), the annual distribution in the Kwando discharge is much more even, peaking lightly in June-July but with significantly lower overall volumes, that average just over 100 Mm^3/month. The large deluge of water from the Zambezi is therefore the main factor controlling the extent of the flooding. Other factors include pre-wet season storage within Lake Liambezi, Kwando inflows, and potential minor contributions from precipitation within the region (Pricope 2012).

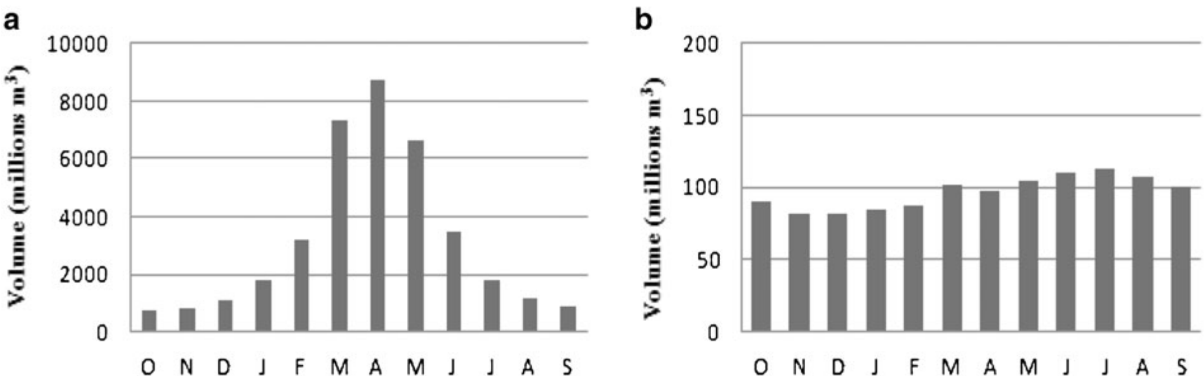


Figure 5.9 Long-term average monthly discharge from Oct to Sep (1965-2009) of (a) Zambezi River (Katima Mulilo gauge) and (b) Kwando River (Kongola gauge) (Pricope 2012).

Remote sensing data can also reveal the inter-annual flood variability observed across the Zambezi Floodplain/Wetlands, Chobe River, and the northern part of the Mamili Wetlands (also known as Linyanti Wetlands). The flooded area extent ranged from 401 to 5,779 km^2 from 2000-2015 (Burke et al. 2016). From these results, a flood frequency map (Figure 5.8) is used to identify how often certain areas of the basin were inundated, a major natural risk factor to consider, given that 53% of the Zambezi Region population are living within high flood risk zones (Burke et al. 2016). The map shows consistent flooding across the Zambezi Floodplain/Wetlands and within the Chobe channel (dark blue), the extent of which decreases moving further westwards (green).

A particularly strong flooding event in the 2008-09 season led to large populations being displaced, coinciding with high rainfall and discharge values recorded across the KAZA TFCA (
Figure 5.7). From the relatively short period of Figure 5.8 (2000-2014), it is not possible to infer long-term indicators of flooding risk, but it does allow high-risk areas to be identified and mitigation strategies to be implemented. Importantly, this approach has also revealed that the best indicator for downstream flooding in the KRB is peak discharge rates measured in the Zambezi River approximately two months prior to expected flooding events (Burke et al. 2016). The combined impact of these rivers, including the Selinda spillway from the Okavango Delta, on the Chobe section of the KRB. In terms of wetland extent and flood risk, this highlights the delicate linkages between the major river systems that flow across the KRS.

Surface water quality
From May to July 2018, transects of systematic river water samples were taken by the National Geographic Okavango Wilderness Project (NGOWP) from the upper reaches of the KRB to an area just below Rivungo, Angola. Similarly, samples along the river course in the Cubango River Basin were sampled in parallel (Figure 5.10 and Figure 5.11). The parameters measured were electrical conductivity, salinity, total dissolved solids, dissolved oxygen, and pH (Mendelsohn and Martins 2018). Of note is the changing pattern of dissolved oxygen in the Kwando River (Figure 5.10). In the uppermost reaches, it is at 0-70%, then rapidly increasing to 90-120% before decreasing again to quite low levels. Decreased levels in dissolved oxygen are likely a response to the continued decrease in topographical gradient away from the Angolan highlands (Figure 3.5). With this, rivers tend to widen and slow down leading to reduced levels of dissolved oxygen. Low levels at the top of the catchment may potentially be due to localized ponding effects but further knowledge is required on the localized sampling sites. This contrasts with the Cubango, which has consistently high levels of dissolved oxygen along the whole river stretch and otherwise exhibited similar trends in the other parameters measured in the study. It is anticipated that these levels remain high because the overall physiography tends toward narrower and steeper channels with relatively higher levels of runoff and good aeration of the water (Baumberg et al. 2014). The headwaters of the Kwando exhibited an acidic pH in the range of 4.9-5.5, before stabilizing closer to 6.5-7.0, whilst moving further down the catchment (Figure 5.11). The low pH values can be attributed to the Ferralic Arenosols in the upper reaches of the catchment (Section 3.6). Electrical conductivity, salinity, and total dissolved solids show similar trends in both basins, with gradual increases in the downstream direction but displaying values that suggest unpolluted freshwater. These findings are corroborated by simultaneous measurements under the NGOWP of river temperature. These data show that where oxygen levels are low, water temperatures are generally lower, consistent with the discharge of more anoxic and colder groundwater to the river (WWF unpubl.b)

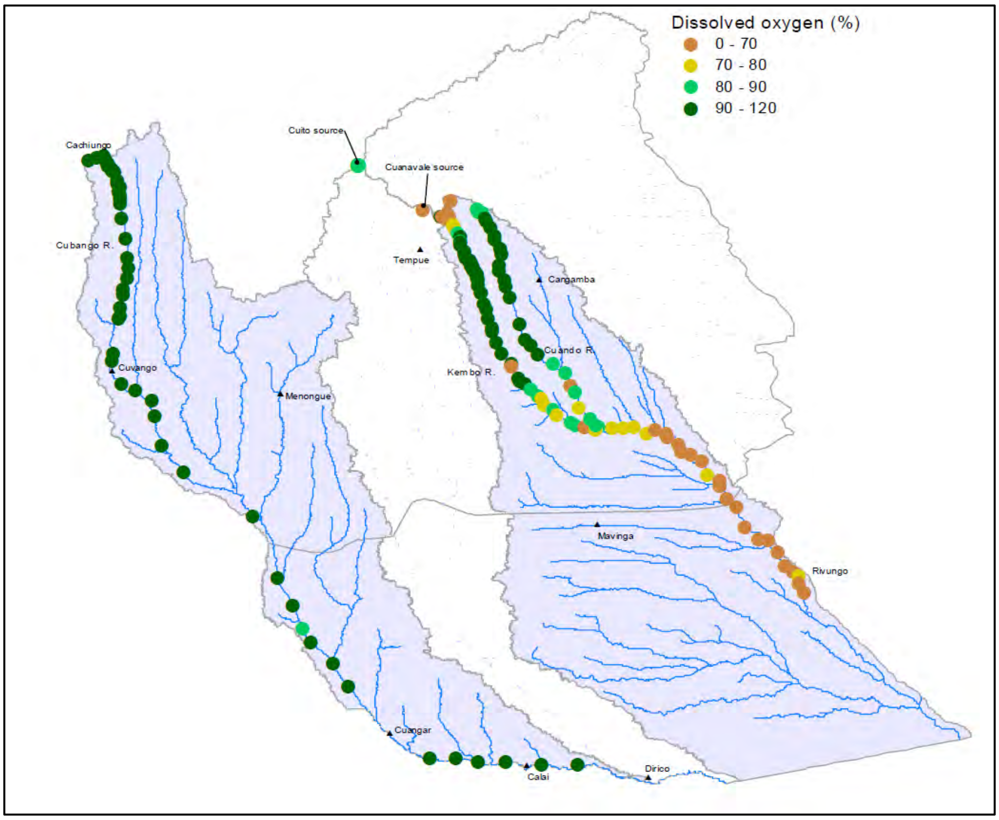


Figure 5.10 Transects of sampling points across the Cubango and Kwando rivers showing the measured percentage of dissolved oxygen, May - July 2018 (Mendelsohn and Martins 2018).

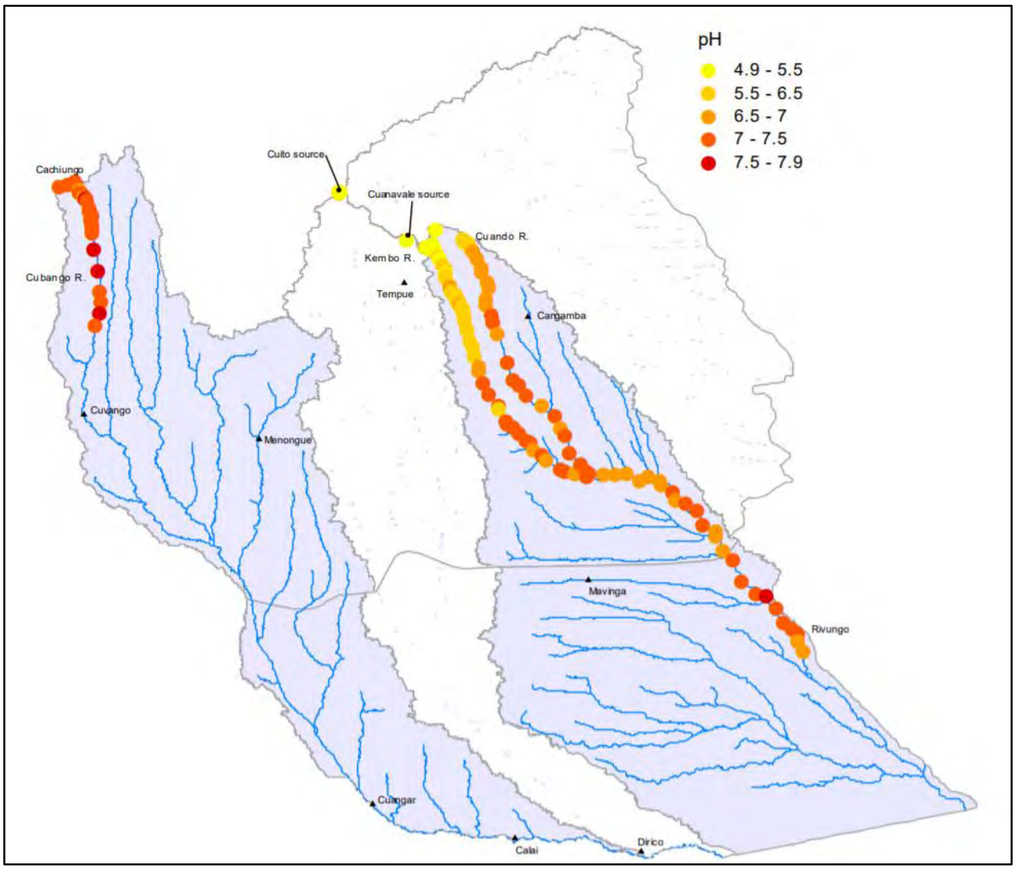


Figure 5.11 Transects of sampling points across the Cubango and Kwando rivers showing measured pH, May - July 2018 (Mendelsohn and Martins 2018).

5.2 Groundwater

5.2.1 Aquifer systems

The information readily available about groundwater in the KRS is disparate and incomplete. This section compiles studies from each country, Angola, Botswana, Namibia, and Zambia. These include areas such as the Zambezi Region, Namibia (Margane et al. 2005; Bäumle et al. 2018); Machile basin (in the Chobe-Zambezi Floodplains WDA), Zambia (Chongo et al. 2015a; Chongo et al. 2015b); and the Okavango Delta, Botswana (McCarthy et al. 1998, Haddon and McCarthy 2005). There is currently no comprehensive study that gives an overall hydrogeological picture within the KRS. Therefore, the purpose of this section is to highlight some of the key lessons that can be derived from this patchwork of studies and their possible applicability across the broader region alongside knowledge gaps to be addressed in future studies. The transboundary nature of the aquifers is considered in more detail in Chapter 6.

Angola
The geological map of the Angolan part of the KRS shows that there is one dominating aquifer type constituted by the Kalahari sands (arelas do calaári) (Figure 5.12). From Section 3.5 and documented studies across the region (Christelis and Struckmeier 2001), this is known to be the main water-bearing lithology, with thicknesses up to approximately 400 m across the KRB. Predominant faults in the region are demarcated on the map and align with tributaries and main channels of the Kwando River (Figure 5.2). A secondary minor aquifer, in the north of the catchment, consists of Limestone, Sandstone, Argillaceous schist, and Marls (calcário, grés, xistos argilos e magras). Based on this extensive desk study, the extent of this aquifer and whether this is hydraulically connected to the Kalahari sands is unknown. There are no known hydrogeological studies, cross-sections, or groundwater monitoring infrastructure from these upper reaches of the basin to gain a comprehensive understanding of the hydrogeology. Therefore, interpretation of the conceptual hydrogeological model (Section 5.2.3) must be built upon existing case studies from across southern Angola that includes the Okavango and Cuvelei-Etosha Basin (CEB), acknowledging that extrapolations are uncertain. No water quality data were available from within the KRS for Angola. However, salinity measurements from 28 points across the CEB, an area situated west of the KRB and ORB straddling the Angola and Namibia border, but outside the KAZA TFCA (Figure 1.1) were analyzed (Himmelsbach et al. 2018). Measured values reached 1500 µS/cm, at the upper limit of WHO potable drinking water guidelines, across boreholes, dug wells, and springs. Springs presented the best water quality with average recordings of 503 µS/cm, while wells typically recorded the highest values across the samples (Serrat-Capdevila et al. 2020).

Botswana
Most work in Botswana focuses on the Okavango River Basin (ORB) and in particular the Okavango Delta. The delta is highly dependent on the seasonal discharge from upstream catchments. As the seasonal river discharge pulse moves through the landscape each year, the predominant shallow sandy (Kalahari) aquifers are firstly replenished before surface water flooding can occur (OKACOM 2020). Therefore, the extent of the annual floods is partially dependent on the cumulative effects of infiltration and depletion from previous seasons and the prevailing groundwater levels (Milzow et al. 2009). Approximately 10-20% of the floodwater is lost to evaporation (average 2,170 mm/year) while the rest is infiltrated (McCarthy 2006). Surface and groundwater within the delta continue to be depleted throughout the year through evapotranspiration due to limited replenishment from local rainfall in the delta area. Evapotranspiration occurs particularly from islands containing forested vegetation. These higher rates of evapotranspiration create a gradient that encourages groundwater flow towards these areas where salts in turn accumulate beneath these islands producing saline waters. This so-called 'saltwater pump' combined with the annual influx of seasonal freshwater then replenishes the surrounding areas preventing the build-up of brines (McCarthy et al. 2012, Bauer-Gottwein et al. 2007).

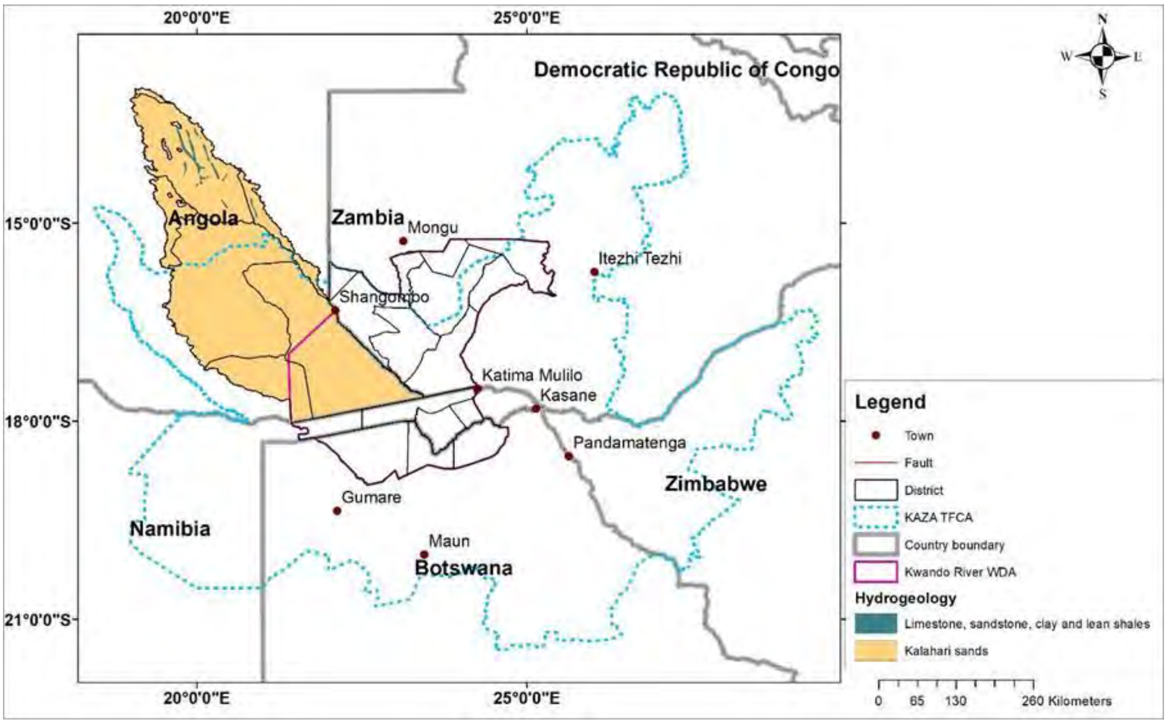


Figure 5.12 Geological map of the Angolan section of the KRS (GIS layers provided by Dept. of Water Resources Planning and Hydrology, Angola).

The Chobe Enclave is situated in northern Botswana, between the Chobe National Park and the Namibian border (Figure 5.5). The existing water supply of villages within the region is based on groundwater pumped from the Chobe River Floodplain where the water has been deemed inadequate due to poor water quality within the Kalahari sediments. Generally, water pumped in the floodplain of the Chobe River is of brown color, high in total dissolved solids, and brackish nature (Franssen et al. 2008). The Kavimba wellfield, situated on the plateau south of the Chobe River, was investigated as an alternative option to supply the Chobe Enclave. The relevant groundwater resources can be described by three units: The floodplain resources in the Kalahari sediments, the plateau resources in the Stormberg Lava (Karoo Supergroup) (Section 3.5.2), and the Kachikau (parallel with the Linyanti) fault line system found in fracture zones, which run along the length of the Chobe River from Ngoma bridge to Kavimba (Figure 5.26). This fault separates the resources in the floodplain and plateau. The aquifers on the plateau and in the floodplain are unconfined. Investigations of the Dept. of Water and Sanitation in Botswana showed that good quality water was found in the boreholes of the wellfield located on the plateau. A groundwater feasibility model was developed to quantify the recharge and discharge of the aquifer and to estimate the impact of a future wellfield (Franssen et al. 2008). The main conclusion was that the Chobe Enclave can be provided sustainably with groundwater pumped from the Kavimba wellfields (Franssen et al. 2008).

Namibia

In Section 3.5, the Kalahari Group sediments were identified as the predominant aquifer-bearing formation across the TFCA region. In the Zambezi Region of Namibia, the sequence varies in thickness from 300 m in the southwest corner down to 30 m in the northeast (Christelis and Struckmeier 2001). Within the formation exists a diverse range of sediments from consolidated sandstones through to unconsolidated materials that are often interbedded with clays. Borehole yields vary between 0-20 m^3/hr (Christelis and Struckmeier 2001). Field-derived experience, however, suggests that low yields may also be attributed to the design and poor maintenance of local boreholes (Christelis and Struckmeier 2001).

Groundwater salinity within the Namibian part of the KRS is often correlated with the proximity of boreholes to rivers, which are directly replenishing aquifers via focused recharge, especially downstream in more arid parts of the basin and during high flows. The groundwater quality often decreases rapidly both laterally and with depth away from the river channels. Christelis and Struckmeier (2001) grade the quality of the groundwater in Namibia based on the letters A-D, a generalized classification system based on the total dissolved solids, a method used to crudely estimate the salinity of groundwater and whether it is potable (A - high quality with total dissolved solids less than 1,500 mg/l, D - not potable with total dissolved solids of more than 3,000 mg/l). In areas close to the Kwando River, the quality is rated A, whilst in other areas close to the Linyanti River, the quality (B-C) is controlled by elevated levels of iron (source not stated). Further east, the water quality is limited by levels of sodium, sulfate, and chloride (A-D), associated with the weathering of silicates due to favorable temperate conditions and CO_2 production in subtropical soils (Bäumle et al. 2018). This also partly explains high fluoride concentrations (Bäumle et al. 2018).

The delineation of aquifers within the Zambezi Region has been classified into the Upper and Lower Kalahari Aquifer systems, UKA and LKA, respectively (Bäumle et al. 2018) (Figure 5.13). The UKA is unconfined and represents the aquifer system easily accessible at shallow depths and broadly covers the entirety of the ORZ. It typically holds brackish groundwater as described above, except close to free-flowing rivers. The discovery of the LKA revealed a deep-seated confined aquifer that contains freshwater. The Kalahari sediments in the LKA are characterized by fine-to-medium grained sandstones, possibly interbedded with clay or varied sandstones, modified by calcareous or siliceous post-depositional deposits. The LKA is confined by a layer of clay or clayey silt with sand likely of lacustrine origin (Bäumle et al. 2018). The LKA is composed of early fluvio-deltaic sediments. A summary of measured transmissivity values shows that there is a significantly higher transmissivity in the LKA, with median values of 59 m^2/day, compared to 20 m^2/day for the UKA (Figure 5.14).

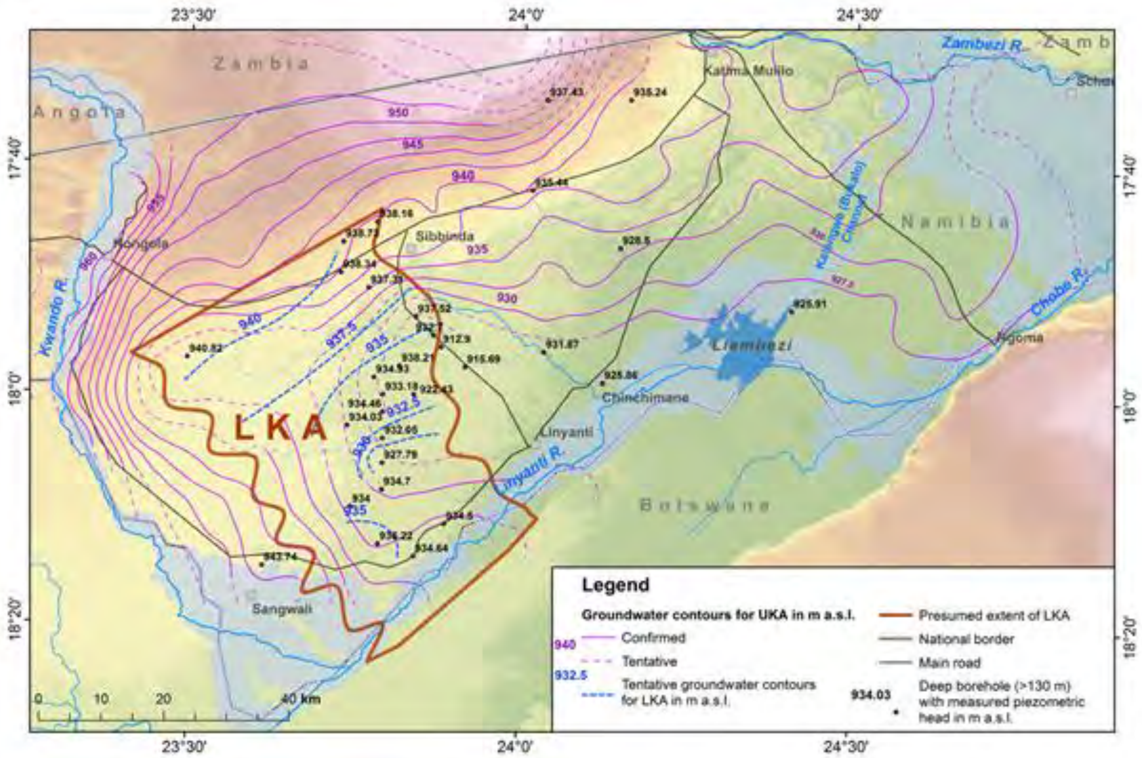


Figure 5.13 Location and piezometric surfaces for the Upper and Lower Kalahari Aquifer (UKA and LKA) systems in the Zambezi Region, Namibia (Bäumle et al. 2018).

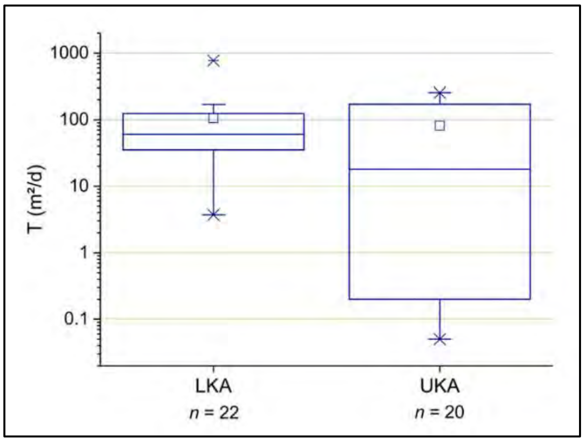


Figure 5.14 Box-whisker plot of transmissivity for the LKA and UKA from pumping test data across the region. n=number of tests (Bäumle et al. 2018).

Two sets of groundwater contours show regional flow trends in a N-S direction for both the UKA and the LKA. Inferred contours for the LKA are constructed based on a provisional drilling program. The data show a smaller N-S gradient for the LKA than for the UKA (Figure 5.13). However, the velocity of regional groundwater flow is very slow in both aquifers (Christelis and Stuckmeier 2001). Notably, in the westernmost region, in proximity to the Kwando, the closer packed contours for the UKA represent an increased gradient that declines away from the river implying that the Kwando is a losing stream and thus river discharge is providing groundwater recharge into the aquifers below (Bäumle et al. 2018).

To visualize the two aquifers, a ground-based transient electromagnetic (TEM) profile was taken in the N-S direction across the Zambezi Region (Figure 5.15). The yellow-green colors represent resistivity values between 10-50 Ωm and are interpreted as freshwater occurrences in the LKA. The aquitard, indicated with red colors, is likely made from clays and represents low resistivity values measured at less than 5 Ωm. The blue, high resistivity areas within the profile concur with basaltic formations of the Karoo sequence (Bäumle et al. 2018). The profile, complemented with more crisscrossing of the region, has been able to conceptually constrain the LKA towards the north and east due to the high resistivity values signified by the Karoo Basalts. The top of the LKA lies at depths between 125 and 150 mbgl, whilst the total depth of the LKA remains unclear given the detection depth limitation of the TEM of a depth of approx. 280 mbgl. The blue upper layers in the profile are demarcated as a shallow aquifer that may indicate the less fresh UKA. It is expected that the TEM can determine resistive layers to about 280 mbgl, presenting a clear limitation to the overall interpretability of the section at depth.

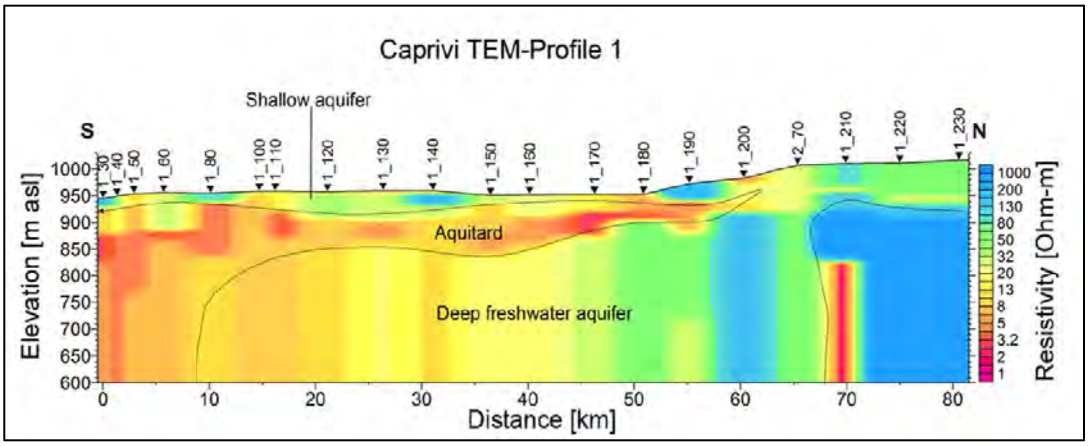


Figure 5.15 A N-S transient electromagnetic profile across the eastern section of the Zambezi Region, Namibia. It shows the occurrence of the UKA and LKA (Bäumle et al. 2018).

Six boreholes were drilled to depths of up to 250 mbgl as part of an investigation into the LKA, the locations of which are shown in Figure 5.16 (denoted 41xxx and 200xxx). Four penetrated the LKA whilst two remained in the UKA to observe the differences in hydraulic head between the aquifers. The head in the confined LKA was approx. 13 m higher than that in the UKA, indicating an ability for groundwater in the LKA to move upwards if there are openings in the confining layer. A summary of the geological logs from the drilling program can be found in Margane et al. (2005) and the KAZA-GROW Literature database[11]. The occurrence of the deep-seated fresh LKA is a large potential water source for the region, although several uncertainties remain regarding recharge and groundwater age. The concentrations of ^{14}C reveal approximate mean residency times for groundwater sampled from both the UKA and LKA (Margane et al. 2005). Low percentages of modern carbon indicate that the residency times are >10,000 years for the LKA (4 samples) and approx. 5,000-10,000 years for the UKA (16 samples). There is a general aging trend moving eastwards from the Kongola area to the north-central part of the Zambezi Region. However, the use of radiocarbon dating is limited due to rock-water interactions and limitations concerning measuring capabilities >30,000 years, hence these groundwater ages should be taken as tentative estimates. Further characterization is required before any development plan can be implemented, and the full potential of the aquifer realized. The methods used to delineate its position and occurrence are a significant step forward and will set the precedent for the exploration of deep-seated aquifers within the region.

In terms of current groundwater use within the Zambezi Region, a database of close to 1200 boreholes for water supply and exploration (not all shown) that are located within the UKA was collated (Margane et al. 2005) (Figure 5.16). The coordinates and available details can be found in Margane et al. (2005). From this, it is evident that the placement of boreholes is heavily dictated by current demand and infrastructure with the vast majority of boreholes situated along roads and in proximity to towns.

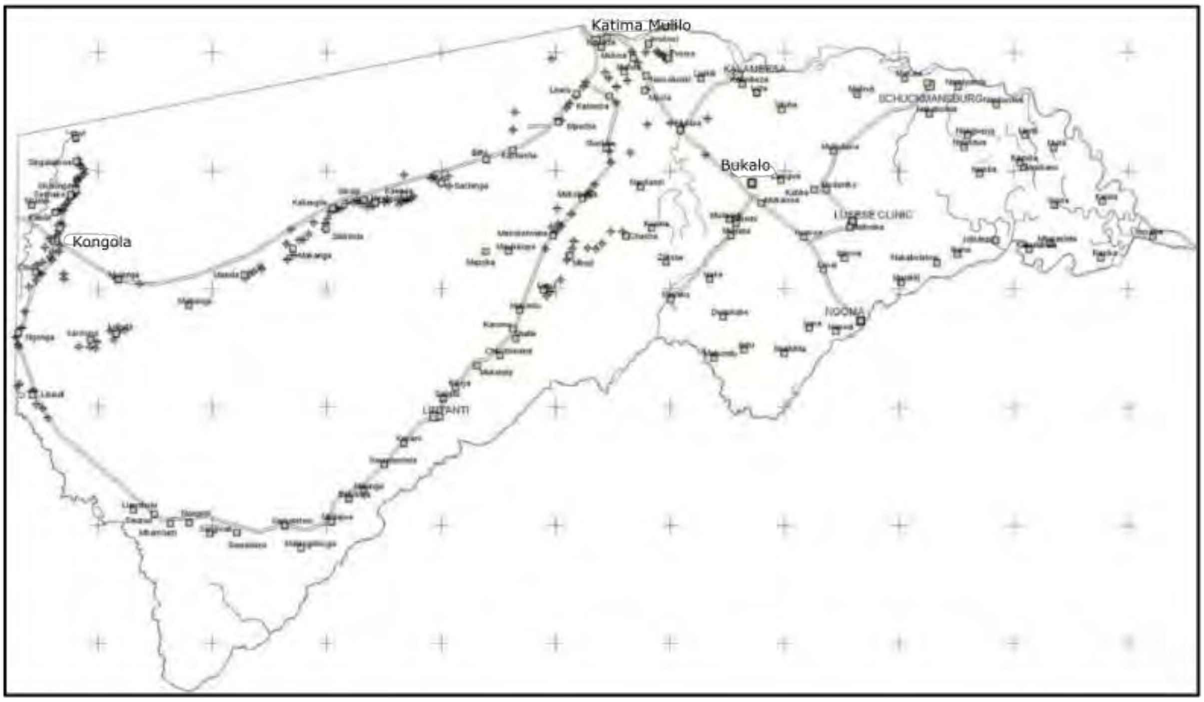


Figure 5.16 Map of 168 water supply boreholes in the Zambezi Region, Namibia (Margane et al. 2005).

Zambia

Sustainable management of groundwater resources is essential for the maintenance of supplies in rural Zambia. To assess the quantity of these resources and the overall groundwater budget, a 3D steady-state numerical groundwater model was produced for the Sesheke District, SW Zambia (Kabika et al. 2013) (Figure 5.17). The surface area of the model covers 11,501 km^2, in which the model boundaries are defined by the Njoko (west), Zambezi (south), and Machile (east) rivers. The area is conceptualized as a three-layer unconfined aquifer constituting Aeolian sands in the upper layer followed by weathered sandstones and basalts beneath (Kalahari sediments underlain by the Karoo Basalts), with a model thickness of 300 m. The surface topography in the sub-basin is characterized by gently undulating plains with complexes of both dunes and pans with a series of channels that drain towards the Zambezi River.

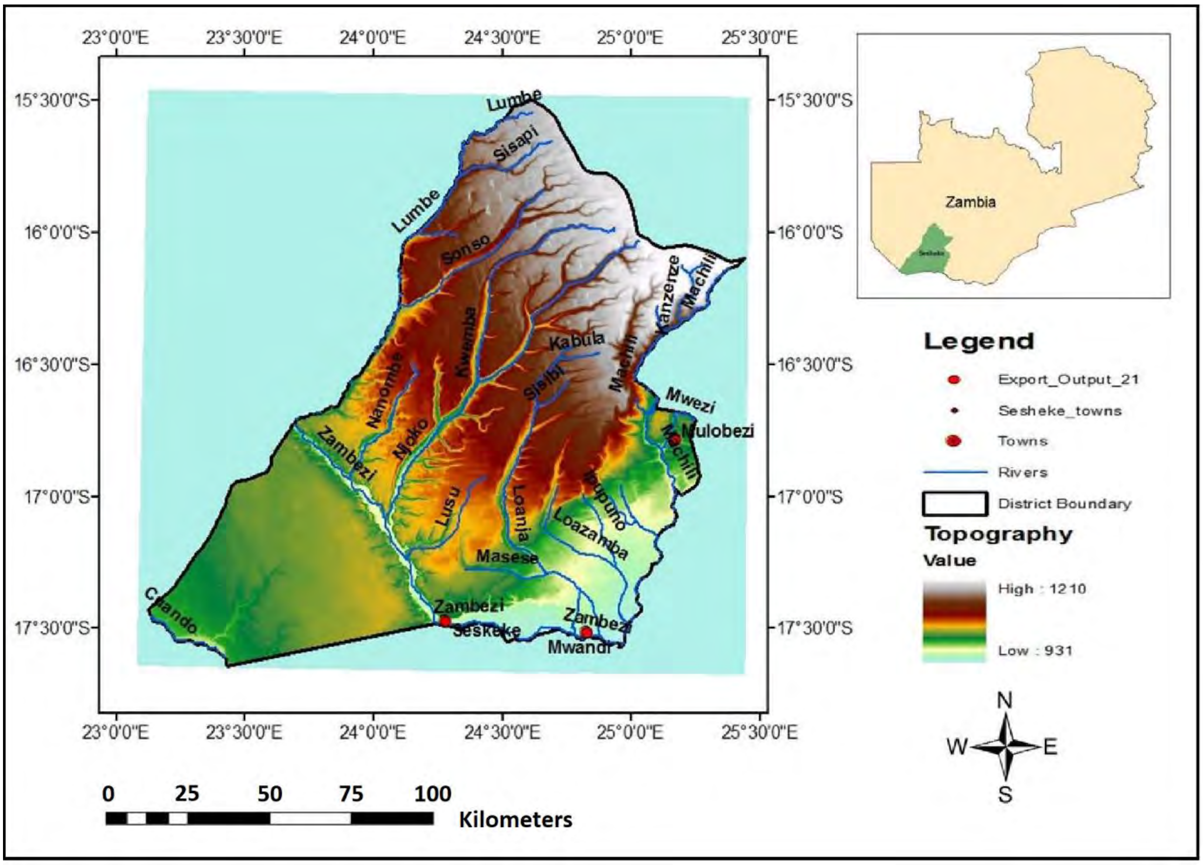


Figure 5.17 Setting of Sesheke District, Western Province, Zambia and topographic profile (Kabika et al. 2013). It includes the Sioma Ngwezi National Park to the southwest, between the Kwando and Zambezi Rivers.

The simulated groundwater contours follow a similar profile to the topography within the region with a hydraulic gradient of 0.0014 from NE to SW as the water table decreases from 1100 to 930 mamsl (data not shown). The simulated average diffuse/distributed recharge values show variability, with greater volumes in the northern areas, 55 mm/year (7.2% MAP), and 28 mm/year in the southern part. From pumping test analyses, the average transmissivity was calculated at 3.61 m^2/day and the hydraulic conductivity was in the range of 0.742-2.614 m/day for the more consolidated sandstone units and 0.09-24 m/day for the loose top Kalahari sands (Kabika et al. 2013). These aquifer characteristics and transmissivity values align with those inferred from the UKA in neighboring Namibia (Bäumle et al. 2018).

Further studies, across a very similar portion of the Sesheke region defined by the model above, used ground-based Time Domain Electromagnetic Surveys, measuring resistivity to investigate the occurrence of groundwater salinity (Chongo et al. 2011). The resistivity variations across the region are shown in Figure 5.18 and Figure 5.19 at 10 m and 30 m depths, respectively. The aquifer is stratified with the upper 10 m having resistivities at typically more than 100 Ωm, which could probably be attributed to dry sands; instances between 20-100 Ωm are more indicative of saturation. Freshwater is typically indicated by values greater than 70 Ωm, brackish 35-70 Ωm, and saline at less than 35 Ωm. The lower resistivities recorded in the southwestern region at 10 m, typically less than 50 Ωm where saline water exists closer to the surface, has a strong coincidence with the remnant Makgadikgadi Lake system that formed because of the ORZ processes (Section 3.5). The salts were concentrated in paleo-evaporite basins and then buried because of the dune migration (Banda et al. 2019). At 30 m depth, the resistivity values are consistently below 50 Ωm suggesting more pervasive groundwater salinity at this depth in this area (Figure 5.19). It is also important to note that other factors such as grainsize and porosity affect resistivity values. Resistivity values increases with increasing porosity and with decrease in grain sizes.

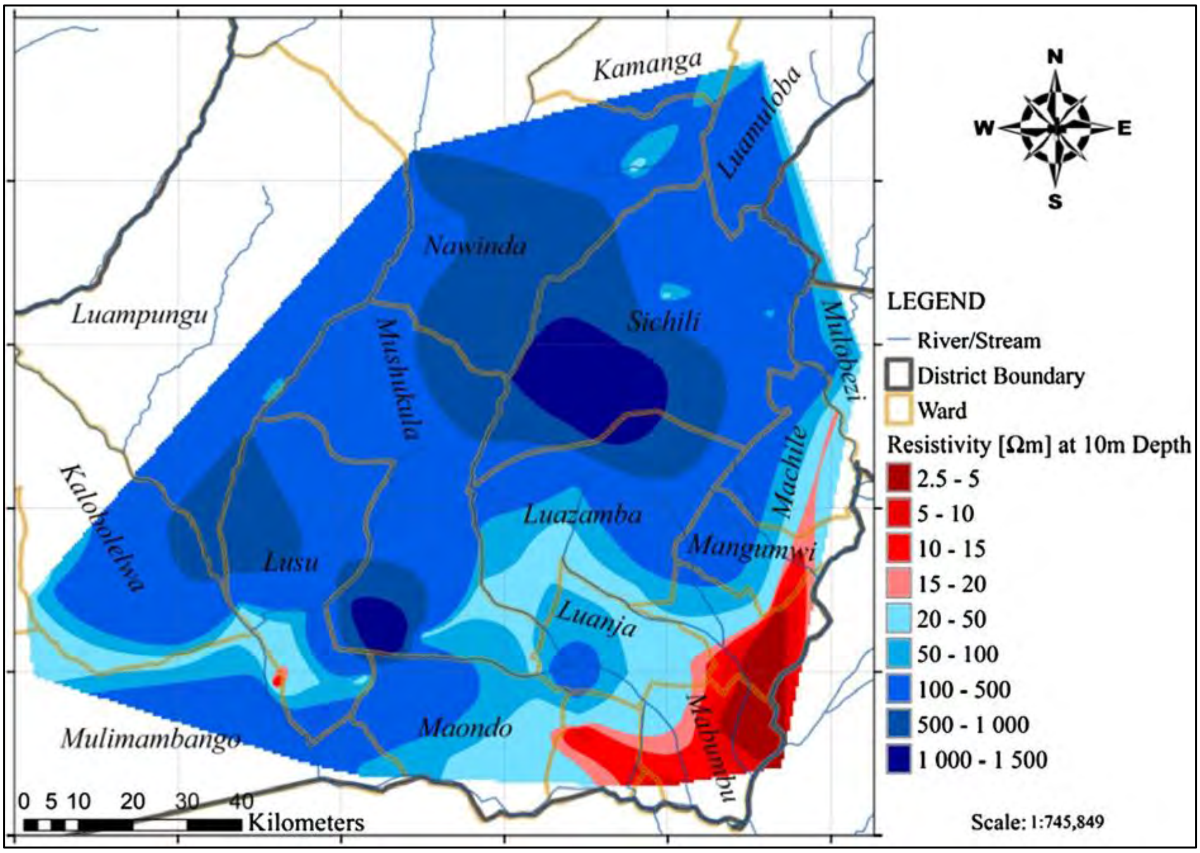


Figure 5.18 Electrical resistivity variations at a depth of 10 m in the Sesheke area, Western Province, Zambia (Chongo et al. 2011).

Further east of Sesheke, just outside of the KRWDA, the Machile-Zambezi catchment (16°-17°54'S and 24°13'-26°22'E) is situated in southwestern Zambia and borders the eastern tip of the Zambezi Region, Namibia, including the river itself. The area has a low gradient topography ranging from 930 to 2000 m above mean sea level, with multiple ephemeral streams that flow into the perennial Zambezi River. A contoured groundwater map was produced using interpolation from groundwater level records across boreholes in the region (Figure 5.20). The depth to the groundwater table was calculated using the difference between these contour values and ground elevation from SRTM data. This strategy produces a high-resolution image that indicates shallower groundwater depths in and around the river channels. This can be seen in the red areas showing a 10 m or lower depth to the water table (Figure 5.20). From this, it is possible to infer the occurrence of focused recharge within these areas.

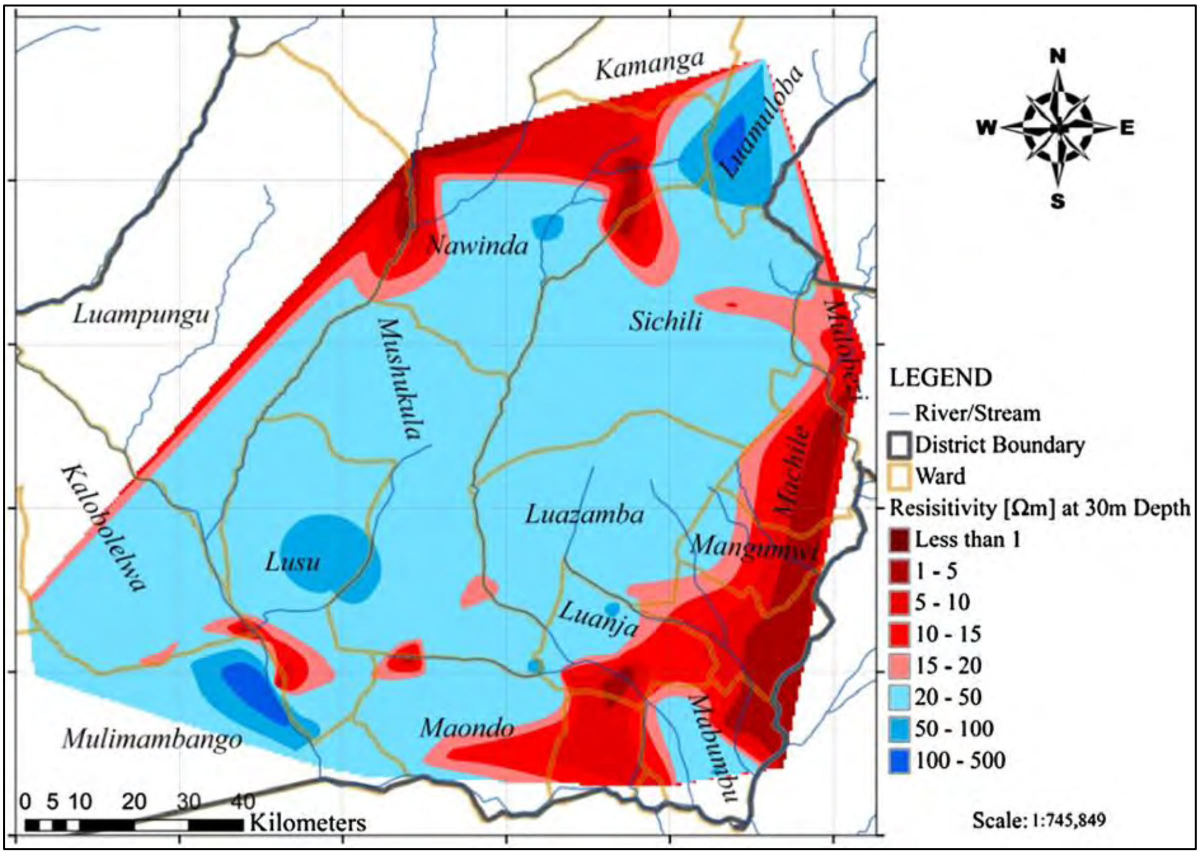


Figure 5.19 Electrical resistivity variations at a depth of 30 m in the Sesheke area, Western Province, Zambia (Chongo et al. 2011).

There is a poor correlation between the values of electrical conductivity and ^{18}O isotopes, indicating that the salinity in the groundwater as a result of the dissolution of minerals rather than recent evaporation. This corroborates the findings described above by Chongo et al. (2011). The age of the groundwater was estimated to be between 4,000-10,000 years based on ^{14}C dating. The sediments leaching these salts at lower depths are derived from clays. In turn, they act as a barrier, reducing the levels and speed of infiltration, but lead to further evapotranspiration and some evapo-concentration at the surface (Banda et al. 2019).

In the southern-central area of the Machile-Zambezi catchment, another study was conducted using a combination of two geophysical methods. Ground-based Continuous Vertical Electrical Sounding (CVES) (small scale) and airborne TEM data (large scale) were used to resolve surface water-groundwater interactions at the interface of the Zambezi River (Chongo et al. 2015a). By using these two methods conjunctively, the airborne TEM can measure resistivities at greater depths whereas the CVES resolves layer thicknesses in the shallow subsurface. The CVES was undertaken along a detailed 6.6 km transect perpendicular to the Zambezi River trending northwest in proximity to the Machile tributary (close to RV 12_27 (south-central borehole) in Figure 5.20). This combined interpretation helped to resolve the conceptual model of freshwater recharging into the saline aquifer. The boundary between fresh and saline groundwater was constrained to 60 m depth adjacent to the Zambezi and reduced to 22 m on a gradual basis along the transect and away from the stream. There is natural occurring salinity variability within the layers as reflected by sediments of variable resistivity. Notably, this study was undertaken in the rainy season with no indication of temporal variation throughout the rest of the year. This reduction in the thickness of the freshwater zone perpendicularly away from the river indicates a losing stream, in which fresh surface water is recharging into the relatively saline aquifer below. The relative contributions of freshwater are driven by a combination of localized seasonal rainfall and flow from upstream, and evapotranspiration. As a result, there are clear implications for groundwater extraction given that the highest quality and quantities of near-surface groundwater lie in proximity to the river systems in these semi-arid areas (Banda et al. 2019).

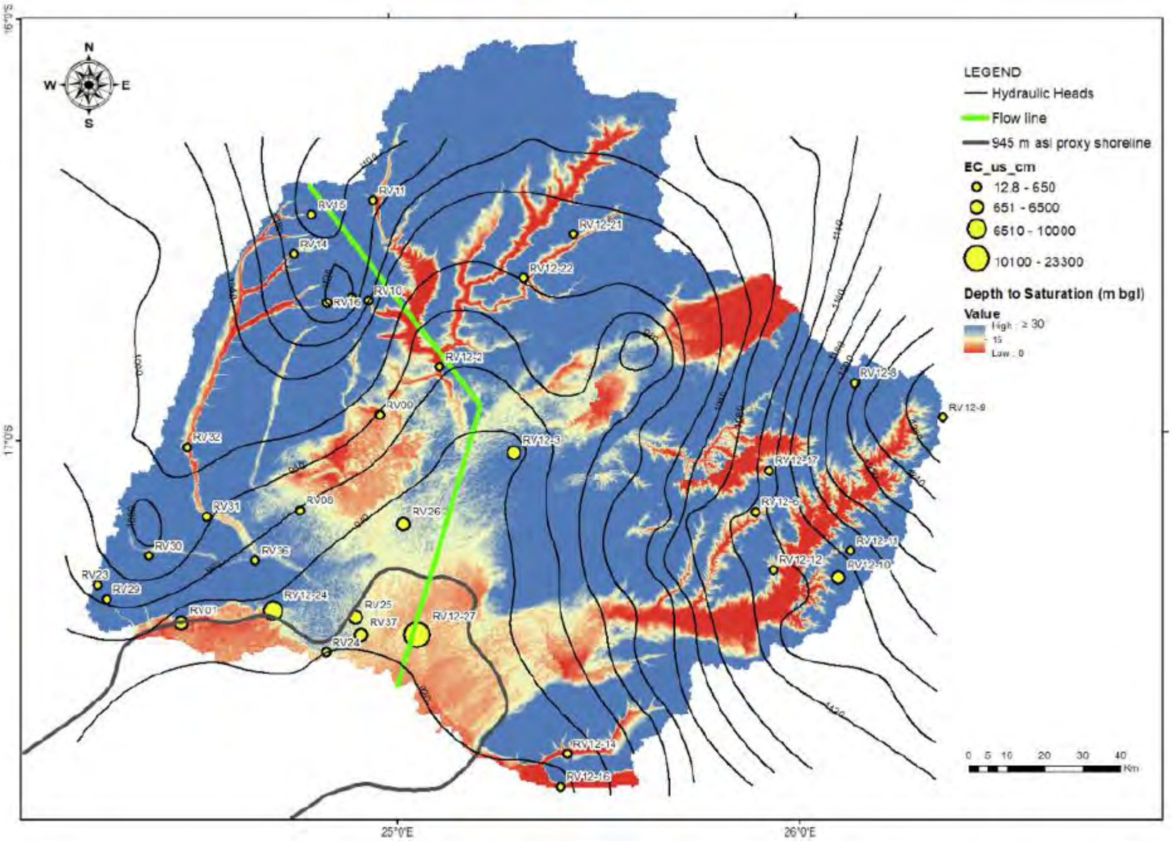


Figure 5.20 Depths to the saturated zone in Machile-Zambezi catchment, Zambia (Banda et al. 2019).

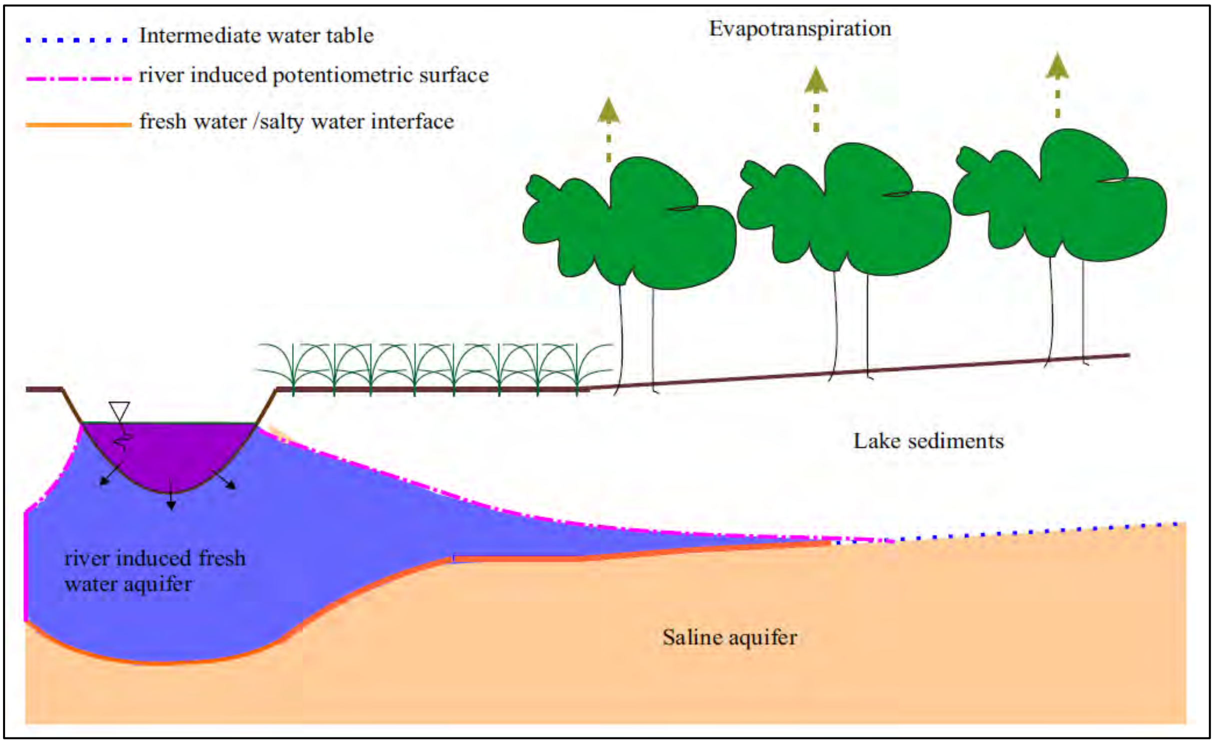


Figure 5.21 Conceptual model depicting surface water-groundwater interactions along the Zambezi River within the Machile-Zambezi catchment, Zambia (Chongo et al. 2015).

Summary of salinity issues

Geophysical tools across southwestern Zambia are shown to be valuable in examining the spatial variability of groundwater salinity levels in the upper sub-surface. Broadly speaking, the results show that saline groundwater is widespread at depths below 30 m in the Sesheke District. The origins of salinity in the region point toward the dissolution of buried salts during the interdune period approx. 4 to 32 ka ago (Chongo et al. 2011). Another source of salinity coincides with known extents of the paleo-Makgadikgadi Lake system on the border zone with Namibia, the full extent of this system is shown in Figure 3.9 whilst the paleo-shoreline and coinciding salinity are shown in Figure 5.20. As such, this may impact large parts of the central KAZA TFCA given its former large coverage across the area. The high salinities of the paleo-lake system are demonstrated by the very low resistivity values recorded in the southeast of the Sesheke District (Figure 5.20).

The conceptual model in Figure 5.21 highlights the impacts of river discharge on groundwater-surface water interactions. These are the main perennial supply of shallow fresh groundwater as indicated in the Machile-Zambezi catchment area (Chongo et al. 2015b) but also from the shallower groundwater in proximity to rivers that indicate focused recharge (Bäumle et al. 2018, Banda et al. 2019).

5.2.2 Geological features

The schematic block diagram (Figure 5.22) shows how the regional tectonic faulting affects the course of the Kwando River. The NE-SW trending faults, a result of crustal extension in the ORZ (Section 3.5) are recognizable by the relatively abrupt changes in topography across some of these faults (Figure 3.8). The faults that significantly constrain the onward flow of the rivers, for example, the Thamalakane Fault for the Okavango River, are responsible for the large inland deltas that form these massive alluvial fans and supporting wetlands today (Gumbricht 2001). In the north, the Kwando River flows perpendicularly across the Katima-Sibbinda Fault. A major shift inflow to the NE is bound by the wall of the Linyanti Fault. The downthrown block to the north of the fault contains the Linyanti wetlands. The Chobe-Gomare Fault represents the southern boundary, along which the Kwando flows until it reaches the Zambezi River. The Zambezi has eroded the Kalahari sediments and exposed the Karoo basalts below (Figure 5.22).

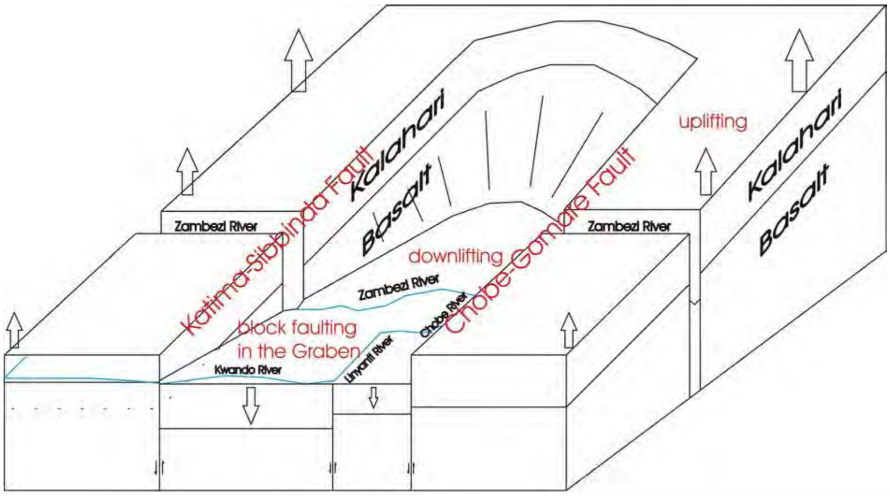


Figure 5.22 Schematic block showing the faulting and up- and downlifting in the central Zambezi Region. North is to the left, and south is to the right. The Kwando River is crossing the Zambezi Region, flowing in from the left and making a sharp turn to the east along the Linyanti Fault and yet another cross-over to follow the Chobe-Gomare Fault (Margane et al. 2005).

5.2.3 Conceptual hydrogeological model of the Kwando River Basin

Assimilation of knowledge from the various studies presented can be used to build a conceptual model for the aquifer systems and groundwater dynamics within the KAZA TFCA region. In alignment with established rainfall patterns, basin-scale modeling results from the neighboring Cubango and Cuito River Basins indicate diffuse/distributed groundwater recharge values of up to 170 mm/year in the upper catchments decreasing to 100 mm/year further downstream (Baumberg et al. 2014). Furthermore, the infiltration of water into the Kalahari sediments within the Angolan highlands has recently been detected using remote sensing (Interferometric Synthetic Aperture Radar), monitoring changes in ground uplift and subsidence in response to the rainy season across the Cuvelai-Etosha Basin (CEB). A conceptual model of groundwater recharge that was produced shows how recharge from the Angolan highlands goes on to recharge the deep-seated confined Ohangwena 2 aquifer through a regional groundwater flow system, while exact replenishment areas and rates remain uncertain (Figure 5.23) (Himmelsbach et al. 2018).

This conceptual hydrogeological model may be representative across other reaches of the Angolan highlands, including the KRB. Isopach maps reveal the thickness of the Kalahari sediments to be up to 400 m in the Linyanti Swamps region then decreases northwestwards towards the Angolan highlands (Haddon and McCarthy 2005). This means that there is a large potential for groundwater storage in the lower part of the basin, although there have been limited broadscale studies to verify this within the lower region and very little information regarding groundwater systems in the Angolan part of the basin. In addition, there is little known about the role of the faults that are typically coinciding with and occupied by the Kwando River channels and many of its tributaries in the Angolan part of the basin (Figure 5.2 and Figure 5.12). These may act as conduits for further recharge in the upper portions of the KRB. High salinity in these formations, especially in the lower, more arid parts, remains an issue, as indicated in Section 5.2.1.

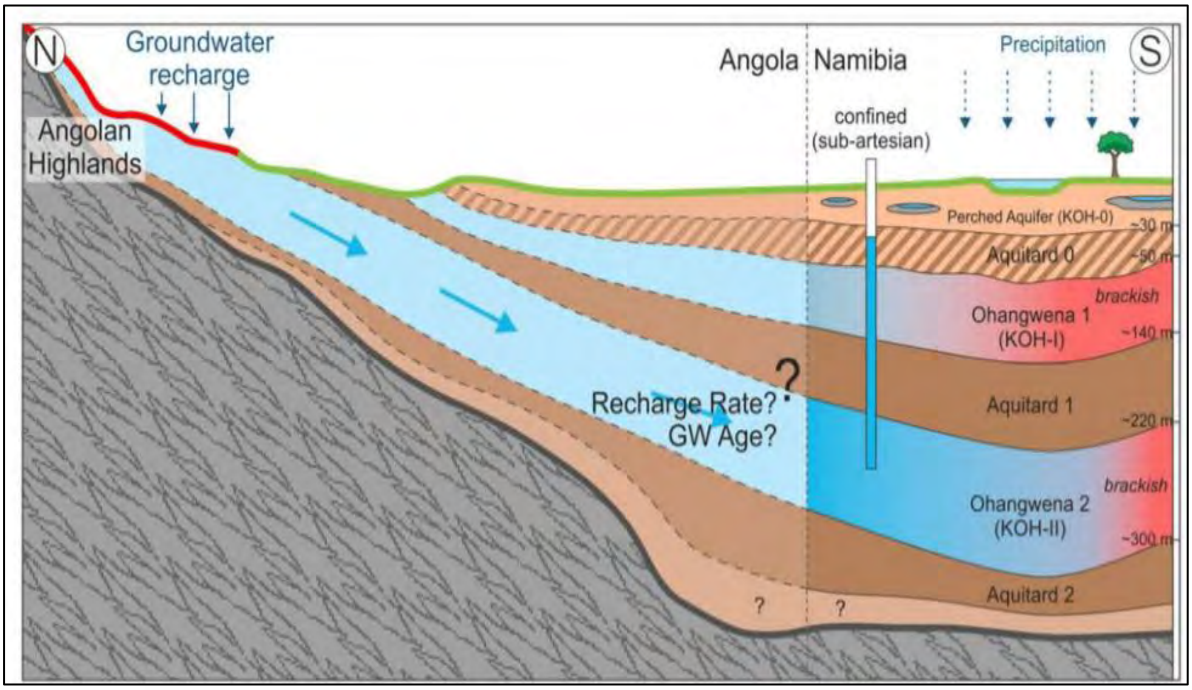


Figure 5.23 Conceptual model of the aquifer system and groundwater recharge mechanisms across the Cuvelai-Etosha Basin shared between Angola and Namibia (Himmelsbach et al. 2018).

The topographic profile of the KRB is relatively flat. From 300 km before the border with Namibia, there is an extremely shallow gradient of 23 cm/km (Mendelsohn and Martins 2018). The slow movement of water within the lower basin is demonstrated in the discharge levels observed at Kongola, which show almost constant levels throughout the year (Figure 5.6 and Figure 5.9). There is no reactionary spike in discharge with respect to seasonal rainfall as observed in the Okavango (Cubango and Cuito) (Figure 5.6), particularly in contrast to the Zambezi, which is very seasonal (Pricope 2012) (Figure 5.9). The KRB might be more likely to attenuate and lose water to evapotranspiration in the middle reaches due to its low relief and the thick soils and dense vegetation (Baumberg et al. 2014, Mendelsohn and Martins 2018) than to recharge it into larger regional and deep groundwater systems like the CEB. However, this is a conceptual model that needs testing, refinement, and verification.

In the lower parts of the KRB, the aquifer system is split into an upper and lower aquifer (UKA and LKA, respectively (Figure 5.24) with a generally much deeper upper extent due to the downlifting between faults in some places (Bäumle et al. 2018). A sedimentary layer (lacustrine origin) creates confinement between the two aquifers. In the Zambezi Region, these aquifers are bound between the Katima-Sibbinda and Chobe-Gomare Fault (Figure 3.8 and Figure 5.22). The LKA represents an early fluvio-deltaic sedimentary sequence deposited prior to rifting via discharge from the Kwando and Zambezi rivers. Rifting then occurred in the early to middle Pliocene, in which the LKA was tectonically displaced and partially constrained within the Horst graben structure (Figure 5.24). The faults that constrain the modern-day graben structure (Katima-Sibbinda, Linyanti, and Chobe-Gomare Faults) are assumed to be responsible for the very limited modern recharge of the LKA along the northern graben shoulder with the Linyanti Fault acting as a conduit for upwards movement and discharge of groundwater directly into the wetland areas (Bäumle et al. 2018).

The conceptual model differs from the one for the CEB (Figure 5.23) as the latter describes continuous regional aquifer systems connecting the upper and lower parts of the basin. While little is known about any regional groundwater systems in the ORB, it is clear, that this system is more dominated by surface water dynamics, due to the relatively more rock-dominated upstream sections where most precipitation falls, as evident from the very dynamic and seasonal surface water flow system. The ORB (and the KRS) is also dominated by the rift ORZ, defining the delta layout, while this is not the case for the CEB.

Hence, the KRB seems to adhere to a conceptual model somewhere between the ORB and the CEB. It is not extreme in terms of being either groundwater-dominated, as the CEB, or surface water dominated, as the ORB, but it is perennial with stable annual flows. They (the KRB) are all endorheic, or partially endoreic systems, governed either by rift zones or simple topography (the CEB – though the CEB outflows are unclear). Hence, the KRB is likely one of the most complex systems conceptually, as it is governed by close, but not-well-understood surface water-groundwater dynamics, complex tectonics in both the up and downstream parts, as well as some possible level of regional aquifer flow processes.

Furthermore, major uncertainties are related to the transboundary character of the groundwater systems in the border regions of the KRS (Chapter 6).

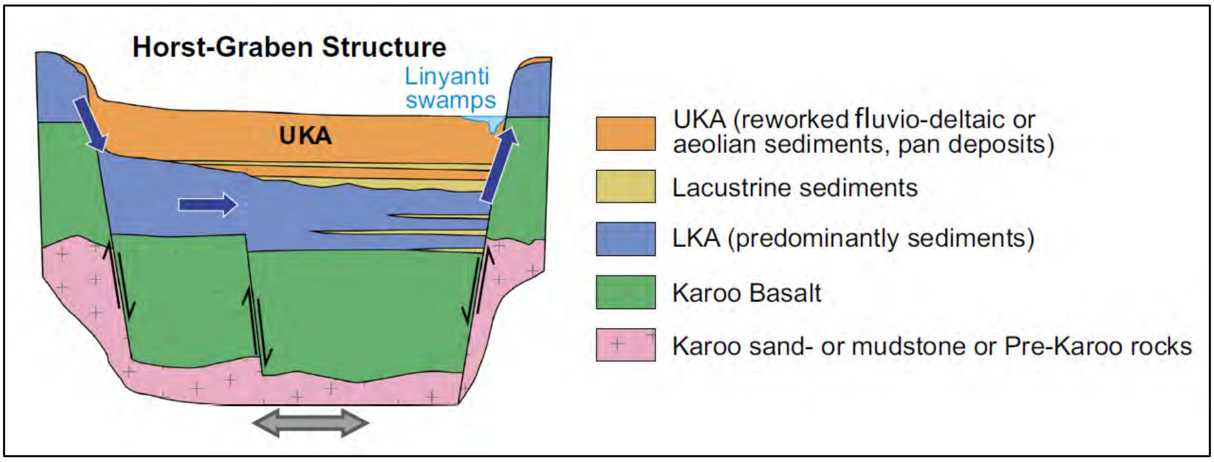


Figure 5.24 Conceptual model of the horst and graben structure of the Zambezi Region, Namibia, showing the tectonic control on the UKA and LKA systems and the confining lacustrine layer(s) between them (Bäumle et al. 2018).

5.2.4 Groundwater quality

Similar to Section 5.1.3, measurements of total dissolved solids are measured along groundwater flow paths within the lower reaches of the Kwando River (Figure 5.25). These values increase along the approx. 80 km flow path due to notable increases in chloride, sulfate, sodium, and alkalinity, whereas calcium and magnesium remain low. Additionally, at 40-60 km the levels of fluoride begin to exceed the WHO maximum guideline recommendations of 1.5 mg/L, increasing to levels of more than 4 mg/L at approx. 70 km (Bäumle et al. 2018). At levels above 1.5 mg/L, there is an increased risk of dental and skeletal fluorosis in humans. The freshly recharged waters in the Kwando floodplains display the lowest total dissolved solids values, followed by the LKA, and then that of the UKA settings. The general evolution of groundwater types in the region transitions from Ca-Mg-HCO3 to Na-(HCO3 + Cl + SO4) (Bäumle et al. 2018).

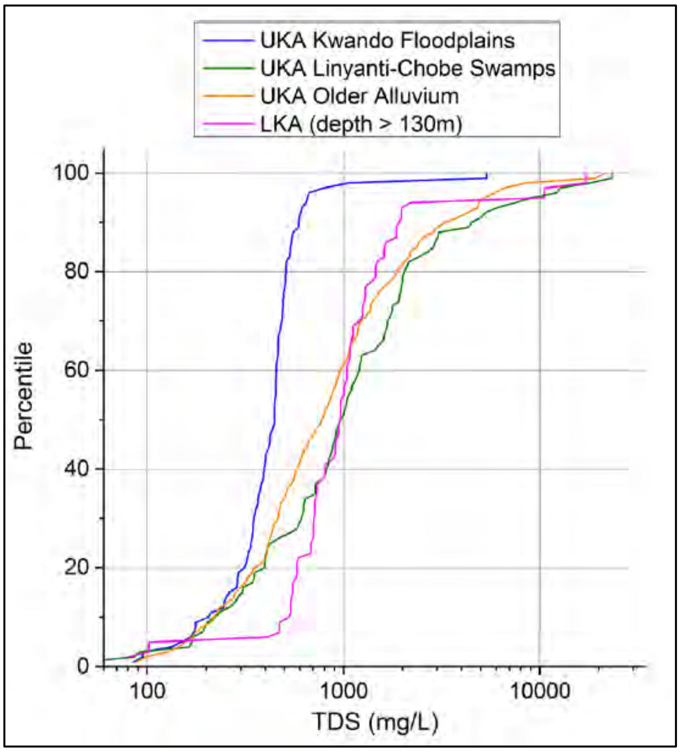


Figure 5.25 Percentile plot showing the general evolution of total dissolved solids along the flow paths between the UKA and LKA in the lower parts of the KRB, from the Kwando floodplains to the Zambezi Region (Bäumle et al. 2018).

5.2.5 Groundwater monitoring, development potential, and climate change adaptation

Mapping existing groundwater infrastructure and water monitoring locations

A map of boreholes (used for either water supply or exploration) was produced based on data acquired during the literature review and the early consultation phase with stakeholders (Figure 5.26). These boreholes represent a subset of the total number of mostly abstraction wells, particularly in the Zambezi Region (c.f. Figure 5.16). Information regarding four recent water supply boreholes in the Sioma Ngwezi NP was provided by S. Mayes, Peace Parks (Appendix I). There are four simple reports in the KAZA-GROW database[11] that provide information from the field reports on borehole depth, borehole casing, static water level, and yield based on an initial pumping test. It is known that the Manjinga and Ijobwe boreholes are non-functioning, the cause of which is unknown. The set of boreholes for water supply in the Simalaha Community Conservancy lies outside of the KRWDA but is useful to incorporate given that these boreholes are currently being drilled/installed (G. Homer, pers. comm.) and they may provide further information on groundwater quantity and quality. The borehole series denoted 41xxx and 200xxx are the boreholes used to explore the UKA and LKA (Section 5.2.1). A series of borehole logs for these can be found in the online KAZA-GROW database.[11]

In addition, many surface water level monitoring stations along the length of the lower stretches of the Kwando River are included, the primary datasets for which are in the online KAZA-GROW database.[11] Finally, the only river gauge on the KRB, at Kongola, is highlighted in Figure 5.26. The time series from the Kongola river flow gauge is shown in
Figure 5.7. The individual datasets from the surface water level monitoring stations are incomplete and not generally suitable for further analysis given the inconsistency of the measurements recorded.

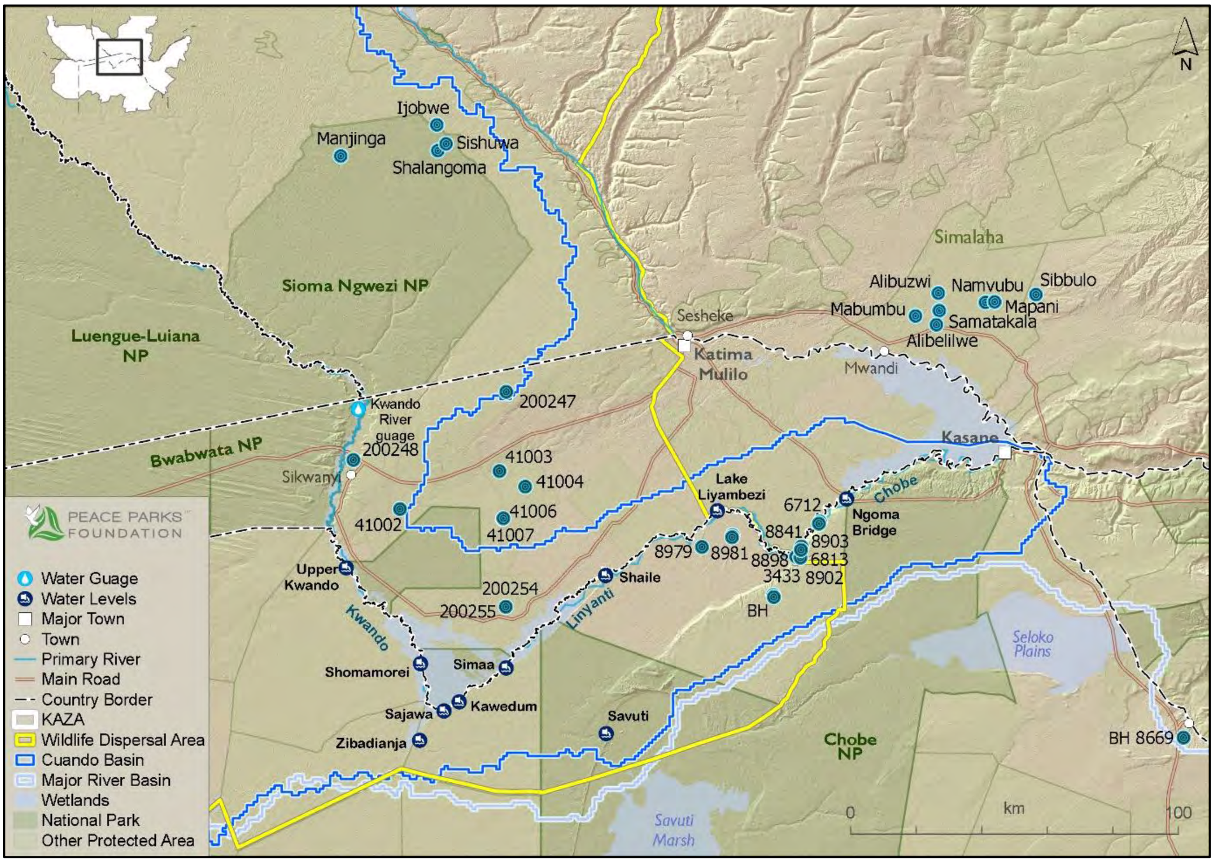


Figure 5.26 The location of a subset of surface water level monitoring stations ('Water Levels'), observation or exploration boreholes (dark green), and the Kongola river flow gauge ('Water Guage') within the lower KRB (Peace Parks 2022).

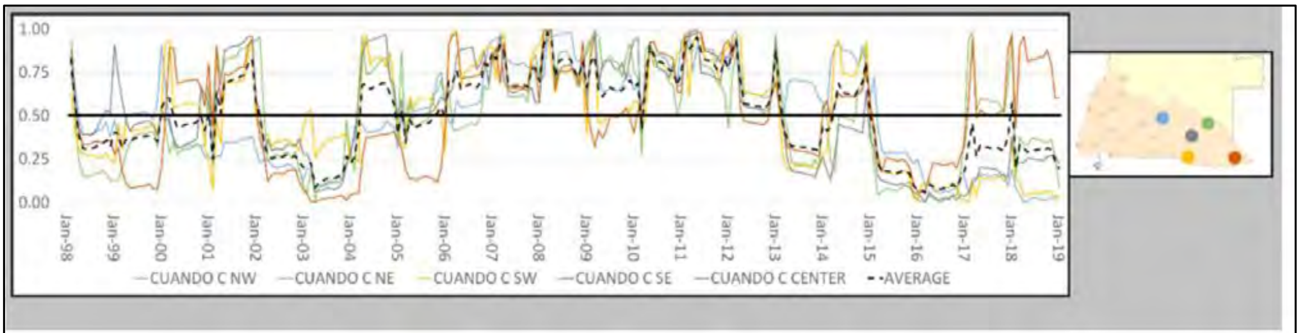
In Botswana, the majority of existing water supply boreholes are located in the western regions of the KAZA TFCA, along the eastern margin of the Okavango Delta Panhandle (not shown here). The cluster of boreholes represents the Kavimba wellfield that was developed to provide groundwater to several villages within the Chobe Enclave (Kachikau, Mabele, Kavimba, Parakarungu, and Satau as well as numerous smaller villages). Communities are also dependent on water supply pipelines from the Chobe River directly. (K. Keetile, pers. comm.).

Generally, speaking, the floodplains in the eastern section of the Western Zambezi region, close to the Zambian border, are often too saline to sustain communities and therefore depend on water pipelines fed from the Zambezi River with a treatment plant based at Katima Mulilo. In the western section, surrounding Kongola, relatively shallow boreholes exploit groundwater at 30-50 m. However, at 70-80 m, it is found to become saline, which suggests the presence of a perched aquifer fed by the Kwando River within this region. Groundwater exploration is focused on this western section given the known presence of the freshwater LKA at approx. 115-120 m depth. Groundwater monitoring in the area has been hampered by ongoing problems with vandalism, and a lack of loggers, and given that this region is not designated nationally as a high priority because groundwater levels remain steady throughout the year in the LKA (S. Ihemba and A. David, pers. comm.).

Climate change adaptation

The importance of groundwater as a perennial relatively accessible source for water and food security will increase under changing climate regimes (Taylor et al. 2013). As highlighted in Section 3.2, it is anticipated that Angola will be one of the most affected regions in southern Africa in terms of decreased precipitation levels and a higher risk of extremes. As most of the KRS depends on water from Angola, and other counties are already the driest, climate impacts will impact severely across all Partner States to the KAZA TFCA.

A recent World Bank report, detailing water security and drought risk in the southern parts of Angola, examines how groundwater can partly help alleviate drought, including in the Cuando Cubango Province (the furthest south-easterly province lying mostly in the KRB), (Serrat-Capdevila et al. 2020). Figure 5.27 shows the development of the Drought Exceedance Probability Index (DEPI) from 1998-2019 for the Cuando Cubango Province across broad areas of the province (Center, NW, NE, SW, and SE), (Serrat-Capdevila et al. 2020). The index is based on the calculation of cumulative monthly rainfall anomalies and indicates drought conditions when the DEPI is less than 0.5. There was a significant drought across southern Angola from 2013-2019, even greater, so in further westerly provinces (data not shown), the local impacts of which were magnified by the lack of drought resilience infrastructure.



Note: Values between 0.5 and 0 indicate drought, more intense as the DEPI values decrease.

Figure 5.27 A time series of drought index (DEPI) across the Cuando Cubango Province, Angola, 1998-2019 (Serrat-Capdevila et al. 2020).

Drought risk regions within the Cuando Cubango Province were identified through mapping that included drought hazard (DEPI Index), exposure (population density), and community vulnerability (water resource reliability, quality, and financial dependency). The resulting high-risk districts were Luengue, Cuito Cuanavale, Savate, Maue, and Bondo. Luengue lies within the KRB and the KAZA TFCA, whilst the town of Cuito Cuanavale lies on the border of the KAZA TFCA, and the Cuito Cuanavale District lies partly within the borders of the KAZA TFCA perimeter in the northwest corner.

In terms of drought mitigation solutions, two case studies were carried out in the Cuvelai basin and Namibe Province. The solutions included surface water harvesting, sand dams, and managed aquifer recharge, all heavily reliant on groundwater and aquifers. No case studies were presented for the Cuando Cubango Province. The selection of appropriate water resource options within a given community was based on local hydrology, geomorphology, and hydrogeological information derived from field missions. The study assumed that groundwater is relatively resilient to drought, whilst local conditions may affect its availability and accessibility as well as quality. To provide increased water security, many complementary strategies were identified concerning groundwater. This included the systematic collection of information on boreholes, aquifer characteristics, groundwater levels, and groundwater quality. The report suggests a moderate groundwater potential in the Cuvelai Basin at depths of 5-200 m but stipulated that this is based on current limited knowledge and that the exploration for the presence of deep fresh groundwater needs to be confirmed. Moreover, given that recharge rates are low in these areas, it is important to fully assess the potential prior to development.

This region-specific identification of solutions has close links to the vulnerability mapping that will be carried out as part of the KAZA-GROW project and helps identify the role groundwater could play in alleviating drought conditions and enhancing climate resilience. Even though only a few case studies exhibited features within the KAZA TFCA, they demonstrate clear examples of how groundwater may play a supporting role conjunctively with surface water in the determination of localized solutions.

Forward planning within the Angola portion of the KRS should focus on the vulnerable areas surrounding Luengue and Cuito Cuanavale. The Luengue region is highly dependent on the Luiana River system. Fritz von Krogisk, the consultant to the KAZA TFCA Secretariat (Appendix I), highlighted the seasonal nature of the river and the particular vulnerability of wildlife, which during drought migrate and concentrate further downstream towards the Kwando floodplains (pers. comm.). This region was also mentioned for its particularly high biodiversity in the stretches of the upper Luiana. It was noted that the effects of drought are compounded by a combination of factors that not only relate to investments in water resources development, but also data availability, community-level planning, and larger institutional capacity (Serrat-Capdevila et al. 2020).

It is important to note that drought and climate change impact more broadly, in Angola, due to its upstream relation to the Partner States, will have compounding effects on both water quantity and quality in these countries. For example, during drought, as surface water flows diminish, there may be a risk of groundwater resources turning more saline due to evapo-concentration, or due to lack of replenishment from freshwater recharge along losing rivers. Hence, adaptation measures will be critical across all KAZA TFCA countries, not just Angola. Additionally, modeling has shown that climate change has reduced the likelihood of large-scale flooding events in the Okavango Delta. The analyses show that this reduction is a result of higher temperatures and consequently increased evaporation (Wolki et al. 2014). Given the predicted increases in surfaces temperatures and reduction in precipitation in various National Parks along the length of the KRB (Table 3.1), in combination with modeling predictions of reduced Kwando River discharge volumes (Box 1), it is possible to infer that large scale flooding events are less likely to occur. The scale and extent of these consequences on long-term groundwater supplies and aquifer storage remain unknown. Serrat-Capdevila et al. (2020) began to explore how parts of the KAZA TFCA may respond to build drought resilience to some of the challenges of climate change.

5.3 Recommendations to improve the knowledge of groundwater resources

The following recommendations are outlined to improve the conceptual hydrogeological model of the KRB and the knowledge base to develop the groundwater potential in the KRS:

To further refine the conceptual hydrogeological model of KRB, the following is recommended:

- Collate primary/remotely sensed data on precipitation, evapotranspiration, soil profiles, geology, groundwater levels, the river flows, etc.
- Advance in particular water resources investigations that include quantification of river baseflows, surface water-groundwater interactions, and identification of recharge and discharge areas. This will help the assessment of Groundwater-Dependent Ecosystems (GDEs) and e-flows (Section 7.5).
- Advance geological/geophysical/aquifer mapping in the region to understand the role of faults and wider tectonics in regional and up/downstream flows in the KRB.
- Review previous hydrogeological modeling to validate/update models for groundwater/ environmental flows, salinity issues, and climate change impacts. The full water balance and flow dynamics can only be fully resolved by a 3D integrated hydrological (including groundwater) model, although the current lack of groundwater and other supportive data needs to be addressed in any model setup.

To fully comprehend and cautiously develop the groundwater potential, the following is recommended:

- Expand groundwater monitoring in particularly vulnerable areas (high demand, incipient resource degradation) as well as in hotspot areas with appreciable potential and include efforts to assess both groundwater quantity and quality.

- Consider options for climate change adaptation in the KRS, particularly through cautious groundwater development for drought protection and livelihood development for local communities. Given the conservation imperative, success with respect to adaptation strategies and implemented measures strongly hinges on nature-based solutions and balancing trade-offs across human water supply and livelihoods needs, and ecosystem/wildlife resilience.

6 TRANSBOUNDARY AQUIFERS

6.1 Transboundary aquifers in SADC

SADC counts on approximately 30 currently identified and mapped TBAs (IGRAC 2021, Villholth and Altchenko 2014) (Figure 6.1).

These aquifers are receiving increasing attention as groundwater generally is becoming more developed due to population growth and climate variability and other pressures, rendering surface water less reliable. Since these transboundary resources are currently being explored and exploited to a relatively limited extent in SADC, it is important that joint assessments are carried out, and progressively international agreements on their development, management, and protection take place. Groundwater resources are broadly used across SADC, typically for distributed domestic supply for rural communities, while intensive and large-scale use is largely still limited. However, with a trend towards more use by sovereign states of these resources, e.g. for urban use, for agriculture, and for mining and industrial uses, including deeper resources so far not developed, it is important that joint knowledge bases and cooperation mechanisms are put in place for identified and targeted systems. It is particularly critical to avoid harmful impacts from unilateral use of, or impacts on, the resources across the borders, calling for states to be aware of their TBAs, their potential, and vulnerabilities.

6.2 Transboundary aquifers in the KAZA TFCA

Figure 6.1 shows the location of the TFCAs and TBAs across the SADC region. The labels 1-5 indicate the five identified TBAs fully within or partially within the KAZA TFCA, in accordance with the map of Transboundary Aquifers of the World (IGRAC 2021). The names, aquifer countries, surface area, and official identification numbers (IDs) of these five TBAs are given in Table 6.1.

The Transboundary Waters Assessment Programme (TWAP 2016) was an initiative supported by the Global Environment Facility (GEF) designed to pull together a wealth of information for a global baseline assessment of TBAs. The initiative brought together representative contributors from the Partner States to TBAs to summarize readily available data and information to create the first global TBA inventory.

Figure 6.1 Distribution of transfrontier conservation areas (TFCAs) overlaid with transboundary aquifers (TBAs) across the SADC region (IWMI - from IGRAC (2021) and Peace Parks (2021)).

Table 6.1 Transboundary Aquifers (TBAs) located in or overlapping with the KAZA TFCA

ID in Figure 6.1	Name of TBA	ID in Global TBA Map (IGRAC 2021)	Countries sharing the TBA	Surface area (km2)[a]
1	Nata Karoo Sub-basin / Caprivi deep-seated Aquifer	AF14	Angola, Botswana, Namibia, Zambia	90,982
2	Northern Kalahari / Karoo Basin / Eiseb Graben Aquifer	AF10	Botswana, Namibia	12,336
3	Eastern Kalahari Karoo Basin	AF12	Botswana, Zimbabwe	127,000[b]
4	Medium Zambesi Aquifer	AF16	Zambia, Zimbabwe	10,705
5	Arangua Alluvial Aquifer	AF18	Mozambique, Zambia	21,235

Source: IGRAC (2021)
[a] Source: IGRAC (2015)
[b] Source: SADC-GMI (2020)

6.2.1 The Nata Karoo Transboundary Aquifer

The Nata Karoo Sub-basin Aquifer or simply the Nata Karoo TBA, (ID=1 in Figure 6.1, and Table 6.1) directly overlaps the KRB and the KRWDA and is the most relevant for this TDA. It is situated in the southern part of the basin and encompasses a broader region across the central KAZA TFCA. It likely intersects the five countries, Angola, Botswana, Namibia, Zambia, and Zimbabwe, as well as the two basins, the Okavango and the Zambezi, though its present extent and delineation are to be considered preliminary (Figure 6.2). It has a seemingly more detailed outline across Botswana and Namibia, but no details are provided in TWAP (2016) for how the given delineation was achieved. More work is required to fully map and understand its extent, both laterally, as well as in the subsurface.

The two countries listed as contributing to the information provided in the TWAP report are Zambia and Namibia, leaving it unclear as to the role of the other three countries in the process. As such, this provides limitations on the possible interpretability of the current TBA delineation, analysis, and summary.

The current synthesis highlights a two-layered system, for which a summary of the hydrogeological parameters is provided in Table 6.2 (TWAP 2016):

1) The first layer is defined as the unconfined Kalahari sediments that stretch regionally across the entire area. On average, the depth to the water table is 13 m (Namibia) and 20 m (Zambia)
2) The second confined layer sits below and has a much smaller coverage, mainly in Namibia (Zambezi Region) and stretching into Botswana. The average depth to the top of this deeper aquifer is 128 m (Namibia)

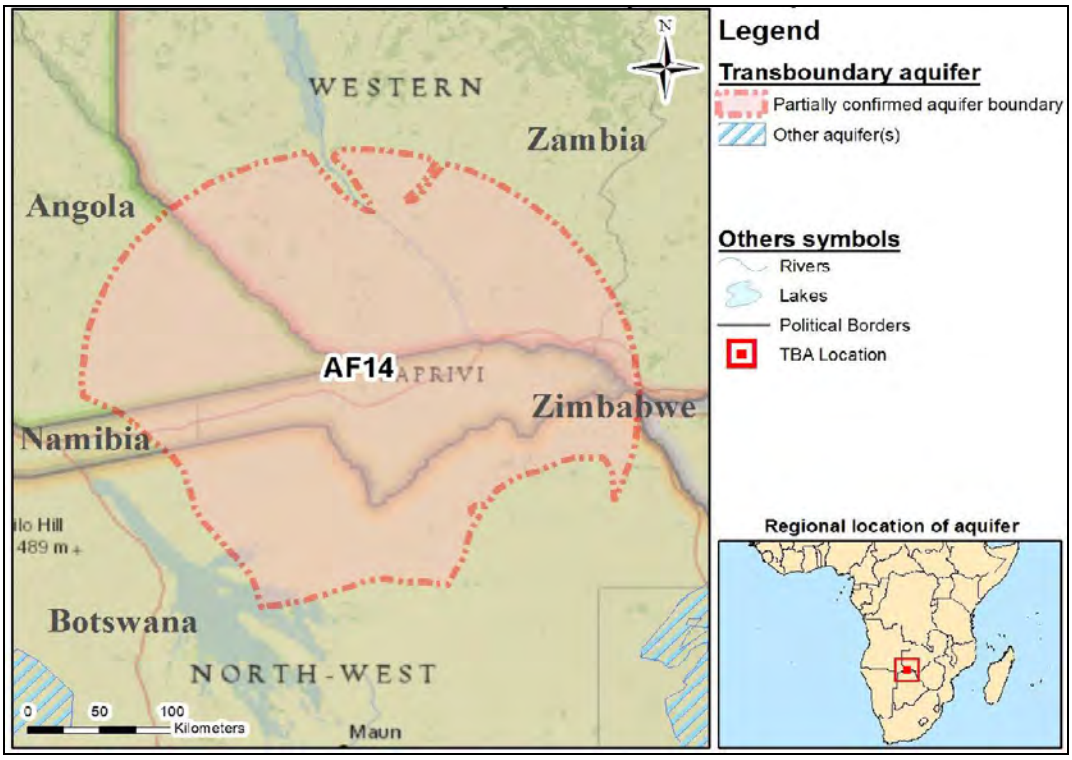


Figure 6.2 Preliminary boundary of the Nata Karoo Sub-basin transboundary aquifer (TWAP 2016).

Key preliminary data for the Nata Karoo TBA are given in Box 5.

Box 5. Key preliminary data for the Nata Karoo Transboundary Aquifer

Total area: 80,000 km^2
Number of countries sharing: 5 - Angola, Botswana, Namibia, Zambia, Zimbabwe
Estimated Population: 260 000
Climate zone: Tropical Dry
Rainfall: 630 mm/year
Hydrogeology/aquifer type: Single to multi-layered aquifer
Degree of confinement: Mainly unconfined - confined in places
Main Lithology: Sediments (mostly sand) and sedimentary rocks (mostly sandstone)

Source: TWAP (2016)

The two-layer conceptual model for the Nata Karoo TBA agrees with the Upper and Lower Kalahari Aquifers (UKA and LKA) (Bäumle et al. 2018) presented in Section 5.2.1. Given that Bäumle et al. (2018) described them in detail after the publication of the TWAP report (2016), and with a focus on the Namibian context, could explain the lack of consistency. In TWAP, the lateral extent of the lower aquifer is not well defined but suggests that it extends into Botswana, whereas in Bäumle et al. (2018), the LKA is well defined by geophysical and geo-structural evidence, and there is no indication that the LKA extends into Botswana. Broad estimates that provide a sense of scale suggest that the total groundwater volume across Namibia and Zambia is approx. 40 km^3. However, considering that the delineation is still uncertain, this figure is associated with large uncertainty. In accordance with the conceptual model for the region, the shallower aquifer (UKA) is likely to have high levels of salinity, particularly in areas away from the rivers, whilst the deep aquifer (LKA) is known to hold freshwater.

TWAP (2016) highlights that 60% of the UKA in Namibia is unfit for human consumption due to high levels of salinity and fluoride.

Table 6.2 Summary of key hydrogeological parameters of the Nata Karoo Sub-basin.

	Distance from ground surface to groundwater table (m)	Depth to top of aquifer formation (m)	Full vertical thickness of the aquifer (system)* (m)	Degree of confinement	Predominant aquifer lithology	Predominant type of porosity (or voids)	Secondary Porosity	Transmissivity (m^2/d)
Angola								
Botswana								
Namibia	13**	130**	190	Aquifer Mostly unconfined, but some parts confined	Sediment - Sand	High Primary porosity fine/ medium sedimentary deposits	No Secondary porosity	190
Zambia	20**	24**	18	Whole Aquifer unconfined	Sediment - Gravel	High Primary porosity fine/ medium sedimentary deposits	No Secondary porosity	25
Zimbabwe								
TBA level								

* Including aquitards/aquicludes

** These values would need revision as a groundwater table higher than depth to top of the aquifer is un-realistic for an unconfined aquifer.

X A value was provided in the questionnaire, but it was considered un-realistic and therefore removed from the table.

Source: TWAP (2016)

6.2.2 Ongoing assessment of transboundary aquifers in the KAZA TFCA

Davies et al. (2013) provided a systematic ranking approach to identifying TBAs of concern in SADC. However, at that point, only two had been identified within the KAZA TFCA - the Eastern Kalahari Karoo Basin (ID=3 in Figure 6.1) and the Medium Zambesi Aquifer (ID=4 in Figure 6.1). These are described as 'troublesome' and 'potentially troublesome', respectively, applying a categorization that includes groundwater flow (degree of recharge and GW-SW interaction) and aquifer vulnerability, knowledge and understanding, governance capability, socioeconomics, and water demand, and environmental issues. In response, and as a reflection of demand from the Partner States, a project commissioned by SADC-GMI is currently undertaking a TDA of the Eastern Kalahari Karoo Basin TBA.[33] The three TBAs (Northern Kalahari/Karoo Basin/Eiseb Graben Aquifer, Medium Zambesi Aquifer, and Arangua Alluvial Aquifer, with ID=2, 4, and 5 in Figure 6.1) have not been subjected to detailed transboundary studies, and are not covered in TWAP (2016).

The OKACOM assessment of groundwater resources in the ORB (OKACOM 2020) undertook an assessment and mapping of TBAs in the basin (Figure 6.3). It is important to note some of the

[33] https://sadc-gmi.org/projects/water-resources-management-research-in-the-eastern-kalahari-karoo-basin-transboundary-aquifer/

differences between the outcomes of the OKACOM study, conducted at a much more local scale, and the aquifers mapped at the global scale (IGRAG 2021, TWAP 2016). The latter does not refer to smaller TBAs and also seems to disregard those, typically alluvial aquifers, that are directly associated with and run along major international rivers. Also, importantly for this TDA, some of the identified TBAs in the OKACOM (2020) study may be trans-basin and shared with the KRB.

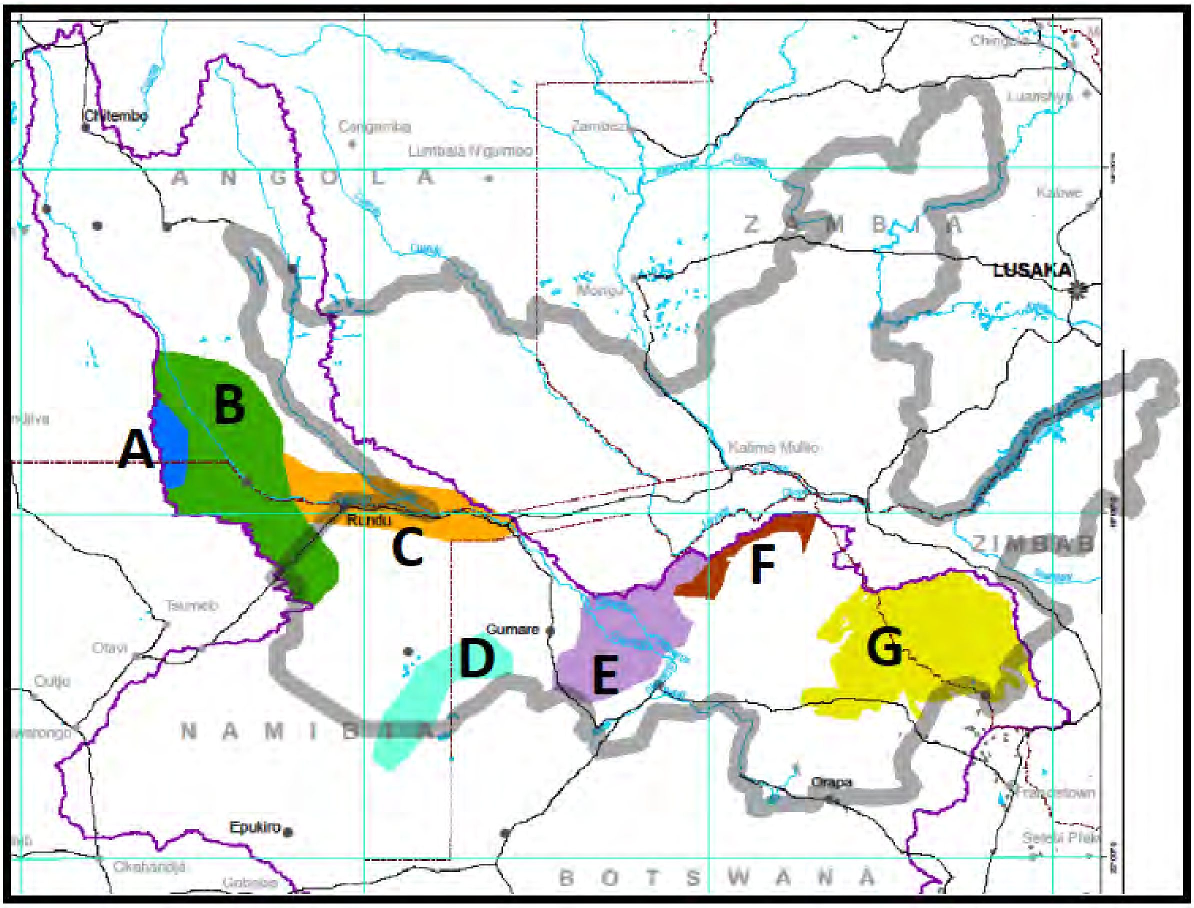


Figure 6.3 Transboundary and/or trans-basin aquifers in the Okavango Basin (purple outline), which lie close to or within the central KAZA TFCA, grey outline, (modified from OKACOM (2020)). Note, some of these aquifers may be trans-basin and shared with the Zambezi Basin. A = Ohangwena Kalahari Aquifer, B = Cuvelai-Etosha Basin, C = Cubango Alluvial Aquifer, D = Northern Kalahari Eiseb Graben Aquifer, E = Caprivi deep Kalahari Aquifer, F = Caprivi deep Karoo Aquifer, G = Eastern Kalahari Karoo Basin (Maitengwe).

From the present and the OKACOM (2020) study, and concerning Figure 6.3, the following list of observations regarding the TBAs in ORB that may be trans-basin with the Zambezi River Basin, and hence also be relevant to the KRS is presented:

Aquifers A and B - These aquifers form part of the recognized Cuvelai-Etosha Basin, corresponding with the Kalahari aquifer (AF13: Cuvelai and Ethosa Basin/Ohangwena Aquifer System (IGRAC 2021)). This area partially overlies with the lower Cubango River Basin (Figure 5.1 and Figure 6.1) but lies outside of the KAZA TFCA.

Aquifer C - The Cubango Alluvial Aquifer is not recognized in the global TBA map (IGRAC 2021). Given that it follows the length of the Cubango River, it does intersect with the KAZA TFCA past the town of Rundu on the border between Angola and Namibia. However, given that such alluvial sediments have a direct hydraulic connection with the river, they are commonly not defined as 'true' TBAs. While not recognized at the global scale, there are clear merits to highlighting these on a more regional level due to the high-potential availability of perennial shallow groundwater resources in proximity to the river. Main aquifers like these that run along international borders will increasingly need to be regulated, as impacts of pumping on one side of the river may impact users on the other side as well as downstream users of surface water, through the hydraulic connection between the aquifer and the surface water.

Aquifers D and G - Aquifer D, the Northern Kalahari/Karoo Basin/Eiseb Graben Aquifer (AF10), and Aquifer G, the Eastern Kalahari Karoo Basin TBA (AF12), are already designated as TBAs in the global TBA map (IGRAC 2021), of which the latter is located in the KAZA TFCA (Figure 6.1 and Figure 6.3).

Aquifers E and F - Aquifer E, the Caprivi deep Kalahari Aquifer, and Aquifer F, the Caprivi deep Karoo Aquifer, lie at the edge of the ORB, falling within the approximate perimeter of the Nata Karoo (Figure 6.2). Although the aquifers appear to be fully in Botswana, and only mapped within the ORB, it is likely that both extend beyond the basin and into the Zambezi Basin, as well as Namibia, and therefore are transboundary and likely form part of the Nata Karoo TBA.

In Figure 6.3, the Caprivi deep Karoo Aquifer has a NE trending northern border that aligns with the NE-SW faults that demarcate the graben structures within the ORZ, e.g., the Chobe Fault (Figure 6.4). Its southern border, on the other hand, clearly aligns with the southeastern perimeter of the Nata Karoo, indicating that this aquifer is included in the Nata Karoo (Figure 6.2). Hence, it appears likely that overlapping aquifers between Botswana and Namibia are governed partly by the faults (maybe connected hydraulically or separate aquifers, depending on the permeability of the faults). The extent of such elongated aquifers/aquifer parts to the NE and SW cannot be determined by the faults. This could mean that the Nata Karoo TBA could extend further SW or NW than suggested in Figure 6.2 and connected/aligned with the Caprivi deep Kalahari Aquifer (Figure 6.3).

Also, as apparently only Zambia and Namibia contributed to the TWAP, means that the delineation remains to be finalized, including any extension into Angola, Zambia, and possibly Zimbabwe. With high socioeconomic development in the Zambezi Region and surrounding regions, as seen from the human footprint map for the KAZA TFCA (KAZA TFCA 2014) (Figure 7.2) and the vulnerability map by IWMI (2021c), it is likely that pressure on water resources will raise in these areas, and further attention to such shared resources will increase, and maybe preferentially for the deeper aquifers, which appear to hold better quality water. However, since these resources are old and little renewable (Bäumle et al. 2018), it will be critical to set up proper exploration and exploitation plans as well as cooperation mechanisms.

Finally, it is also possible to infer that the Nata Karoo is a trans-basin, crossing the Okavango and Zambezi River Basins. This will open opportunities and the need for inter-basin cooperation regarding transboundary resources. This epitomizes the need for data sharing across boundaries, in this case, to primarily assess the extent and nature of the TBAs but also for ongoing and future development and cooperation around the aquifers.

6.2.3 Data and knowledge gaps

From Chapters 5 and 6, the following data and knowledge gaps have been identified related to a better understanding of the KRS and the associated TBAs, with a focus on the Nata Karoo TBA:

1. **Improved delineation and further assessment of the Nata Karoo TBA**. From the TWAP report, there are only two out of five countries (Zambia and Namibia) have contributed to the delineation of the Nata Karoo transboundary aquifer (TWAP 2016). Furthermore, in OKACOM (2020), the full extent of the Nata Karoo in Botswana is unknown, even if there may be indications from the

literature that transboundary and trans-basin aquifers exist between Botswana and Namibia. The OKACOM report further indicates two different aquifers (the Caprivi Deep Kalahari and the Caprivi Deep Karoo Aquifers), while not providing details of their delineation. Therefore, there is substantial work to be done in terms of harmonization and interpretation to better understand the hydrogeology and regional extent of the Nata Karoo transboundary aquifer(s). To accomplish this, geophysical (airborne or otherwise) investigations may be undertaken to improve the understanding of, not only the Nata Karoo, but also all of the transboundary aquifers in KAZA TFCA.

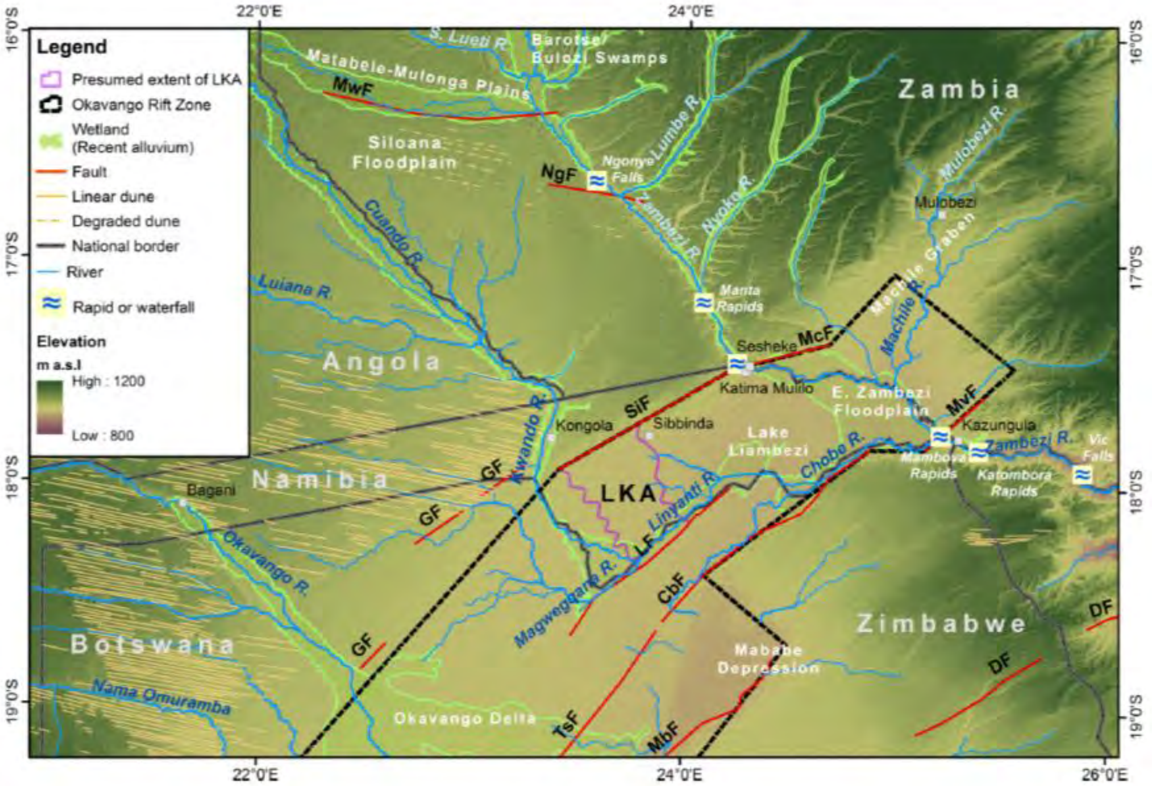


Figure 6.4 Elevation, geomorphology and main structural features in the northeastern part of the ORZ, The faults are abbreviated as follows: CbF = Chobe Fault, DF = Deka Fault, GF= Gumare Fault, LF = Linyanti Fault, MbF = Mababe Fault, McF = Machile Fault, MvF = Mambova Fault, MwF = Mwamba Fault, NgF = Ngonye Fault, SiF = Sibbinda Fault, TsF = Tsau Fault (Bäumle et al. 2018).

2. **The groundwater ages and recharge rates of the LKA**. What would be the long-term impacts of groundwater development within this aquifer, total storage, and sustainable abstraction in line with expected demand increases, effects of climate change, etc?
3. **What effect does rainwater have on groundwater quality** away from the river sections in arid/semiarid areas? Is it all being evaporated? Can diffuse recharge be quantified (as a rule of thumb, e.g., precipitation under 400 mm in semi-arid areas doesn't lead to any diffuse recharge (typically <10 mm/year) – knowledge from southern Africa (Xu and Beekman 2019)? What are the water quality implications of climate change and more pressure on groundwater resources?
4. **Resolving the full water balance and more detailed flow dynamics for the KRB** and neighboring catchments to be able to draw direct comparisons and devise adaptation and management plans. The semi-quantitative analysis carried out in the TDA provides indications and possible hypotheses, but there is no comprehensive quantitative study to resolve the groundwater circulation patterns and interactions with GDEs/surface water at the basin scale, which are critical to understanding environmental processes and requirements as well as climate risks, sustainable development scenarios, and climate change adaptation options.

6.3 Recommendations to close the knowledge gap on transboundary aquifers

From this chapter, the following recommendations are outlined to close the knowledge gap on the Nata Karoo TBA and TBAs more generally within the KAZA TFCA:

- Harmonize and expand geological and hydrogeological datasets and maps across borders of the Partner States to assist interpretation of the regional extent of the Nata Karoo TBA system and to improve knowledge surrounding other TBAs in the KAZA TFCA.
- Conduct geophysical (airborne or otherwise) investigations to improve the delineation, laterally as well as vertically, of the TBAs in KAZA TFCA, with priority on the Nata Karoo TBA. This should also include selected exploratory drilling and isotopic studies and 3D groundwater modeling.
- Create joint databases, knowledge management hubs, and data sharing mechanisms for the harmonized hydrological and hydrogeological data sharing and application as a component of enhancing transboundary cooperation around shared aquifers.

7 ECOSYSTEM SERVICES, ENVIRONMENTAL RISKS, AND TRANSBOUNDARY ISSUES

7.1 Ecosystems and their goods and services

Ecosystems, whether natural or anthropogenic, can be broadly classified into two major categories: aquatic and terrestrial. An ecosystem is an ecological unit, in which biotic (living) and abiotic (non-living) components interact, sustain life, and function as a single unit (Balasubramanian 2008). The benefits to human populations derived from these systems are termed ecosystem services.

Freshwater wetland ecosystems in the KAZA TFCA include rivers/streams, floodplains, and inland deltas, like the Okavango Delta (Box 6), lakes, the desert ecosystems, and vegetation assemblages, ranging from savanna grasslands, and shrubs to miombo and mopane woodlands (Maquia et al. 2019, OKACOM 2010), dry forest and closed woodland (Figure 3.6). Protected areas in the KAZA TFCA, which encompass a wide diversity of ecosystems, include 20 national parks, 85 forest reserves, 22 conservancies, 11 sanctuaries, 103 wildlife management areas (WMA), and 11 game management areas, altogether covering an estimated area of 371,394 km^2 (71%) under 'wildlife' management, leaving an estimate of 148,520 km^2 (29%) for agricultural land use including rangeland, and built-up area (KAZA TFCA 2014) (Figure 3.7). The areas range from national parks under state control to multiple-use areas under community management (e.g., the conservancies). The seasonality of the ecosystems governed by climate, in terms of flooding, water, and vegetation availability, provides the unique character of KAZA TFCA (KAZA TFCA 2014). KAZA TFCA is home to vast wetland ecosystems, some of which are dependent on natural inflows and annual flooding regimes resulting in seasonally flooded grasslands – providing habitats for diverse habitats and biodiversity and providing various ecosystem goods and services for local populations (One Earth, 2021) (Box 6).

In paleo-evolutionary terms (in the Pliocene to Holocene), the two major river basins (the Zambezi and Okavango) were closely interlinked hydrologically in that both these river systems contributed flows to major wetlands, including the Okavango Delta (Cumming 2008). This study reveals that this interlinkage feature has influenced the biodiversity of the area and has important implications for present wetland species and their conservation. This illustrates the clear link between geology/morphology, hydrology, and ecosystems. Additionally, the wetland vegetation is of major importance and creates much of the biodiversity as well as being the source of the uniqueness of the area. KAZA TFCA (2014) estimates a total of over 100 species of fish have been recorded in the KAZA TFCA, and the high level of biodiversity is of particular importance in sustaining the local populace and the economy at large in aquaculture and fisheries-related activities.

Box 6. The Okavango Delta

The Okavango Delta (15,000 km^2) is located in northwestern Botswana and is Africa's third-largest inland alluvial fan and the continent's largest endorheic delta (UNESCO World Heritage Centre, 2021). It is a dynamic and complex aquatic/terrestrial ecosystem, composed of permanent and seasonal swamps and drainage rivers, characterized by varied climate regimes and environmental factors.

UNESCO World Heritage Centre (2021) emphasized that the Okavango Delta is home to some of the most endangered species of large mammals, such as the cheetah, white rhinoceros, black rhinoceros, African wild dog, and lion. The ecological integrity of the wetland system is considered to being largely untransformed and close to pristine conditions. The biota has uniquely adapted their growth and reproductive behavior, particularly the flooded grassland biota, to be timed with the arrival of floodwater towards the dry winter season of Botswana (UNESCO World Heritage Centre, 2021). KAZA TFCA (2014) estimates a total of 128 species of mammals (including 20 large herbivores) have been recorded with major populations of large mammals that are not well represented in other parts of the African continent, including the red lechwe and the sitatunga antelopes.

A clear southwest to northeast annual rainfall gradient from low (100 mm) to relatively high rainfall (approx. 1100 mm) in the north, results in a corresponding gradient in the geographic occurrence of large mammal and tree species, with the highest numbers of species in the northeast and eastern part of the KAZA TFCA (Cumming 2008). This trend also characterizes the vegetation structure resulting in desert shrubs to the south and the increasing prevalence of forest ecosystems towards the north (Cumming 2008). This applies outside the major drainage/delta systems.

Ecosystem Services: Tourism and Conservation

One of the critical benefits the KAZA region offers is the extensive wildlife population that is essential for tourism. Tourism is used as a vehicle to enhance biodiversity conservation, economic development, and poverty alleviation through job creation initiatives in the Okavango and Zambezi River Basins (Mogende 2016, Suich 2008). Conservation efforts contribute to maintaining rich biodiversity with efforts to protect species such as the African wild dog, the wattled crane, the slaty egret, sable and roan antelope, the Nile crocodile, and Cheetah (KAZA TFCA 2014).

In addition, the rural communities directly and/or indirectly depend on natural resources and hence the conservation of the KAZA TFCA is vital for their livelihoods. These natural resources include water resources, thatching grass, edible and medicinal plants, reeds, wood, and wildlife (Glatz-Jorde et al. 2014).

7.1.1 Groundwater-dependent ecosystems

Murray et al. (2006) defined groundwater-dependent ecosystems (GDEs) as "ecosystems that must have access to groundwater to maintain their ecological structure and function." However, Colvin et al. (2007) argue that the term is difficult to define and means different things in different countries. In some publications, the term GDEs has been used to describe ecosystems that are found and restricted to below ground, within an aquifer. For example, Eberhard (2004) acknowledges the role groundwater plays in sustaining ecological processes and health of many surface ecosystems and is critical towards defining physical and chemical habitat conditions for subterranean aquatic animals (stygofauna).

Additionally, GDEs may be characterized as either aquatic or terrestrial. Colvin et al. (2007) indicate that wetlands, swamp forests, floodplains, lakes, rivers, caves, and springs are examples of probable aquatic GDEs. In contrast, some of the terrestrial GDEs include riverine forests, riparian zones, and other phreatophytic vegetation, like deep-rooted trees in savannas and deserts. It is clear that groundwater underpins critical ecosystem services, and that changes to groundwater systems, from climatic or anthropogenic processes, may alter groundwater levels, storage, recharge, or discharge, which in turn are key to sustaining important ecosystems.

GDEs are too often overlooked and seldom incorporated within groundwater studies, as such, very few have been undertaken in southern Africa and the ecological impacts of climate change on GDEs in the SADC region are largely unknown (Majola et al. 2021). A recent study in the Tuli-Karoo TBA, situated at the juncture of Botswana, South Africa, and Zimbabwe, highlights that sustainable GDE management lies within integrated water resources management to assess which groundwater processes control the effects of climate-induced impacts on GDEs (Majola et al. 2021).

Given the above, and the explored interactions between surface and groundwater detailed throughout Chapter 5, in particular in the context of the KRB, some examples of candidate GDEs include the Kwando River itself, riparian wetlands, and the Linyanti-Chobe floodplains. In addition, potential groundwater-dependent terrestrial ecosystems in the KRB include vegetation dominated by Kalahari, miombo, mopane, and teak woodlands, which are deep-rooting trees that tap into the sub-surface water (Fanshawe 2010, OKACOM 2010). It is important to note that more than often, groundwater and surface water interact, and their interdependencies may provide critical ecosystems, as the 'saltwater pump' example illustrates (McCarthy et al. 2012, Bauer-Gottwein et al. 2007) (Figure 7.1).

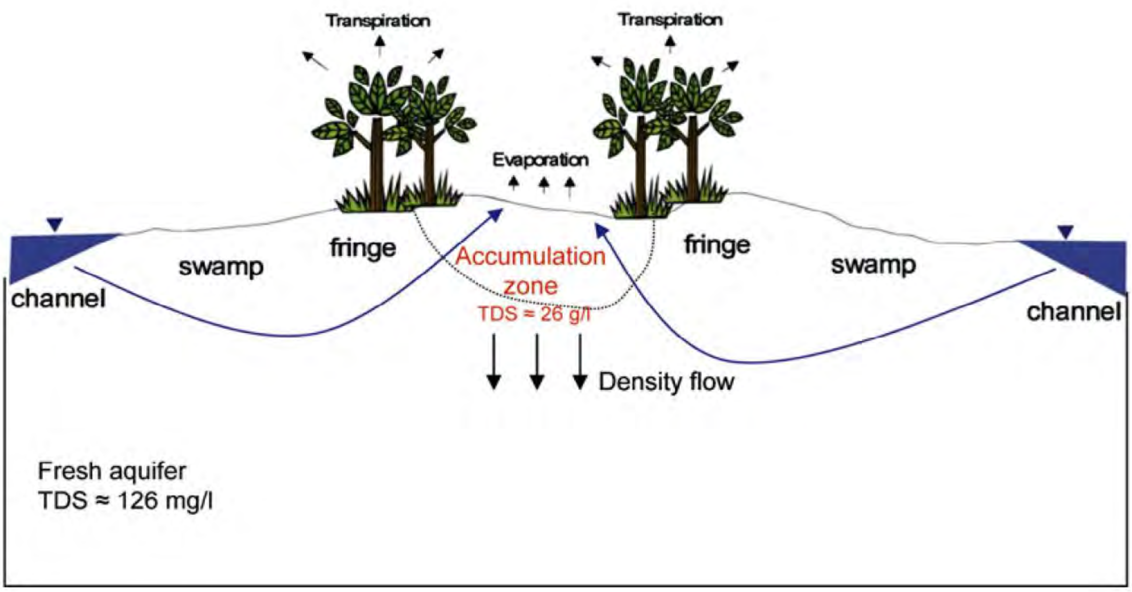


Figure 7.1 Conceptual model for the 'saltwater pump' on an island in the Okavango Delta. The water demand by evapotranspiration on the island is satisfied by freshwater inflow from the river. Salinity accumulation occurs under the island and may sink and disappear to deeper groundwater due to density differences (Bauer-Gottwein et al. 2006).

7.1.2 Environmental flow requirements

The term environmental flow (e-flow) was originally recognized in the Brisbane Declaration (2007) as the flows that describe the quantity, quality, and timing of water required to sustain freshwater ecosystems and human well-being that depend on these systems. However, the term "environmental flows" has been used differently across the world, and examples of various terms that have been used include instream flow needs, ecological reserve, ecological water demands, environmental water requirements, compensation flow, and minimum flow requirements, among others (WMO 2019). Furthermore, the e-flow concept has evolved shifting its meaning from the traditional view of minimum water amounts to a more comprehensive and holistic understanding of any given freshwater ecosystem and its dynamics and its ecosystem services and uses (WMO 2019)

In the context of the KAZA TFCA, one of the e-flow assessments within the KAZA TFCA was an integrated flow assessment done by King et al. (2009) for the Okavango River (Box 7). The basins consist of the areas drained by the Cubango, Cutato, Cuchi, Cuelei, Cuebe, and Cuito rivers in Angola, the Okavango River in Namibia and Botswana, and the Okavango Delta.

So far, no assessments of e-flows have been performed for the Kwando River, though this is currently in progress, under the leadership of WWF-Zambia (Box 4) due to its significance in sustaining downstream areas with perennial water flows, including important wetlands, like the Linyanti/Chobe Wetlands. The KRB in many respects presents similarities to the ORB, and results of studies like the one by King et al. (2009) demonstrate potential future development and climate risks. While the Kwando River is relatively pristine, there is also increasing pressure on the basin from climate change and from various upstream development plans that may alter flows significantly. In addition, it is recognized that groundwater, is linked to floodplains in the upper parts of the Kwando River, like in the case of the Cubango/Okavango River, and in particular, the Cuito tributary plays a critical role in sustaining baseflows, and by implication e-flows. Further understanding of these processes is warranted in upcoming investigations.

Box 7. E-flow assessment for the Okavango River

The King et al. (2009) study describes the Okavango River system as a flood-driven system with the presence of floodplains throughout, but most prominently on the Cuito River in Angola, on the Okavango along the Angola/Namibia border, and in the delta in Botswana. These floodplains sustain the river in the dry season and store floodwaters that would otherwise increase flooding downstream. The simulations of flow regimes were undertaken with the Pitman model considering eight sites along the up- to downstream reaches of the Okavango River systems. A scenario analysis includes the effects of climate change predicted from global circulation models using statistical downscaling procedures, covering overall wetting and drying, as well as effects of local development plans with the assumption that increased development is tied to higher water usage. The findings indicate that at Sites 1, 2, 3, 5, and 6, the Mean Annual Runoff (MAR) declines to 93-97% of Present Day (PD) under the Low (Development) Scenario, to 85-91% under the Medium Scenario and to 69-79% under the High Scenario. The largest impacts are observed under the High Scenario and at the most downstream sites, indicating modest reduction of MAR along the system, mostly through diversions for agriculture and urban areas. In addition, taking into consideration climate change, the overall trend is that the flood season starts a little earlier, lasts longer, having higher flood peaks, and providing more water than PD, particularly in the wettest scenario and in the upper parts of the basin.

Furthermore, the study finds that the Cuito River is key to the functioning of the whole lower river system, because of its strong year-round flow, its wet-season storage of floodwaters on vast floodplains, and the gradual release of water back into the river in the dry season. However, the model assumes that the surface water-groundwater flows are unidirectional, i.e., there is only infiltration from surface water to replenish groundwater reservoirs and is therefore unable to fully capture the impacts of wet-season storage.

The level of development represented by the High Scenario would have a significant impact on the river system, and severely reduce the services it presently provides. This situation would be mirrored by the Medium Scenario under the driest climate change condition. Until there is more certainty regarding climate change predictions, it cannot be assumed that the river ecosystem will continue to support present beneficial uses beyond the Low Scenario of development. If the wettest climate change condition manifests, then development could proceed to the Medium level without an overall loss of ecosystem function.

The results further indicate that predicted impacts are likely underestimated as the localized impacts of infrastructure construction, the longitudinal impacts of fragmentation of the system, and the direct impacts of increasing human numbers have not been factored in. The overall conclusion made is that future development and climate change have the potential to lead to significant transboundary ecological and social impacts. As such, the costs in terms of ecosystem degradation could be perceived as outweighing the economic benefits of development.

Source: King et al. (2009)

7.2 Wildlife and biodiversity

A Transfrontier Conservation Area (TFCA) is transboundary between two or more sovereign countries, encompassing one or more protected areas as well as multiple-resource areas for the use of communities and private landholders, managed for the sustainable use of natural resources (Singh 1998). The TFCA concept aims to integrate the conservation of biodiversity and rural development (Munthali et al. 2018). The TFCA concept works toward allowing key ecological processes to continue across borders and to function using dedicated border-crossing wildlife migration corridors (Munthali et al. 2018). Regarding wildlife biodiversity, KAZA TFCA aims to establish functional wildlife connectivity patterns throughout its protected landscape (van Tienhoven Stichting 2021). According to van Tienhoven Stichting (2021), actual landscape linkages among several protected areas have yet to be realized, resulting in isolated wildlife populations across the KAZA landscape, with the additional need to avoid functional corridors from disappearing due to both anthropogenic and natural factors. Some of the activities associated with anthropogenic factors include ongoing illegal logging in forested areas and illegal land clearing in communities. Naturally associated factors include a drying climate that reduces the amount of natural forage and water availability emphasizing the need to conserve these wildlife corridors, particularly those occurring across human-impacted landscapes (van Tienhoven Stichting 2021). This is particularly essential considering that wildlife migrates in search of scarce resources, often in seasonal patterns, and may in the process ignite human-wildlife conflicts.

By creating larger connected areas, TFCAs also help wildlife to adapt to climate change, enabling movement away from climate-stressed areas. This is particularly important in southern Africa where climate change may lead not only to drier conditions but also to changes in precipitation patterns that will affect the distribution of plants and animals, both spatially and temporally (KAZA TFCA 2014). The important interlinkages between areas through the larger river systems, and their seasonal and spatial variability, also enhances connectivity across KAZA TFCA, implying the critical need for integrated natural, including water resources, management across these large systems, to preserve these hydraulic connections critical for habitats and wildlife.

Some of the key protected areas in the KAZA TFCA include the Victoria Falls (which traverses both Zambia and Zimbabwe) and the Okavango Delta in Botswana (KAZA TFCA 2019). The Okavango Delta provides refuge and water to crocodiles, lions, leopards, hyenas, rhinoceroses, baboons, and several other wildlife including the endangered African wild dog. KAZA TFCA (2019) estimates that more than 600 bird species populate the skies in the KAZA and that 524 species are known to breed within the TFCA; there are 76 palearctic migrants and an additional 52 intra-African migrants. Additionally, ornithologists have identified 12 Important Bird Areas which provide favorable habitat conditions for various bird species within the KAZA TFCA. The KAZA TFCA is home to Africa's largest contiguous elephant population as well as major populations of buffalo, hippopotamus, lechwe, roan, zebra, wildebeest, waterbuck, puku, bushbuck, and the sitatunga among others (KAZA TFCA 2019). Kafue NP in Zambia contains one of the last remaining viable populations of wild dogs on the continent (Carlson et al. 2004), and white rhinoceros' may be found in small numbers around the Okavango Delta area. Additionally, Timberlake and Childes (2004) estimate the presence of approximately 128 and 50 species of reptiles and amphibians respectively in the KAZA, although the distribution and status of many species in Angola and south-west Zambia are still unknown.

Challenges exist that impede the sustainable transfrontier management of wildlife. Lindsey et al. (2014) reveal that due to the clearance of natural vegetation and conversion of land to agriculture and livestock grazing, as well as hunting for domestic and commercial use, wildlife populations and natural habitats are under pressure in protected areas such as Game Management Areas (GMAs). Ongoing efforts to ensure inclusivity, partnership, and legally defined and protected rights in so far as the use of wildlife and access to benefits therefrom is to include approaches such as Community Based Natural Resources Management (CBNRM) (Davis et al. 2020).

Initial CBNRM programs were funded by USAID through the Wildlife Conservation Society, initiated in the mid-1980s, and managed by the Government of Zambia focusing mainly on the GMAs in the Luangwa Valley around Kafue NP and the Lower Zambezi Valley. These programs were based around shared revenues from hunting fees and channeling the funds back into the community for social infrastructure projects and law enforcement. To further support CBNRM, subsidiary legislation was introduced in Zambia in the early 1990s to partially decentralize authority over wildlife to communities through what is known as the Administrative Management Design for Game Management Areas

(ADMADE), under the jurisdiction of the Department of National Parks and Wildlife Service (Davis et al. 2020).

In the late 1990s and based on the CBNRM approach, community conservancies also began to proliferate within Namibia under the Namibian Association of Community Based Natural Resources Management Organizations. They are designed to maintain connectivity between the protected areas within the KAZA TFCA as well as supporting these communities to sustainably manage their lands using zoning strategies to separate agriculture and livestock from wildlife using Transboundary Natural Resources Management (TBNRM) forums. These offer conservancies and other active and recognized community-based organizations (CBOs), rural communities, and their traditional leaders a voice on conservation matters at a transnational level (NACSO & MEFT 2021). Through the TBNRM forums, the Integrated Rural Development and Nature Conservation (IRDNC) body can assemble stakeholder communities to share information, engage with competent authorities, train community game guards, and organize joint patrol exchange trips among the rural communities of the five countries (NACSO & MEFT 2021). Four TBNRM forums have been in place since 2002, with MoUs set up between Namibia and the relevant adjoining countries to enhance transboundary cooperation with further endorsement from the respective KAZA TFCA governments and the KAZA TFCA Secretariat. The forums often undertake collaborative work in areas such as protecting wildlife corridors, erecting veterinary fences, and helping to reduce uncontrolled fires. Those that sit along the banks of the Kwando include The Chobe Enclave Community Trust – Bamunu – Salambala Conservancy Forum (Namibia/Botswana), the Kwandu-Imusho Transboundary Forum (Namibia/Zambia), and the Kwandu Community Transboundary Forum (Namibia/Zambia/Angola).

These platforms may also be enhanced and provide the principles and platforms of international best local practice for multi-country water and groundwater cooperation, in addition to the established local natural resource management, while in the long term potentially formalizing cooperation (into the treaty, agreement, or other) through these ongoing structures.

7.2.1 Human-wildlife conflicts

There is no doubt that human livelihoods and economies around the world depend on ecosystem goods and services derived from nature, including natural resources such as wildlife. With respect to transnational wildlife management policies, the KAZA TFCA aspires to promote the sustainable utilization of wildlife while preserving healthy populations in the face of human interaction across the five Partner States. The KAZA TFCA approach attempts to alleviate the problem of human-wildlife conflict (HWC) and place the coexistence of wildlife and people at the core of socio-economic systems. It should be noted that the nature of human-wildlife dynamics may either be characterized by conflicts that could be potentially destructive or, on the other hand, be characterized by a neutral or beneficial coexistence.

FAO defines HWC as any human-wildlife interaction which results in negative effects on human social, economic, or cultural life, wildlife conservation, or the environment.[34] Typically, such conflicts are associated with competition for the same limited natural resources. Numerous cases from countries including those in the developing world demonstrate the severity of human-wildlife conflicts (Decker et al. 2002). A study by Stoldt et al. (2020) revealed that one of the main management challenges of the KAZA TFCA is how to favorably manage the HWCs under growing human and wildlife populations and other pressures, e.g., from climate change. HWC, in the form of crop raids by elephants, hippos, and buffalo, or predation on livestock by lions, leopards, hyenas, and crocodiles, has impoverished subsistence farmers and also caused fatalities. Water can also be the cause of HWC, as both humans

[34] https://www.fao.org/forestry/wildlife/67288/en/ (as updated: March 3, 2021).

and wildlife compete for the same drinking water sources, or humans need to access water from water bodies inhabited by e.g., crocodiles. One of the aims of KAZA TFCA is to coordinate efforts in various protected areas to control HWCs. Gross et al. (2021) cite the reduction, fragmentation, and degradation of habitats for wildlife as the main driver of HWCs. Habitat destruction by either human or natural causes implies that wild animals will be losing space and relevant resources for their survival thereby further increasing competition. Communities experiencing negative impacts on agricultural production and livelihoods, a decrease in the quality, and even loss of life, quickly oppose conservation which can lead to the removal, killing, and even eradication of the species involved in the conflict. An example of an HWC event involving lions, occurred in 2012 and 2013, in which cattle predation happened in community conservancies adjacent to two smaller national parks (Mudumu and Nkaza Rupara NPs) and peaked at 135 livestock kills. In retaliation, 17 lions from one national park were killed (Hanssen et al. 2020). This human-lion conflict continued, and by the end of 2014, only a single adult female from one pride remained (Hanssen et al. 2017). To manage the situation to a tolerable level, the Kwando Carnivore Project was initiated in 2013 to analyze the situations in which predation occurred. Gross et al. (2021) reveal that it was evident that predations occurred when free-ranging, unprotected cattle roamed the area during the evening and at night. An effective strategy to combat the negative consequences of HWC evolves around collaborative approaches amongst the stakeholders involved that ensure wildlife connectivity and resource access across human-inhabited spaces along with the relevant accommodating infrastructure.

7.3 Environmental and health risks

This section highlights the potential threats to the environment and human and wildlife health in the KAZA TFCA.

Disease

One of the critical threats experienced in KAZA TFCA relates to disease issues that result from the co-existence of wildlife and livestock (FAO 2021). As an example, livestock farming within KAZA TFCA has led to the transmittance of Foot and Mouth disease between livestock and Cape Buffalo when in close contact. Rural communities that share resources such as common pastures and water points with wild animals may lead to outbreaks – suggesting that these shared areas are likely sites of transmission. This is a potential environmental and health risk that may emerge and has been demonstrated in the past to cause a major setback to economic activities associated with the international trade of beef from KAZA TFCA and the SADC at large (FAO 2021).

Many countries in the SADC region value both livestock and wildlife sectors, and agriculture forms an essential component of rural livelihoods within the KAZA TFCA (Chapter 4), and this has triggered countries to evaluate how best to manage risks from diseases. Therefore, it is imperative to manage local development and wildlife conservation from a health perspective (Cumming et al. 2015, Thomson et al. 2013). Preventative measures such as veterinary fences may be emplaced, or increasingly natural barriers may be relied upon to separate the populations (Brito et al 2016) combined with 'commodity-based trade'[35], which could alleviate the disease burden and help support local farming communities. As a result, the occurrence and accessibility of both livestock and wildlife, to essential water and gazing resources in a coordinated manner play a key role in the prevention of disease transmission. At the same time, the challenges associated with finding the right balance between open landscapes, addressing land use rights, and promoting safe trading regulations have been highlighted (Cumming et al. 2015, AHEAD 2004-2022[36]).

[35] Commodity-based trade approaches focus on the safety of the beef production process, rather than on the animal disease situation in the locality of production. http://www.wcs-ahead.org/kaza_ahead_fao_workshop_2016/kaza_ahead_fao_workshop_2016.html
[36] http://www.wcs-ahead.org/workinggrps_kaza.html

The encroachments of natural habitats from anthropogenic pressures are a major driver of Zoonotic diseases; those that transfer between humans and wildlife, for example, Avian Influenza and COVID-19. The protraction of COVID-19 in the KAZA TFCA and globally at large, has devastated livelihoods and economies, leaving nature more vulnerable to further degradation, which reiterates the need for the availability of clean and safe water for all to combat the pandemic. The risks of emerging novel diseases increase with changes in land use that are being re-purposed for agriculture or infrastructure development, resulting in a decrease in biodiversity, increased habitat fragmentation, and a greater number of human encounters (Gross et al. 2021). The conservation of natural ecosystems maintains a high level of biodiversity and minimizes the risks of these transmissions occurring (Wilkinson et al. 2018). In line with HWCs (Section 7.2.1), this further highlights the importance of a well-connected landscape and healthy ecosystems, as this offers the best mitigation strategy for zoonotic disease prevention (FAO 2020).

The sudden death of an elephant population in northern Botswana and Zimbabwe was investigated by van Aarde et al. (2021). The restriction of freshwater supplies may have led these large mammals to resort to consuming water polluted by blue-green algae blooms. Alternatively, confined conditions and relatively high animal densities coupled with the occurrence of an unknown contagious disease are another potential cause. van Aarde et al. (2021) argue that malicious poisoning and poaching are unlikely causes.

Within the waters of the Zambezi River, the first documented outbreak of Epizootic Ulcerative Syndrome (EUS), or red spot disease, infecting freshwater and brackish fish, was confirmed in the Chobe-Zambezi rivers in 2007 (Sibanda et al. 2018). The fish die-off was significant and may also cause sickness in humans consuming under-cooked affected stock (reliefweb 2019). The most affected country was Zambia, where over 2000 villages and some 700,000 people were at risk of food insecurity because fish is not only a source of revenue in many rural districts but is also the cheapest available source of protein (reliefweb 2019). The source/origin is unknown, but the disease is known to have spread across continents, now affecting at least 24 countries globally (reliefweb 2019). Given the large and transboundary nature of the Zambezi River system, cases were further detected in Namibia, Botswana, and Zimbabwe. The spread and the interconnected nature of the disease highlight the importance of international cooperation and monitoring to be able to quickly mobilize on disease containment (Sibanda et al. 2018).

Anthropogenic threats

Land-use change drives changes in sediment dynamics (especially in the uplands in Angola), water quality, and abundance and distribution of biota, e.g., through deforestation and conversion to agriculture and cattle grazing (OKACOM 2011a). Cumming (2008) argues that land degradation and desertification are triggered by anthropogenic factors mainly associated with inappropriate land use such as excessive deforestation and uncontrolled wildland fires. These impacts appear to be more prevalent in Mudumu, Sioma Ngwezi, and Luengue-Luiana National Parks within the KAZA TFCA. Fire-related desertification has several environmental consequences, primarily soil erosion and non-native plant invasions (Neary 2009). In the context of the KAZA TFCA, Mpakairi et al. (2018) found that fires in the area predominantly occur during the dry season, making lightening an unlikely ignition agent, thus implying that human impacts are the likely trigger. Consequently, fire management in KAZA TFCA should involve efforts to educate local communities and tourists about the ecological hazard of wildland burning.

Other anthropogenic threats to wildlife and biodiversity are associated with poaching (Munthali et al. 2018), over-fishing (Peace Parks 2020), habitat fragmentation (Stoldt et al. 2020), and water scarcity and contamination (KAZA TFCA 2014), which are aggravated by the growing human population, underdeveloped rural livelihoods, and climate variability (Stoldt et al. 2020). The COVID-19 pandemic has increased poaching for local consumption, as the access to food has decreased (Akinsorotan et al. 2021), and generally, the net impact of COVID-19 on conservation and the environment is assumed to be negative (Lindsey et al. 2020).

The drivers of poaching are often complex and multifaceted, yet it remains one of the most pertinent anthropogenic threats in the KAZA TFCA Wildlife Dispersal Areas (WDAs) (Munthali et al. 2018). According to Munthali et al. (2018), the three classes of poaching in the KAZA TFCA include 1) **subsistence poaching** typically targeting small game meant to meet subsistence needs and characterized by low technology (e.g., the use of traps and snares); 2) **commercial poaching** characterized by advanced technologies, including firearms, GPS and mobile phones; and 3) **a hybrid form of poaching**, which is reportedly a common practice in KAZA TFCA and typically combines commercial and subsistence poaching (Munthali et al. 2018). Poaching at a commercial scale in the KAZA TFCA operates within organized syndicates that target commercially valuable species, e.g., elephants, lions, leopards, black rhinos, white rhinos, and others (Munthali et al. 2018).

Overfishing and the usage of unsustainable fishing practices are reportedly another threat in KAZA TFCA (Peace Parks 2020). For example, one of the unsustainable fishing practices occurring on both the Namibian and Zambian sides of the Zambezi River is the use of monofilament gill nets. These are less durable and are frequently discarded in rivers, resulting in the nets trapping and killing fish and other animals, such as birds, snakes, and even larger animals such as hippos (Peace Parks 2020).

According to KAZA TFCA (2014) human footprint map, the Angolan portion of the area shows a low impact and limited infrastructure, due in part to the lingering impacts of more than twenty-five years of civil war. Botswana also has low overall human impact, but relatively high impact along the Okavango Delta panhandle (the part before the river flows diverges into the actual delta), the western and southwestern delta fringes, and along the Zimbabwe and Namibia borders in the east and northeast. In Namibia, impacts are low in the southwestern portion of the KAZA TFCA, but fairly high in the eastern Zambezi Region and around the population centers of Katima Mulilo and Rundu. In Zambia, the impact is generally low except for high impacts in the south-eastern section, while very high impacts prevail just outside the KAZA TFCA boundary on the east. In Zimbabwe, impacts tend to be high to very high throughout its KAZA TFCA area with the exception of the broad area around and inside Hwange NP. The general explanation for this pattern is that the population is higher in the east, decreasing westward, except for the area around Rundu.

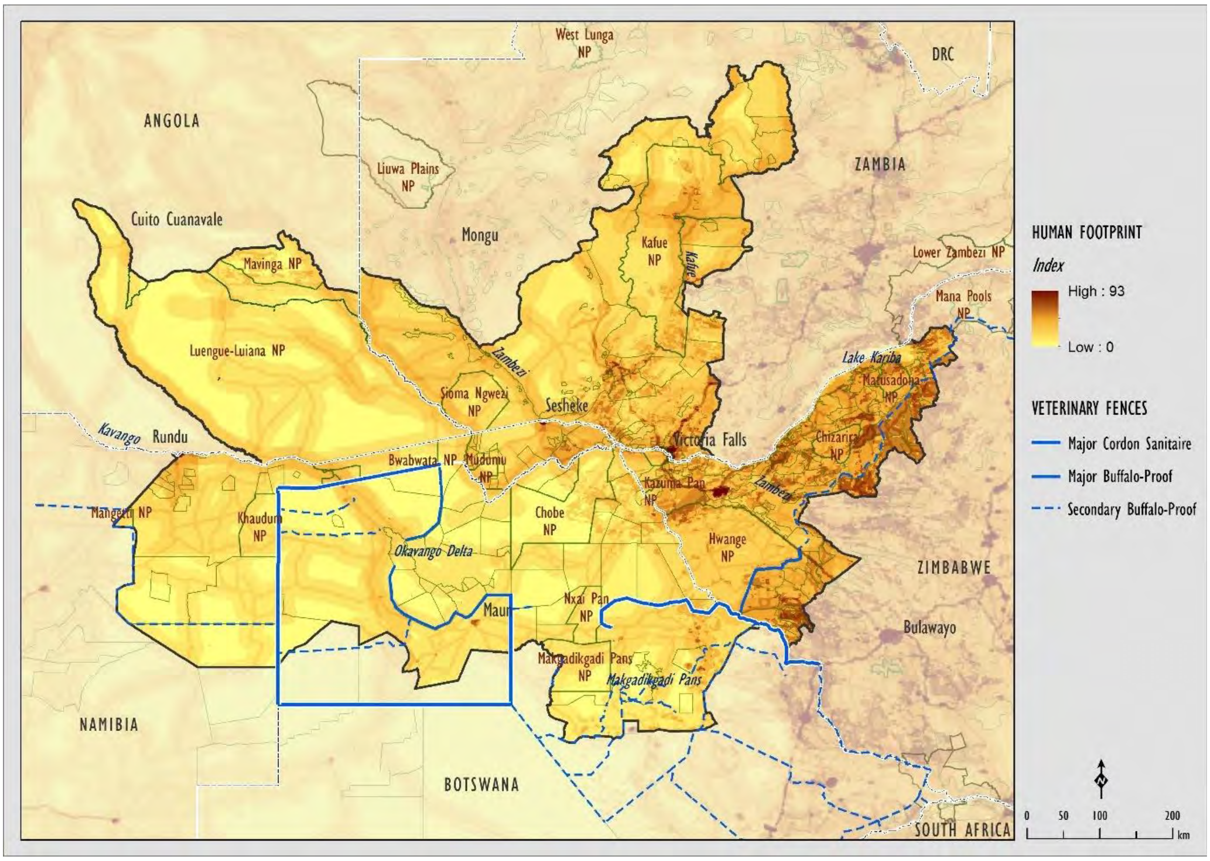


Figure 7.2 Human footprint map for KAZA TFCA (KAZA TFCA 2014)

Understanding the suitability of water quality in any given area in the KAZA TFCA to support various uses is essential. For example, in the Zambezi River Basin, water quality problems range in magnitude, form, and source (World Bank 2010). Major sources of pollution emerge from domestic waste and agricultural and industrial effluents. Degraded water quality adversely affects economic growth and environmental integrity as well as poses direct threats to both human and animal health. The World Bank (2010) highlights that while most of the cities in the Zambezi River Basin have sewage treatment works, other towns lack these treatment facilities, and one critical town is Livingstone where Victoria Falls is situated and is part of the KAZA TFCA. This results in the accumulation of untreated domestic sewage, which primarily causes high trophic conditions (associated with nitrates and phosphates) in aquatic environments, also termed eutrophication. It should be noted that eutrophication can also be associated with the indiscriminate discharge of agricultural effluents resulting from excessive fertilizer application, mostly associated with commercial farming. However, relatively little is known about the actual extent of water quality degradation in the KAZA TFCA.

Other major threats to the KAZA TFCA ecosystems have been identified as habitat destruction, particularly riparian and well-developed woodlands, from human encroachment giving rise to increased HWCs, especially where unprotected land borders prevail (KAZA TFCA 2014). Finally, there is an increasing threat from industrial development, commercial fish farms, intensive agriculture, and associated pollution and mining activities, e.g., in the Ngamiland District in Botswana. The potential threat of large-scale infrastructures, such as dams in either the Okavango or Kwando Rivers remains.

Climate Change

Munthali et al. (2018) highlight climate change as one of the greatest environmental risks to ecosystem resilience and human and wildlife health in the KAZA TFCA. It is vulnerable to various manifestations of climate change that include variability and a potential overall reduction in water resources, risk of food insecurity due to decline in agricultural production, change and loss of biodiversity, increases in vector and waterborne diseases, and increased desertification due to changes in rainfall and intensified land use.

A study by Andersson et al. (2006), like that of King et al. (2009) (**Error! Reference source not found.**), applied the pitman hydrological model to assess the impact of various development and climate change scenarios on downstream river flows within the Okavango River System. Predictions indicate that the potential impact of climate change, as simulated by a selection of Global Climate Models (GCMs), on long-term mean flow exceeds that associated with the development scenarios. However, Andersson et al. (2006) indicate that the uncertainty in these predictions is high. Nevertheless, there is a clear indication of reduced flow from 2050 onwards, with implications that the mean future river regime in the Okavango River may be similar to the most extreme dry conditions observed from historical records (Andersson et al. 2006).

7.4 Transboundary issues

Transboundary conservation issues across the KAZA TFCA

Among the key defining aspects of the KAZA TFCA is the interstate migration of wildlife within the region. The TFCA concept aims to ensure that key ecological processes proceed to function even where borders have politically divided ecosystems and wildlife corridors (Munthali et al. 2018). One of the key drivers of wildlife migration is the pursuit of vegetative and water resources. Loarie et al. (2009) revealed that elephants move about 3 km/day in wet landscapes and up to 6 km/day in drier ones. This is of relevance to KAZA TFCA as groundwater is increasingly developed within protected areas, as a means to provide drought relief for critical wildlife populations, and possibly also to manage migratory patterns of wildlife and avoid HWC (S. Mayes, pers. comm.). Such issues require further attention going forward as there are generally large trade-offs between mitigating drought and general water shortage for wildlife and promoting conservation and biodiversity (Shannon et al. 2009). These aspects tie to the water scarcity vulnerability mapping and the integrated groundwater potential mapping in the context of the KAZA-GROW project (IWMI 2021c).

Transboundary water resources issues in the KRS and KAZA TFCA

With respect to transboundary issues, or disputes, related primarily to water development and management in KAZA TFCA, and potentially in specific border regions, relatively little information is available in the published or grey literature (e.g., for the ORB: Earle and Méndez (2004)).

Issues around TBAs and groundwater in the KRS are currently not reported. Generally, transboundary issues can be categorized into three main types, namely but not limited to the following:

1. Issues of common and potentially transboundary character, but not of transboundary concern
2. Issues of transboundary character, but not of transboundary concern
3. Issues of transboundary character, and transboundary concern (i.e., potentially requiring transboundary cooperation)

Transboundary issues and joint priorities that emerged as part of the early TDA process, with relevance for (ground) water management and regional cooperation, include:

- Definition of the Kwando River as a separate river system with endorheic properties, or as a tributary to the Zambezi River, and implications for the management responsibility of ZAMCOM and Partner States
- The need for a higher degree of incorporation of groundwater into ZAMCOM strategies and plans.
- The issue is that the upper catchments of the Kwando River and Barotse Floodplain are not incorporated into water management for the KRWDA.

- The need for integrated modeling of the KRB, including explicit incorporation of groundwater, as a tool to understand surface-water-groundwater interactions, climate change and development impacts, and for determining e-flows.

7.5 Recommendations to protect ecosystems and reduce environmental risks

In this chapter, the following recommendations are highlighted to protect ecosystems in the KAZA TFCA and reduce environmental risks:

- Work towards co-producing an **e-flows assessment** of the Kwando River Basin (KRB). This should take specific account of the role of groundwater in supplying baseflows.
- Investigate **Groundwater-Dependent Ecosystems (GDEs)**. These systems include wetlands, riparian vegetation, rivers, and deltas. There are significant GDEs in the KRB (e.g., the Linyanti Wetlands, Lake Liambezi, and the Kwando River itself). These investigations would support the identification of potential (transboundary) Ramsar sites as well as critical approaches to their long-term management.
- Consider the role of water resources (including groundwater) in inflicting and alleviating **environmental risks** such as human and animal disease, anthropogenic threats, and climate change. An appreciation of the complexity of the contexts shows that solutions are not just about the provision of Artificial Water Points (AWPs) but that these must take into consideration the risks of HWCs, local conservation strategies, and wildlife migration in a transboundary context.
- Ensure that all issues are approached with a **transboundary lens** so that the solutions benefit humans, ecosystems, and wildlife across the entirety of the KAZA TFCA.

8 LEGAL, POLICY, AND INSTITUTIONAL FRAMEWORKS

Preceding sections have highlighted the main socioeconomic activities and biophysical environment of the KAZA TFCA, and within it the KRS. This chapter presents the legal, policy, and institutional environment currently surrounding the region in terms of governing freshwater resources and conservation activities at various levels, with a specific focus on the management of groundwater, in its role in supporting conservation, livelihoods, and economic development and with focus on the transboundary aspects. A range of international, regional, transboundary, and national legal, policy, and institutional arrangements[37] are assessed in relation to groundwater demand and supply management for conservation and socio-economic development because of climatic changes. A review of the gaps therein concerning freshwater and conservation management is provided. The chapter shapes the argument for and proposes a TFCA-level Groundwater Management Framework (TGMF) for the KAZA TFCA and TFCAs more broadly in SADC, concluding by presenting elements that could form part of such a TGMF.

8.1 Integrated frameworks for freshwater and conservation governance

8.1.1 The SADC context of freshwater and conservation governance

[37] Institutional arrangements in the context of this TDA refer to the organizations and associated formal resolutions and interactions in place to manage freshwater and conservation including their terms of reference and policy underpinnings.

The KAZA TFCA brings together freshwater and conservation governance challenges and opportunities. This introduces potential overlaps among existing frameworks, which require further understanding and coordination to enhance the building of synergies. An especially important consideration is the role that RBOs play within the KAZA TFCA and that enables streamlining and coordination of freshwater, ecosystem, and conservation-related activities (Figure 8.1). In this report, the focus is not on the various sectors, i.e., WASH, livelihoods, wildlife conservation, etc. related to water, but rather on the management of the freshwater resources, which in turn enable the achievement of these sectoral goals.

Globally, TFCAs are conceptualized as possible peace-building mechanisms also referred to as peace parks (Carius 2006). It is believed that building cooperative arrangements around shared natural resources allows for peaceful conflict resolutions. Such cooperative arrangements have been known to withstand political unrest between their constituting nations (Carius 2006). However, despite the proclamation of the SADC Programme for Transfrontier Conservation Areas in its fifth component that "*Member States acknowledge that the primary beneficiaries of TFCAs must be these rural communities who have an intrinsic right to be involved in the decision-making processes*" (SADC 2013), there are documented controversies around the establishment of TFCAs and the sociopolitical power dynamics in the southern Africa region (Büscher 2010). These are related to unrealized benefits by local communities and the disruption of livelihoods in the transition to conservation (Mogende 2016, Sinthumule 2017). Hence, the dual value proposition of TFCAs linked to ecotourism and improved livelihoods (Büscher 2010) needs to be continuously revisited and upheld.

Water demand in the KAZA TFCA emanates from conservation and tourism activities, urban and economic development, as well as local communities. Policies and institutional structures that support the various sectoral water demands are thus an important consideration, especially given increasing climate change and developmental impacts. It is particularly important to bear in mind the vulnerability that communities often face concerning basic water and sanitation services and access to water for small-scale irrigation and grazing land for livestock within TFCAs. Sinthumule (2017) contends that TFCAs in SADC have generally not benefitted the livelihoods of indigenous communities as would be expected, partly due to lack of access to resources like water, or, due to competing interests for the same resources by other sectors.

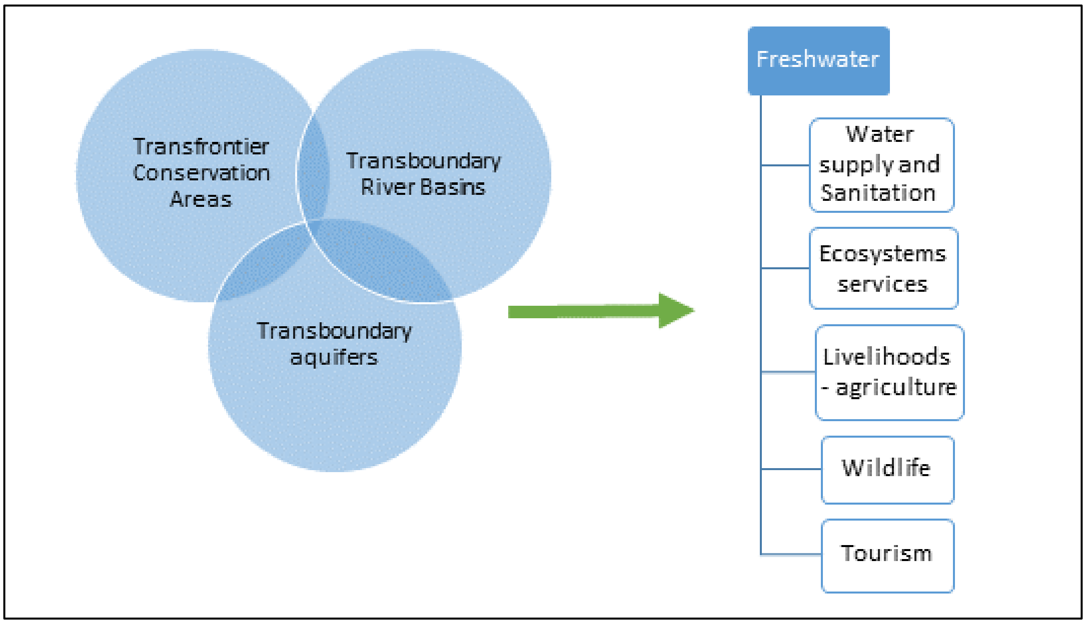


Figure 8.1 Integrating transboundary governance frameworks in the KAZA TFCA towards freshwater governance for (i) water supply and sanitation (ii) ecosystem services (iii) livelihoods (iv) wildlife conservation and (v) tourism and other economic sectors.

Several levels or layers of analysis and scales of governance emerge in the KAZA TFCA (Figure 8.2). At each level, water, including groundwater, has a specific role to play in sustainable development and food and water security. For instance, at the river basin level, groundwater connected to the river system supports baseflows. At the TFCA level, groundwater supports wildlife and ecosystem conservation, tourism, and local communities and livelihoods, overlapping with basin organization functions. At the Nata Karoo level, the refinement of the aquifer delineation opens up opportunities for transboundary cooperation around the shared resources at both local as well as international levels. Critically, the governance layers are not discrete units but rather integrated across the various scales. The various governance frameworks relevant to these layers will be addressed in the following sections.

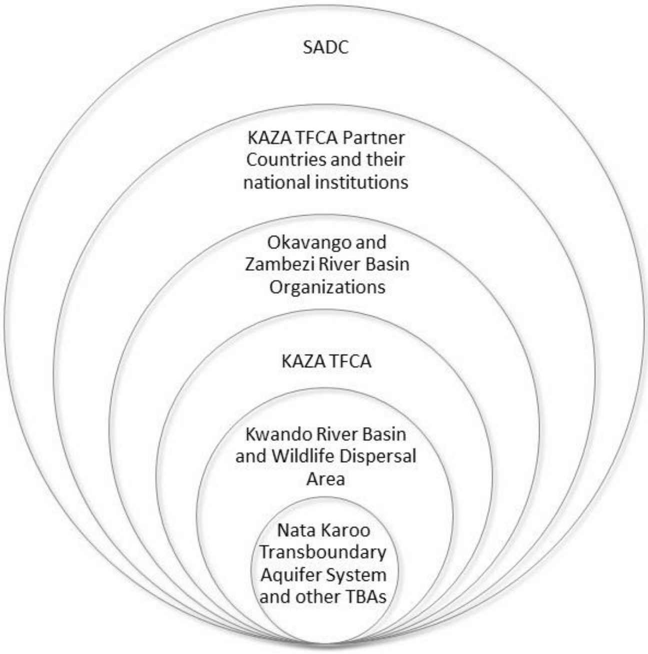


Figure 8.2 Layers of transboundary governance in the KAZA TFCA relevant to this study.

8.2 International frameworks for shared freshwater and conservation governance

8.2.1 International freshwater governance frameworks

The need to further transboundary water cooperation has led to high-level calls in recent years, such as statements of the United Nations Secretary-General, heads of agencies, and other high-level persons, for countries to develop rivers, lakes, and aquifer arrangements, guided by international water conventions.

The following three central focus governance frameworks apply to fresh water, with some specific focus on groundwater.

Convention on the Protection and Use of Transboundary Watercourses and International Lakes (Water Convention)

The Water Convention was adopted in Helsinki in 1992 and entered into force in 1996. While the Water Convention was originally envisaged for the European region, since March 2016, all UN Member States can accede to it. Ratification has been slow with only 37 states having ratified the Convention while 16 have signed[38]. Between 2018 and 2021, five African countries have acceded to the Convention: Chad, Senegal, Ghana, Guinea-Bissau, and Togo[39]. Under the Water Convention, the Model Provisions on Transboundary Groundwater have been developed to guide transboundary cooperation on shared groundwaters. Nine provisions are presented as central to transboundary groundwater cooperation including the principles of no significant harm and reasonable utilization. In addition, specific provisions on the common identification, delineation, and characterization of groundwater as well as the conjunctive use of surface and groundwater are also highlighted (UNECE 2014).

[38] https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-12&chapter=27&clang=_en
[39] https://unece.org/environment-policy/water/about-the-convention/introduction

Convention on the Law of the Non-Navigational Uses of International Watercourses (Watercourses Convention)

The Watercourses Convention was adopted in 1997 and came into force in 2014.[40] Since then, ratification has been slow with only 37 states having ratified the Convention while 16 have signed[41]. Eckstein observes that interest in the Convention is fading despite its accommodating framework structure (Eckstein, 2020). None of the KAZA member states have ratified the Convention. However, the SADC Revised Protocol on Shared Watercourses aligns closely with the Watercourses Convention, for example, as far as the establishment of basin agreements and supporting institutions (Centre for Water Law, Policy and Science n.d). Similarly, both the Water Convention and the Watercourses Convention are closely aligned and supplement each other rather than contradict (UNECE 2016). Together, they foster a better understanding of international water law, and countries can be a party to one or both Conventions (UNECE 2016).

Draft Articles on the Law of Transboundary Aquifers

The Draft Articles on the Law of Transboundary Aquifers were adopted by the International Law Commission of the United Nations General Assembly in 2008. They provide important guidance on the legislative framework for shared aquifers. However, the Draft Articles are not yet in force. Allan et al. (2011) provide three factors of justification for the adoption of the Draft Articles: (i) About 90% of freshwater resources are contained in aquifers; (ii) The need to fill the gap of the UN Watercourses Convention; and (iii) Unique groundwater attributes, e.g., slower, but greater risks and impacts from contamination and over-abstraction.

While the discussion is ongoing on the future of the Draft Articles, it is clear that groundwater should not be simply subsumed under surface water provisions, but should rather be made more visible in policy, including transboundary policy, based on its centrality to maintaining ecosystems and building water and food security and resilience. The Draft Articles remain an agenda item on the United Nations General Assembly for 2022 (United Nations and UNESCO 2021). Although they have not come into force, they have been applied in informing transboundary cooperative agreements such as on the Guaraní Aquifer shared by Argentina, Brazil, Paraguay, and Uruguay in 2010 (UN 2019). The SADC RSAP IV also seeks to raise awareness of the Draft Articles among its member states (SADC 2016). The application of the Draft Articles to conservation areas is not documented.

There is no single, comprehensive international water convention adequately addressing various waters, including surface water and groundwater. What is missing at this level is a protocol on shared aquifers, which clearly outlines the unique proposition of groundwater use and occurrence within broader water and natural ecosystems, and how it should be sustainably developed, used, protected, and managed.

8.2.2 International conservation governance frameworks

The Ramsar Convention on Wetlands

The Convention on Wetlands of International Importance, also known as the Ramsar Convention or the Convention on Wetlands, was signed in the city of Ramsar, Iran in 1971 and came into force in 1976. It is one of the most prominent global environmental conventions[42], which provides a framework for the sustainable management and use of wetlands including transboundary wetlands. It is an intergovernmental treaty that has been ratified by the majority of the United Nations member states.

[40] https://legal.un.org/avl/ha/clnuiw/clnuiw.html
[41] https://treaties.un.org/Pages/ViewDetails.aspx?src=IND&mtdsg_no=XXVII-12&chapter=27&clang=_en
[42] Also known as multilateral environmental agreements (MEA): https://www.unep.org/explore-topics/oceans-seas/what-we-do/working-regional-seas/partners/global-multilateral.

For a site to be declared a Ramsar site, it has to meet at least one of nine criteria pertaining to biodiversity and unique features (Table 8.1). The designation process is initiated by the interested party and involves a series of steps of collecting ecological data, assessing ecosystem services, and gaining support from local stakeholders, after which the formal designation process can begin (Ramsar Regional Center – East Asia 2017).

Table 8.1 Nine criteria for designating a wetland a Ramsar wetland.

No.	Criteria
1.	Contains a representative, rare, or unique example of a natural or near-natural wetland type found within the appropriate biogeographic region.
2.	Supports vulnerably endangered or critically endangered species or threatened ecological communities
3.	Supports populations of plants and/or animal species important for maintaining the biological diversity of a particular biogeographic region
4.	Supports plant and/or animal species at a critical stage in their life cycles, or provides refuge during adverse conditions
5.	Regularly supports 20,000 or more water birds
6.	Regularly supports 1% of the individuals in a population of one species or subspecies of water birds
7.	Supports a significant proportion of indigenous fish subspecies, species or families, life-history stages, species interactions, and/or populations that are representative of wetland benefits and/or values and thereby contribute to global biological diversity
8.	Is an important source of food for fish, spawning ground, nursery, and/or migration path on which fish stocks, either within the wetland or elsewhere, depend
9.	Regularly supports 1% of the individuals in a population of one species or subspecies of wetland-dependent non-avian animal species

Source: Ramsar Convention Secretariat, 2010

The definition of wetlands covers a broad range of habitats from lakes, rivers, and riparian zones, to mangroves and salt marshes, and coral reefs. The scope of the convention is therefore extensive, with 2432 sites declared as Ramsar sites across the world as of Nov 2021[43]. Currently, there are no international conventions that cover conservation and water resources in a similar manner as the Ramsar Convention.

Implementing structures for the convention include the secretariat, advisory missions, capacity-building programs, and regional and local initiatives (Table 8.2). These mechanisms ensure that the convention is implemented, and its requirements strengthened across contracting parties.

Table 8.2 Institutional structures and mechanisms for implementing the Ramsar Convention.

Ramsar implementing structures	Responsibilities
Conference of the Contracting Parties	Policy making organ of the convention made up of government representatives of the contracting parties
Standing Committee	Oversees Convention affairs and the activities of the Secretariat. It comprises elected Contracting Parties who serve for three years.
Ramsar Convention Secretariat	The Secretariat's administrative duties related to maintaining the List of Wetlands of International Importance and providing

[43] https://en.wikipedia.org/wiki/List_of_Ramsar_Wetlands_of_International_Importance

Ramsar implementing structures	Responsibilities
	administrative, scientific, and technical support to contracting parties, in relation to the implementation of the Strategic Plan
Scientific and Technical Review Panel	Provides scientific and technical guidance to the Conference of the Parties, the Standing Committee, and the Secretariat
Ramsar Advisory Missions	A technical assistance mechanism providing expert advice to contracting parties about how to respond to threats to the ecological character of a Ramsar site and associated wetland issues
Ramsar Communication, Education, Participation, and Awareness Programme	Focuses on capacity building, education, participation, and awareness-raising for individuals and communities to participate in wetland and water resources management
Ramsar Regional Initiatives	Support cooperation and capacity building on wetland-related issues in specific regions

Source: Ramsar (2016)

To maintain the Ramsar sites in a state that continues to satisfy the specified criteria (Table 8.1), Ramsar employs several guidelines on the sustainable use of wetlands, highlighting relevant elements with a bearing on freshwater conservation, including transboundary, and how this relates to groundwater/aquifer management (Table 8.3).

Table 8.3 Ramsar resolutions and guidelines with some focus on groundwater aspects.

Resolution	**Relevance**
Ramsar Strategic Plan 2016-2024 Resolution XII.2. Ramsar Strategic Plan 2016-2024	Strategic cooperation between contracting parties can be strengthened through the designation and joint management of transboundary Ramsar sites at the river, lake, and groundwater basin level, with the possible support, upon request, of the Ramsar Secretariat, Ramsar Regional Initiatives, and International Organization Partners as well as other contracting parties and international organizations. Natural resource users at the river, lake, groundwater basin, and national level can be engaged to integrate considerations of wetland contributions to water, biodiversity, and sustainable development targets of the international community.
Managing groundwater Ramsar Handbook 9, 3rd edition	Guidance on the management of groundwater-linked wetlands and how to identify such linkages for best management.
Wetlands and river basin management: consolidated scientific-technical guidance Resolution X.19	Guidance on integrating wetlands into river basin management, including aquifers.
Strategic framework and guidelines for the future development of the list of Wetlands of International Importance of the Convention on Wetlands	Guidance on criteria for inclusion on the List of Wetlands of International Importance. Considers groundwater interlinkages.

Parties are bound by the international law obligations of the convention. However, the convention has no punitive measures for parties who do not adhere to it (Ramsar 2016). Some parties have integrated the requirements of the convention into nationally enforceable laws and its provisions have been legally binding in national courts of law in cases concerning Ramsar wetlands (Ramsar 2016). Contracting parties also tend to lose out if they do not fully adhere to the Convention norms, e.g., through loss of funding for wetland rehabilitation (Ramsar 2016).

Transboundary Ramsar Sites
The Ramsar Convention allows for the designation of transboundary Ramsar Sites and collaboration among countries sharing such sites. However, as for national Ramsar sites, the designation does not imply a legal status:

The term "Transboundary Ramsar Site" refers to a situation where an ecologically coherent wetland system extends across national borders and the Ramsar Site authorities on both or all sides of the border have formally agreed to collaborate in its management, and they have notified the Secretariat of that intent. The Transboundary Ramsar Site label denotes merely a cooperative management arrangement. It is not a distinct legal status for the Ramsar Sites involved and imposes no additional obligations of any kind. The Ramsar Secretariat is not required to investigate, judge, or monitor individual entries on the transboundary Ramsar Sites list". Ramsar Convention Secretariat (2010:26).

Within the KAZA TFCA, this opens up scope for collaboration on shared resources such as the Kwando River. A transboundary Ramsar Sites designation may further foster countries' commitment toward collaboration and joint management.

8.3 Regional frameworks for shared freshwater and conservation governance

8.3.1 Regional freshwater frameworks

SADC Regional Water Policy
The SADC's Regional Water Policy aims to promote regional integration and poverty alleviation within the SADC region (SADC 2005). The policy raises concerns about groundwater pollution as related to sanitation practices and promoting a river basin or watercourse approach to planning and managing shared watercourses. While the policy recognizes the interlinkages between surface and groundwater, the provisions discuss groundwater in as far as it serves surface water resources for example through contribution to baseflows.

SADC Revised Protocol on Shared Watercourses (2000) and other SADC level instruments
The SADC Revised Protocol on Shared Watercourses was put in place to regulate the common use and management of shared water resources (SADC 2000). It provides an institutional framework to meet this mandate, which includes the establishment of international basin organizations overseeing shared watercourses. Further, the Protocol promotes the sustainable and reasonable utilization of shared water resources as well as the harmonization of legislation and policies across countries in the region.

Following the provisions of the 1996 Helsinki Rules and the 1997 Convention on the Law of the Non-Navigational Uses of International Watercourses (UN Watercourses Convention) (Section 8.2.1), this SADC-level legal framework adopts the definition of a watercourse to include both surface and groundwater, referring to "*a system of surface and ground waters consisting by virtue of their physical relationship a unitary whole normally flowing into a common terminus such as the sea, lake or aquifer*". This definition considers only linked surface-groundwater systems and does not include other formations such as fossil or deep-seated aquifers that may not be linked to any surface water bodies.

The provisions are broad but clearly communicate the need to support sustainable socio-economic development. The current protocol was updated from the original 1995 version. This was done to reflect more closely on the UN Watercourses Convention (Centre for Water Law, Policy and Science n.d). The Revised Protocol was signed in 2000 and came into force in 2003.[44]

SADC Regional Strategic Action Plan on Integrated Water Resources Development and Management
The SADC Regional Strategic Action Plan on Integrated Water Resources Development and Management (SADC RSAP) IV (2016-2020) (SADC 2016) provides the priority plans for implementing the water component of the Regional Indicative Strategic Development Plan (RISDP), which currently runs from 2020-2030 (SADC 2020). The plan highlights the pivotal role of groundwater and prioritizes groundwater development and management through priority interventions, some of which have already been affected, such as:

- Operationalizing the SADC Groundwater Management Institute (SADC-GMI)
- Strengthening institutional capacity for the sustainable management of groundwater in SADC, e.g., through strengthening groundwater monitoring and data management systems, supporting the integration of groundwater in transboundary institutions and agreements, and raising awareness of the UN Draft Articles on the Law of Transboundary Aquifers
- Identifying financing for Transboundary Diagnostic Analyses (TDAs) and Strategic Action Plans (SAPs) to support transboundary aquifer management in member states
- Promoting groundwater infrastructure management and development

SADC Climate Strategy for the Water Sector
The SADC Climate Strategy for the Water Sector highlights groundwater as providing a "secure, sufficient and cost-effective water supply" as well as resilience, as climate variation continues to impact the region through droughts and floods (SADC 2011). Objectives related to groundwater highlighted in the strategy include:

- To develop new groundwater sources and secure appropriate groundwater recharge mechanisms
- Protect groundwater resources and improve recharge mechanisms in the long term
- Accelerate service provision and address the vulnerabilities of existing water supply and sanitation systems

Hence, at a regional level, there is an acknowledgment of the role of groundwater in providing water security and resilience, and also increasingly food security, to the 70% of the population that depend on the resource. As a result, several studies have been conducted across the region, some through the SADC-GMI in support of these objectives (CIWA 2020). Increasing challenges related to groundwater and ecosystems under climate change is a new focus that the present TDA contributes.

Zambezi Watercourse Commission (ZAMCOM)
The KAZA TFCA straddles boundaries between the Okavango and Zambezi River Basins. The management of these two transboundary basins occurs through the basin organizations: OKACOM and ZAMCOM. Considering that the largest part of the focus area of this TDA lies in the Zambezi River Basin, this is described first.

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44 http://www.limpopo.riverawarenesskit.org/LIMPOPORAK_COM/EN/GOVERNANCE/SADC/SADC_WATER_PROTOCOL.HTM

The ZAMCOM agreement on the establishment of the Zambezi Watercourse Commission was signed in 2004, although it only first came into force seven years later after ratification from all eight states (Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, and Zimbabwe).

ZAMCOM has three main organs[45]:

i) ***The Council of Ministers (CoM)***, is the highest decision-making body. The CoM adopts policies and decisions and provides other necessary guidance. It meets once annually and may meet in extraordinary sessions at the request of any member state.

ii) ***The Technical Committee (ZAMTEC)***, is the technical/advisory body. ZAMTEC is responsible for the implementation of policies and decisions of the CoM through the ZAMCOM Secretariat.

iii) ***The Secretariat (ZAMSEC)***, is responsible for the provision of technical and administrative services to the Council under the supervision of ZAMTEC. Under ZAMSEC lie both project implementation and working groups.

Traditionally, the focus of ZAMCOM has been on surface water resources, although the Strategic Plan for the Zambezi Watercourse for 2018-2040 (ZAMCOM 2019) clearly defines the watercourse as including groundwater and aquifers linked to surface water:

To align the terminology in the Strategic Plan with the 2004 ZAMCOM Agreement, the term "Zambezi Watercourse" is defined as: the system of surface and ground waters of the Zambezi constituting by virtue of their physical relationship a unitary whole flowing normally into a common terminus, the Indian Ocean.

With the growing attention to groundwater associated with its increasing importance for resilience and socioeconomic development, a more deliberate focus on groundwater development and management is gaining traction within basin organizations and warrants a more detailed management and development focus. However, the management of transboundary aquifers is not explicitly articulated in the Zambezi Watercourse Commission Strategic Plan (ZAMCOM 2019).

The strategic plan acknowledges the nexus approach to development and bases the strategy on integrated hydropower, agriculture, water supply services, and catchment and natural asset management (ZAMCOM 2019). To support livelihoods in agriculture, investment in small-scale agriculture water storage and rainwater harvesting, as well as localized groundwater recharge were identified as some of the strategies to implement. Catchment management would also serve to increase groundwater recharge (ZAMCOM 2019). The strategy also highlights the need for conservation of freshwater ecosystems indicating the need to set instream flow targets. However, there is no reference to groundwater's role in sustaining instream flows and GDEs. Irrigated agriculture is set to increase to 7% of arable land (ZAMCOM 2019) when all irrigation projects have been commissioned, and ZAMCOM would continue to monitor climate change by analyzing climate-related data. The role of groundwater in food and water security is not explicitly highlighted.

Permanent Okavango River Basin Water Commission (OKACOM)
The agreement between the governments of the Republic of Angola, the Republic of Botswana, and the Republic of Namibia on the establishment of a Permanent Okavango River Basin Water Commission (OKACOM) came into force in 1994. The agreement considers and takes into account the 1966 Helsinki rules.

[45] https://zambezicommission.org/about-zamcom/zamcom-governance

The main governance body is the commission, which consists of three delegations representing the contracting parties. The commission advises the contracting parties on (OKACOM Agreement 1994[46]):

- Measures and arrangements to determine the long-term safe yield of the water available from all potential water resources in the Okavango River Basin
- The reasonable demand for water from the consumers in the Okavango River Basin
- The criteria to be adopted in the conservation, equitable allocation, and sustainable utilization of water resources in the Okavango River Basin
- The investigations, separately or jointly by the contracting parties, related to the development of any water resources in the Okavango River Basin, including the construction, operation, and maintenance of any water works in connection therewith
- The prevention of pollution of water resources and the control of aquatic weeds in the Okavango River Basin
- Measures that can be implemented by any one or all the contracting parties to alleviate short-term difficulties resulting from water shortages in the Okavango River Basin during periods of drought, taking into consideration the availability of stored water and the water requirement within the territories of the respective Parties at that time
- Such other matters as may be determined by the Commission.

Based on the TDA completed for the ORB (OKACOM 2011a), the basin authority developed and is now implementing its 2011 Strategic Action Programme (SAP) (OKACOM 2011c), which is drawn across four thematic areas:

- Livelihoods and socio-economic development
- Water resources management
- Land management
- Environment and biodiversity

There is extensive reference to groundwater in the SAP, e.g., related to surface water-groundwater interactions, salinity issues, and the priority for groundwater monitoring both in terms of quantity and quality. There is an acknowledgment of the need to further understand the recharge of groundwater and its potential as an alternative source of water supply (OKACOM 2011a). Two dedicated studies on groundwater have been commissioned by OKACOM (OKACOM 2020, OKACOM 2010). The latter addresses potential transboundary and trans-basin aquifers (Section 6.2.1) and advocates for targeted monitoring of these systems. While not mentioning the role of groundwater in sustaining ecosystems, the SAP clearly recognizes that the ecosystem integrity of the Cubango-Okavango must be maintained as well as the value of ecosystem services. The more recent groundwater assessment acknowledges that only a limited number of specific studies have been identified and only general comments can be made on this surface water/groundwater nexus (OKACOM 2020).

Proposed interventions related to groundwater (OKACOM 2011b), which are mostly mirrored in OKACOM (2020), include:

- Delineation of aquifers, groundwater recharge areas, and groundwater control and protection zones
- Development of a common groundwater monitoring strategy for assessment of groundwater level and quality
- Drilling and installment of additional monitoring boreholes where needed

[46] https://www.fao.org/3/w7414b/w7414b0m.htm

Multi-Country Cooperation Mechanisms - Stampriet Transboundary Aquifer System

In 2007, the Orange-Senqu River Commission (ORASECOM), the RBO overseeing the Orange-Senqu River Basin shared by Botswana, Lesotho, Namibia, and South Africa, put in place a Groundwater Hydrology Committee with a focus on groundwater-related issues in the Orange-Senqu River Basin. In 2016, under the UNESCO-IHP Governance of Groundwater Resources in Transboundary Aquifers (GGRETA) project, two models for a multi-country cooperation mechanism (MCCM) on the shared Stampriet Aquifer were developed. One would operate as a standalone committee made up of the three countries' water department representatives and operationalized through an MoU. The other model would be nested within the ORASECOM structure and linked to the Groundwater Hydrology Committee. The decision to go for the second model was endorsed in 2017 by the Ordinary meeting of the ORASECOM Forum of the Parties[47]

LIMCOM Groundwater Committee

In 2019, the Limpopo Watercourse Commission (LIMCOM), the RBO overseeing the Limpopo River Basin shared by Botswana, Mozambique, South Africa, and Zimbabwe, instituted the LIMCOM Groundwater Committee (LGC) in response to the growing need to provide oversight for groundwater management in the basin. Three transboundary aquifers have been identified in the Limpopo Basin (Villholth and Altchenko 2014), where groundwater provides for the needs of rural communities, commercial farmers, mining, and growing urban centers. The LGC terms of reference (LIMCOM 2019) combine a mix of facilitating transboundary cooperation through integrating and harmonizing groundwater provisions across the member states, supporting the updating of protocols and agreements as well as collaborating on institutional arrangements for shared aquifer management.

The scope of work of the LGC includes (LIMCOM 2019):

a. Development and management of the groundwater resources of the basin
b. Implementation of the relevant provisions of the LIMCOM agreement, including the standardized form of collecting, processing, and disseminating groundwater data or information
c. Implementation of the groundwater activities and projects from the LIMCOM strategic and short-term plans
d. Preparation of project proposals for resources mobilization for the development of groundwater resources management
e. Serving as a clearinghouse for new concepts and strategies for conjunctive water resources management
f. Implementation of other activities that may be assigned to it by the LIMCOM Technical Task Team and/or the Commission

Two of the three transboundary aquifers identified in the Limpopo River Basin are underlying established TFCAs: The Tuli Karoo Aquifer (in the Greater Mapungubwe TFCA) and the Limpopo Basin Aquifer (in the Great Limpopo TFCA) (Figure 1.1).

The Nata Karoo transboundary aquifer

The Nata Karoo Aquifer straddles parts of both the Zambezi and Okavango basins (Figure 1.2). In this case, the aforementioned arrangements, of nesting groundwater committees responsible for groundwater and transboundary aquifers in the RBO institutional structure, may need to be further adapted since the Nata Karoo falls in the jurisdictions of more than one RBO. Considering the geographic position of the TBA, it will be critical that OKACOM and ZAMCOM work towards co-managing the shared aquifer, potentially with a strong role for the KAZA TFCA Secretariat with respect to shared conservation issues.

[47] https://www.internationalwaterlaw.org/blog/2019/12/09/botswana-namibia-and-south-africa-develop-joint-governance-mechanism-for-the-stampriet-aquifer-system-in-the-orange-senqu-river-commission/

Knowledge of the aquifer continues to advance. Also, the demands for groundwater in the region are increasing, and with it the need for governance structures for sustainable management and development. The KAZA TFCA counts on another four TBAs (Figure 1.1), which will also require future attention in terms of transboundary cooperation mechanisms and institutions.

8.3.2 Regional/SADC conservation frameworks

SADC governance framework for conservation

SADC counts on an expansive framework relevant to conservation through a number of protocols and instruments (SADC 2017) (Table 8.4). The instruments are applied across the SADC member states and give direct or indirect guidance on the management of aspects of TFCAs. The instruments seek to promote harmonization between national legal, policy, and institutional frameworks and encourage transboundary cooperation to enable a coordinated approach to shared natural resource management.

Table 8.4 SADC protocols related to conservation.

SADC Protocols
1998 Protocol on Tourism
1999 Protocol on Wildlife Conservation and Law Enforcement
2000 Revised Protocol on Shared Watercourses
2001 Protocol on Fisheries
2002 Protocol on Forestry

Source: SADC (2017)

Under the SADC TFCA program, 18 TFCAs are currently existing or in the process of formalization (Figure 8.3) (SADC 2013) covering more than 1 mill km^2 (EC 2015). Guidelines on the establishment of SADC TFCAs were developed in 2014 offering guidance on various aspects of TFCA establishment, including selecting governance models and defining the geographic extent and financial sustainability (SADC 2014). The 18 TFCAs have been categorized according to their stage of development, where Category A TFCAs are Established TFCAs, Category B is Emerging TFCAs, and Category C is Conceptual TFCAs (SADC 2013).

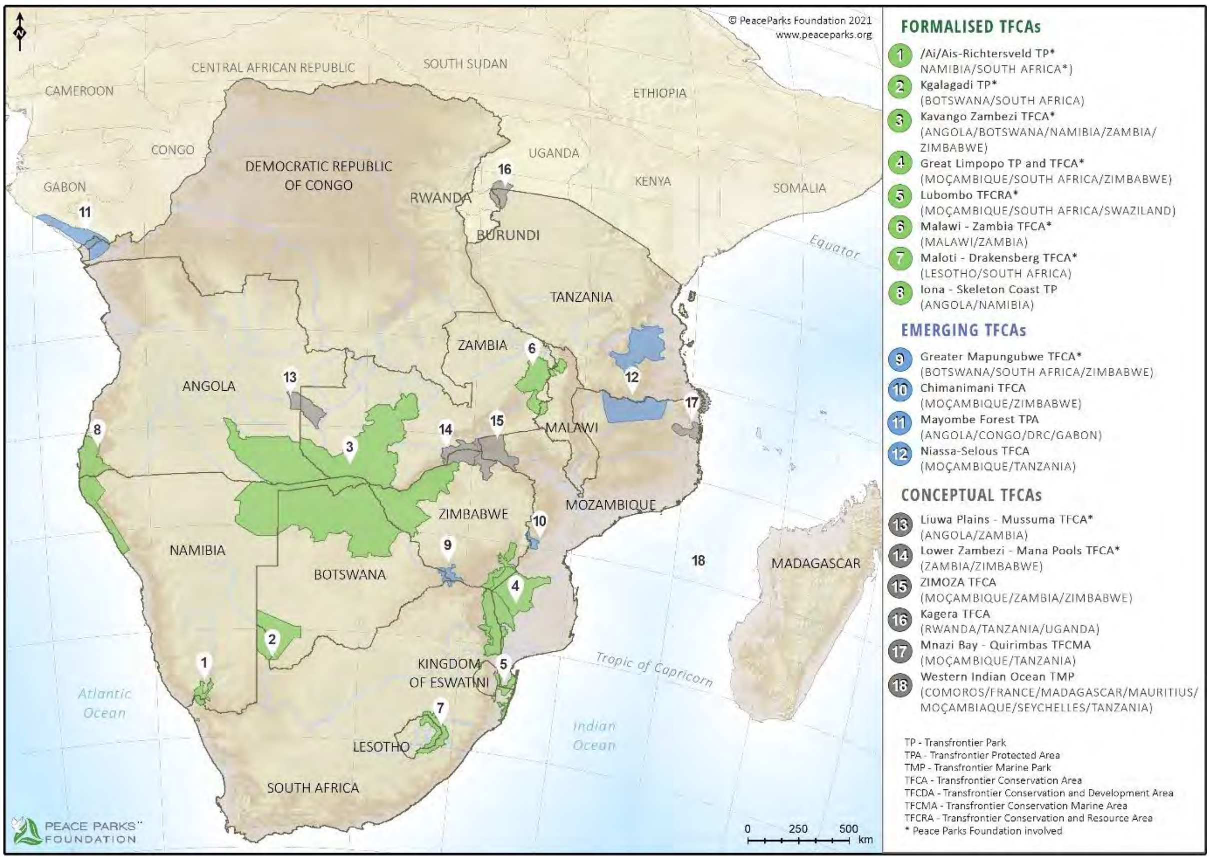

Figure 8.3 Location of TFCAs in SADC (Source: Peace Parks 2021).

Given the multiple land uses in TFCAs, there is scope for the TFCA program to provide more integrated guidance on freshwater governance, including groundwater, within TFCAs aligned with the roles of RBOs, and projects like the KAZA-GROW provide such opportunity.

Initially, SADC TFCAs were to be established among countries without the involvement of the SADC Secretariat[48]. However, the importance of the SADC Secretariat as a vehicle for channeling funding from International Cooperation Partners, and the financial and technical difficulties faced by individual countries to facilitate TFCA formation processes necessitated the involvement of the Secretariat through the TFCA program adopted in 2011 (SADC 2013). Further, it was noted that donor funding for the continued functioning of TFCAs is unsustainable and needs to be augmented by other income generation activities in the TFCAs (SADC 2014). The SADC TFCA program, therefore, serves to coordinate the formation and management of all TFCAs in the region in line with regional socioeconomic and conservation goals.

The vision of the SADC TFCA Program is underpinned by community-centeredness, regional integration, and sustainable management with a core focus on the communities living within and around TFCAs (SADC 2013). It comprises seven components:

- Advocacy and harmonization
- Enhancement of financing mechanisms for TFCAs
- Capacity building for TFCA stakeholders
- Establishment of data and knowledge management systems
- Enhancement of local livelihoods

[48] Principal Executive Institution of SADC: https://www.sadc.int/sadc-secretariat

- Reducing the vulnerability of ecosystems and people to the effects of climate change
- Development of TFCAs into marketable regional tourism products

Some of the key activities across the seven components include establishing a functional regional TFCA Stakeholder Forum, development and implementation of a regional training program, and production of different sets of guidelines for identified TFCA priority areas such as Community Based Natural Resources Management (CBNRM) (SADC 2013).

The program is implemented through a set of institutional structures (Figure 8.4).

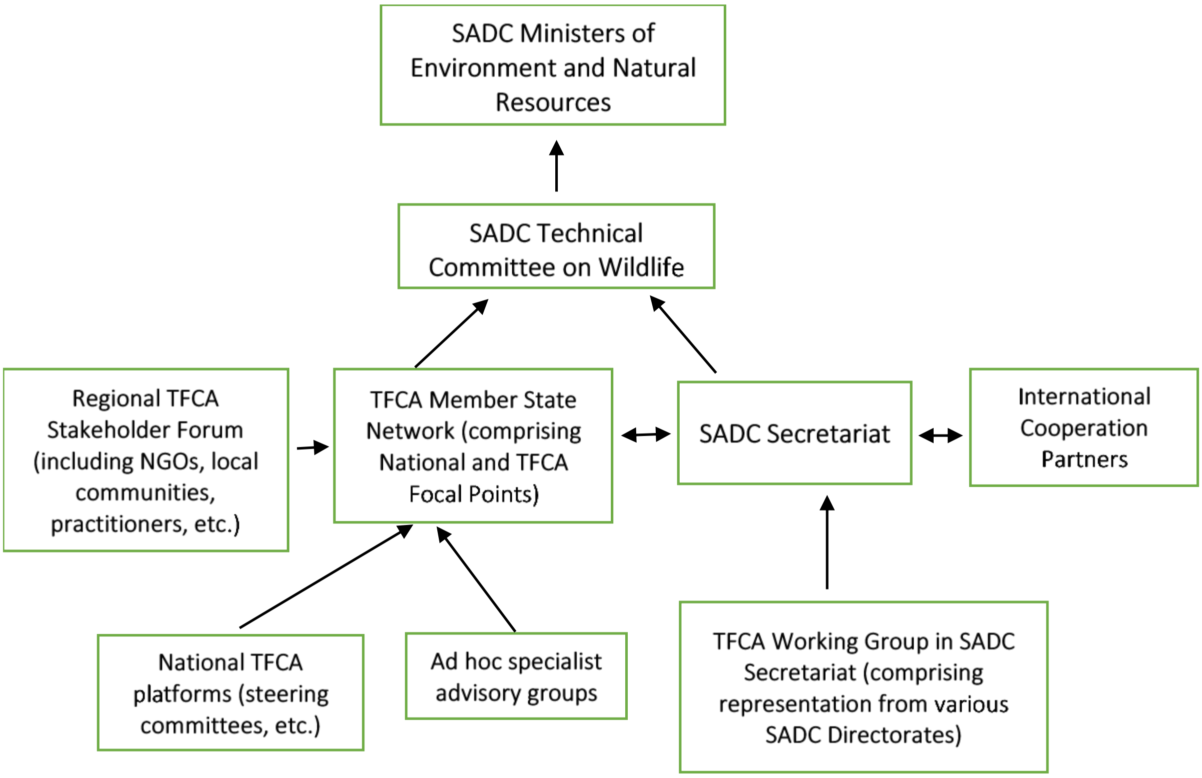

Figure 8.4 Organogram for implementing the SADC TFCA Program (SADC 2013).

KAZA TFCA Treaty

The KAZA TFCA Treaty to establish the KAZA TFCA was signed in 2011 following an earlier MoU that formed the TFCA in 2006 among the five countries: Angola, Botswana, Namibia, Zambia, and Zimbabwe (KAZA TFCA 2011). Through the mandated environment, natural resources, and tourism ministries, individual states appointed implementing agents who are '*responsible for the coordination and implementation of the provisions of this Treaty*…' (Article 7, KAZA TFCA 2011). The Treaty calls for respecting the sovereignty and territorial integrity of Partner States. Article 9 of the Treaty further articulates the specific role of SADC for the KAZA TFCA as a custodian of frameworks that support the sustainable utilization of natural resources. SADC thus ensures that the KAZA TFCA activities are aligned with SADC provisions for regional integration, harmonization, resource conservation, poverty alleviation, and community empowerment, as well as facilitating technical and financial assistance to support development programs.

A harmonization assessment of conservation-related provisions across national policy and legal frameworks was commissioned in 2013 and showed that while national frameworks were in place for various resource management aspects such as fisheries, wildlife, etc., some inconsistencies were identified in provisions and scope at the transboundary level (KAZA TFCA 2013). Some key areas proposed for further harmonization include (KAZA TFCA 2013):

- Legal recognition of wildlife corridors
- Harmonized land use planning across KAZA TFCA
- Land use planning for wildlife corridors consolidated with existing land tenure regimes
- Harmonized and integrated fishery management systems

Several international conservation-related conventions have been signed by the KAZA TFCA Partner States, besides the Ramsar Convention (Section 8.2.2), e.g., the 1993 Convention on Biological Diversity; the 1979 Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention); the 1975 Convention on International Trade in Endangered Species of Wild Fauna and Flora; and the 1994 United Nations Convention to Combat Desertification (Table 8.5).

Table 8.5 Examples of International conservation conventions signed by KAZA TFCA Partner States.

Convention and year entered into force	KAZA TFCA Parties	Scope
1975 Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)[a]	Angola, Botswana, Namibia, Zambia, Zimbabwe	Ensuring that international trade in specimens of wild animals and plants does not threaten the survival of the species.
1976 Convention on Wetlands (Ramsar Convention)[b]	Angola, Botswana, Namibia, Zambia, Zimbabwe	Wise and sustainable use of wetlands (includes all lakes and rivers, underground aquifers, etc.)
1983 Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention)[c]	Angola, Zimbabwe	Migratory wildlife conservation
1993 Convention on Biological Diversity[b] (CBD)	Angola, Botswana, Namibia, Zambia, Zimbabwe	Conservation of biological diversity, sustainable use of the components of biological diversity, and the fair and equitable sharing of the benefits arising out of the utilization of genetic resources
1994 United Nations Framework Convention on Climate Change (UNFCCC)[e]	Angola, Botswana, Namibia, Zambia, Zimbabwe	Stabilize greenhouse gas concentrations in the atmosphere at a level that will prevent dangerous human interference with the climate system, in a time frame that allows ecosystems to adapt naturally and enables sustainable development.
1994 United Nations Convention to Combat Desertification[f]	Angola, Botswana, Namibia, Zambia, Zimbabwe	Sustainable land management in drylands

[a] https://cites.org/eng/disc/what.php
[b] https://www.ramsar.org/
[c] https://www.cms.int/
[d] https://www.cbd.int/
[e] https://unfccc.int/about-us/about-the-secretariat
[f] https://www.unccd.int/

KAZA TFCA - OKACOM MoU

The transboundary governance frameworks for KAZA TFCA and the RBOs converge on key freshwater elements for conservation, sustainable development, and livelihood support. As such, an MoU was signed between KAZA TFCA and OKACOM in 2018 to benefit from possible synergies coming out of operating in the same shared landscape. A similar process is envisaged between the KAZA TFCA and ZAMCOM[49].

KAZA TFCA organizational setup

The KAZA Treaty establishes the following governance organs:

i) ***Ministerial Committee*** comprising of Partner State ministers and responsible for providing overall political leadership and guidance for the development and management of the KAZA TFCA, in particular: (a) approving programs, plans, and strategies developed for the KAZA TFCA; (b) resolving implementation constraints in the establishment and development of the KAZA TFCA; and (c) ensuring that the KAZA TFCA Partner States benefit socially and economically from the conservation and tourism development program of the KAZA TFCA, while upholding principles of sustainable development, accountability, equality, equity, transparency, and mutual respect.

ii) ***Committee of Senior Officials*** comprising of national Permanent Secretaries or similar and a SADC representative at similar rank. This committee operationalizes the Ministerial Committee's decisions, monitors progress in the development and management of the KAZA TFCA, and identifies funding sources, among other functions.

iii) ***Joint Management Committee*** comprising of two appointed members from each Partner State and one from the SADC Secretariat. This committee is guided by the Committee of Senior Officials and formulates action plans and strategy protocols for the management and development of the KAZA TFCA, ensures stakeholder participation and monitors the operations of the KAZA TFCA Secretariat, among other functions.

iv) ***KAZA TFCA Secretariat*** under the Treaty is responsible for coordinating activities regarding the planning and development of the KAZA TFCA, including drafting action plans in alignment with regional protocols, identifying funding opportunities, and establishing collaboration with other organizations. Under the Secretariat sit working and sub-working groups around specific areas, such as a conservation working group and more recently the Freshwater and Fisheries sub-working groups. The role of the Freshwater and Fisheries sub-working groups is "*to ensure enhanced focus on risks to freshwater ecosystems and habitats, climate adaptation and mitigation, as well as fishery resources in KAZA TFCA".*[50]

v) ***National Committees*** are established by each Partner State, whose operations and composition are nationally determined.

KAZA TFCA Master Integrated Development Plan 2015-2020

The five-year KAZA TFCA Master Integrated Development Plan (MIDP) (2015-2020) (KAZA TFCA 2014) brings together the five National Integrated Development Plans about conservation, infrastructure development, and livelihoods enhancement in the shared conservation area. Development plans are focused on geographic units of six wildlife dispersal areas (WDAs) and consolidated around six thematic areas (KAZA TFCA 2014, van der Sluis et al. 2017):

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[49] https://gripp.iwmi.org/2021/04/12/five-african-countries-join-forces-to-better-manage-shared-groundwater-resources/

[50] https://www.kavanGRZbezi.org/en/news-public/item/48-12th-ministers-meeting-joint-communique

- Natural resource management
- Tourism development
- Infrastructure development
- Integrated land-use planning
- Livelihoods enhancement
- Transboundary political cooperation

The MIDP identifies challenges in the KRWDA including poaching, human-wildlife conflict, lack of accurate land-use data for planning and management, and limited transboundary infrastructure (roads, water, and electricity) among other challenges (KAZA TFCA 2017). Among the project objectives proposed to address these challenges were to foster CBNRM by communities and improving the socio-economic conditions of communities in the KRWDA.

The MIDP identifies actions that can enable the attainment of these objectives (KAZA TFCA 2014):

- Financial and human resources for detailed land-use planning
- Transboundary legal agreement among the four countries sharing the KRWDA (Angola, Botswana, Namibia, and Zambia)
- Financial and human resources to introduce CBNRM
- Availability of financial and technical resources to improve infrastructure

Ramsar implementation in SADC and KAZA TFCA
All five Partner States of KAZA TFCA are contracting parties to the Ramsar Convention following the recent addition of Angola in October 2021. There are four Ramsar sites in the KAZA TFCA, of which none are transboundary (Section 5.1.2) and none associated with the protection of upstream water sources greatly important for iconic conservation areas, like the Okavango Delta.

The Ramsar Convention is important, as it is particularly relevant in the context of the KAZA-GROW work, which falls at the intersection between transboundary water resources management (as included in the Ramsar Convention's broad definition of wetlands) and conservation. Sentiments of having sites within the KAZA TFCA declared transboundary Ramsar sites have been expressed by regional stakeholders, further reiterating the synergies that the Ramsar Convention provides for freshwater and conservation (KAZA TFCA 2019b). One candidate (potentially transboundary) is the Lisima Lya Mwono area, also called the Moxico Water Tower, which includes a 54,000 km^2 trans-basin system of source lakes, peatlands, wetlands, and woodlands in Central Eastern Angola, covering the headwaters of Cuito, Kwando and other Zambezi tributaries (KAZA TFCA 2019b, GoA, 2019a) (Figure 8.5). Such designation is now possible as Angola has ratified the Convention.

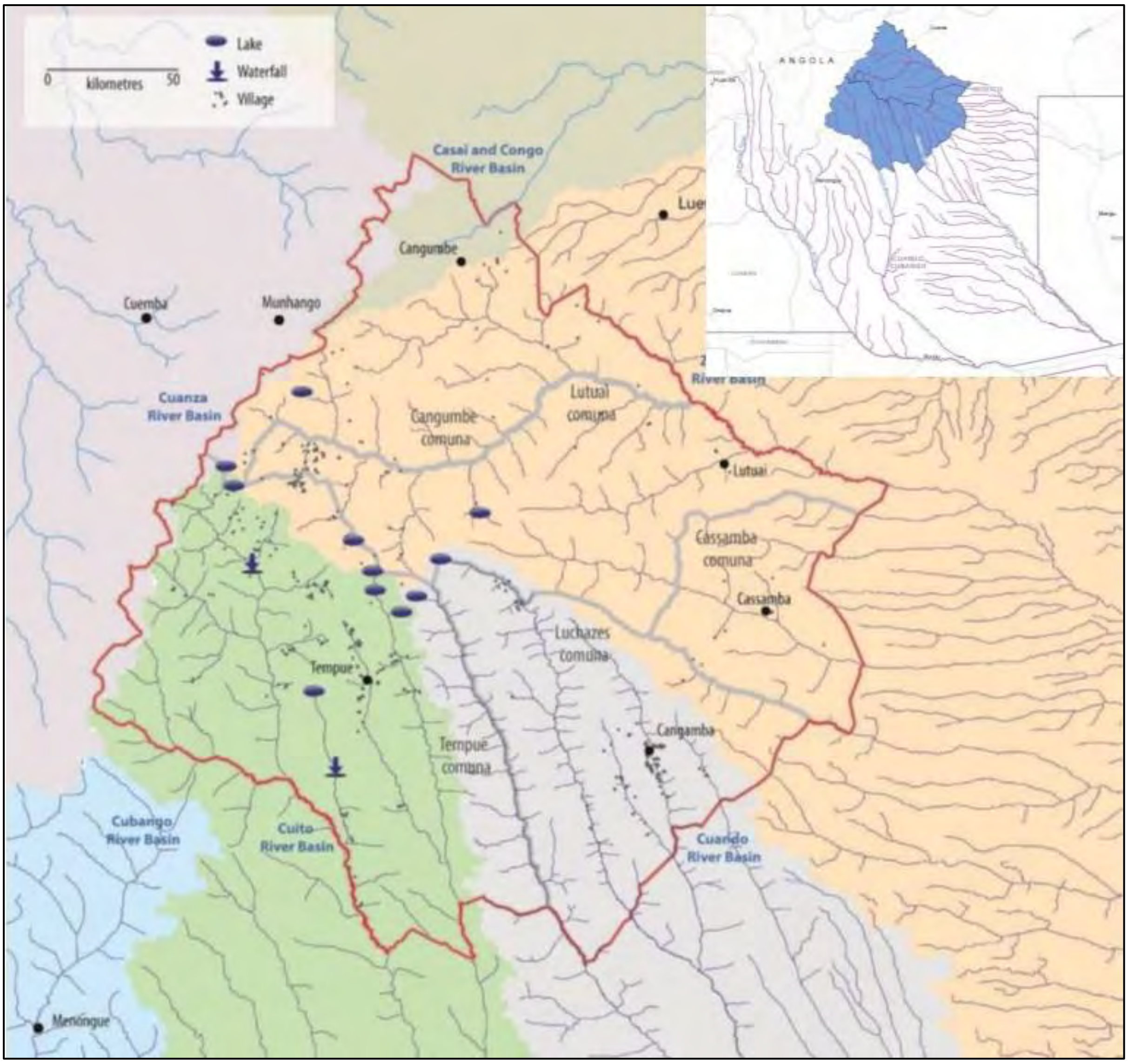

Figure 8.5 The Moxico Water Tower in Angola (Source: GoA, 2019b).

Also, the Ramsar guidelines on managing groundwater (Ramsar 2010) are an important guideline for the KAZA TFCA. The guidelines provide background and supporting information on the linkages between wetlands and groundwater such as how groundwater contributes to wetlands and the ecosystem services they provide (Ramsar 2010). The close association between wetlands and groundwater is an important consideration in both surface and groundwater management, though most often disregarded. It is important to note the overlap between international legal frameworks for freshwater (surface water, wetlands, groundwater), a situation that can benefit transboundary institutions in terms of mutual support. However, this overlap may also be a source of contention of functions if the synergies are not properly aligned.

As an example, the Ramsar Secretariat closely associates with the 1992 *Convention on the Protection and Use of Transboundary Watercourses and the International Lakes* Convention (Water Convention)[51] to advance transboundary cooperation on freshwater (Ramsar 2016). International cooperation in the conservation and management of water resources is, therefore, an important factor in the

[51] https://www.ramsar.org/about/partnerships-with-other-conventions

sustainability of shared natural resources. As there are currently no transboundary Ramsar sites in the KAZA TFCA, there is scope for the addition of such sites, and their integrated management within the KAZA TFCA has to be accounted for, both from a policy and institutional angle and at the transboundary level. In this case, there is good scope for the KRWDA, or the KRB, or parts of them, to qualify as a transboundary Ramsar site, as mentioned above. However, it is worthwhile to note that the designation of a transboundary Ramsar site does not provide legal status, but rather a cooperative arrangement reached by countries sharing a wetland. The designation could definitely elevate the attention to the preservation of critical headwater areas of the KRB.

There are currently four Ramsar regional initiatives operating in western and eastern Africa[52]. Challenges associated with limited financial and human capacity have been cited as impeding the success of the regional initiatives in Africa (Ramsar 2015).

8.4 National frameworks for freshwater and conservation governance

8.4.1 National freshwater frameworks

In addition to the various international and regional provisions on conservation and freshwater governance covered in the previous sections, individual Partner States adhere to their own enforceable laws and policies. Several laws apply in the KAZA TFCA Partner States, including land tenure, forestry, fisheries, biodiversity, water resources, wildlife, tourism, and trade, among other resource management provisions. The following section provides an analysis of available frameworks in the Partner States of the KAZA TFCA. The analysis is centered around five core indicators for groundwater development and management, rating the extent to which certain focus areas with relevance to groundwater sustainability and linkage to conservation exist or are addressed in current policy and legislative frameworks of individual countries:

1. National groundwater and conservation policies in place
2. Groundwater development for enhancing climate resilience
3. Integrated groundwater and surface water management (conjunctive management)
4. Management and regulation of groundwater abstraction including identification and protection of recharge areas
5. Groundwater-dependent ecosystems (GDEs) in supporting conservation and livelihoods

Using a document analysis method (Bowen 2009), the six indicators were assessed and weighted qualitatively using a prescribed set of scores (Table 8.6), which shows variation in the extent to which each focus area is addressed. The results of the analysis are presented in Section 8.5, (Table 8.8) after reviewing the frameworks in each country in the ensuing sections.

Table 8.6 Indicator scores for assessing national policies and legislation.

***	Focus covered with clear details
**	Focus partly covered with limited details on implementation
*	Focus covered, but not detailed
-	Focus not mentioned within policy or legislation
+	Presence of focus in the national framework

52 https://www.ramsar.org/activity/ramsar-regional-initiatives

Institutional reforms in KAZA TFCA Partner States

Institutional reforms have been a key feature in most Southern African countries. This has largely been necessitated by (i) independence from colonial rule, (ii) response to global conventions, (iii) response to domestic socio-economic and political demands, and (iv) new drivers, such as climate change and demographic change (population growth and migration). Notable reform has been observed across water policies, towards the adoption of the Integrated Water Resources Management (IWRM) principles, which are based on the three pillars of economic efficiency, equity, and environmental sustainability (UNDP 2005). These reforms and transitions have caused practical implementation challenges between the various new laws and previous colonial regimes. This is evidenced for example in the case of the overlap between the colonial era Namibia Water Act of 1956, and the still-to-be-enforced Water Resources Management Act No. 11 of 2013 (Republic of Namibia 2013, Remmert 2016).

Water resources and conservation are largely governed under separate ministries in the five countries. As such, planning mostly takes place separately for water and conservation-related activities. Groundwater is typically managed under groundwater and hydrogeology departments embedded in the water departments of the water ministries, while desk officers dedicated to TFCA management are typically drawn from the different environment, natural resources, and tourism ministries.

Angola water resources legal and policy framework

The Angola Law No. 6/02 on Water Use of 2002 is the overarching legislation for water resources management (GoA 2002). The law touches on groundwater use regulation through licensing. Section 64 of the law deals specifically with groundwater, highlighting restrictions and conditions for use such as maintenance of rechargeable aquifers. The law also includes provisions for groundwater pollution, optimization of non-rechargeable aquifers, and integrated management of surface and groundwater (GoA 2002).

The Kwando River originates in the Angola highlands and is referred to as the source of life in Angola[53]. As highlighted at the KAZA TFCA regional workshop, the changing governance landscape in Angola requires that local development in these headwaters be in harmony with the KAZA TFCA goals for conservation. Propositions include rehabilitation of the Cubango basin, empowering traditional leadership to manage natural resources, strengthening the rights of communities with regard to wildlife, and investing in natural capital assets (KAZA TFCA 2019b). The Strategic Action Programme for the ORB indicates the importance of groundwater contribution to water supply and that aquifers should be protected to continue this provisioning service (OKACOM 2011b).

The KRB in Angola is remote compared to centers of political decision, and as such, the need for a more localized structure for the Zambezi River Management on the Angola portion as indicated in the inception workshop of the KAZA-GROW project (IWMI 2021b). The general plan for IWRM of the hydrographic basin of the Zambezi River in Angola indicates the need for an assessment of the status of groundwater resources (GoA 2017a). There are plans to study the impact of climate change on aquifer systems and regulate the use of potential aquifer recharge areas (GoA 2017a). Identified threats to groundwater were associated with lowered groundwater levels though there are no piezometric networks to monitor groundwater in the Angola portion of the Zambezi River Basin (GoA 2017a). The plan also accounts for the role of freshwater (including groundwater) in the conservation of wildlife such as crocodiles, hippopotamus, and even terrestrial animals such as elephants and buffalo and intentions to participate more actively in KAZA TFCA activities (GoA 2017a).

Botswana water resources legal and policy framework

[53] KAZA-GROW project virtual Inception Workshop, February 2021.

The Botswana Water Act of 1968 is the overarching national water resources management legislation. The law regulates water use by issuing water rights, for both surface and groundwater, through the water apportionment board (GoB 1968). The law has not been revised since it was enacted, although there are ongoing efforts in this regard (Setlhogile and Harvey 2015, Gondo and Kolawole 2019). Reviews of the law have led to the development of supporting policies such as the National Water Policy (GoB 2012, Gondo and Kolawole 2019).

Government efforts have been focused on providing water for its growing population. Surface reservoirs are important infrastructure in Botswana, providing 42% of water demands. Groundwater is also an important resource, contributing 49% to the total water demand, especially in rural areas, while international water transfers contribute 8% (World Bank 2015). Groundwater contributes 60% of Botswana's total water needs, more so in the western parts (World Bank 2017).

The 2012 Botswana National Water Policy highlights the importance of three defining and underpinning elements: (i) equity; (ii) efficiency; and (iii) sustainability (GoB 2012). Human water use is prioritized above environmental water needs, and secondly, the environment is prioritized over industry and livestock. The policy mentions the need to review several water-related policies that govern different water resources such as transboundary treaties and other sectoral laws. Available groundwater stock resources amount to about 100 km^3 although only 1% is recharged by rainfall with a recharge rate estimated at 1.7 km^3/year. Appreciable groundwater resources are saline and deep, especially in the most arid areas of the country (GoB 2012). The country has more than 25,000 official boreholes, of which almost 40% are government-owned for domestic water supply (GoB 2012). The country relies considerably on groundwater resources, in particular for livestock in arid areas, where freshwater is found, which creates trade-offs with conservation and wildlife goals (Perkins 2020). Most notably before the North-South carrier was operationalized, groundwater contributed over 80% of domestic water supplies (GoB 2012). To relieve pressure on groundwater, the 400 km long North-South Carrier[54] was commissioned in 2000 bringing in water from the Letsibogo Dam on the Motloutse River and later, in 2012, from the Dikgatlhong Dam on the Sashe River to the capital area of Botswana (World Bank 2017).

Groundwater quality is a challenge for exploitation due to elevated fluoride levels and salinity in certain areas (GoB 2012). The policy acknowledges the need for conjunctive use of different water sources to augment the limited water resources. The 1956 Boreholes Act legislates the drilling of boreholes and keeping of records and consideration of other aspects such as drilling on tribal land.

[54] https://en.wikipedia.org/wiki/North-South_Carrier

Namibia water resources legal and policy framework

Namibia is an arid country, which relies heavily on the provisions from groundwater. The city of Windhoek uses water supplied through groundwater resources, partially artificially replenished (Murray et al. 2021). The Stampriet Aquifer system, shared between Botswana, Namibia, and South Africa, is an important source of water for irrigation and domestic water (Bann and Wood 2012). The Water Resources Management Act of 2013 (GoN 2013a) is supported by plans such as the Integrated Water Resources Management Plan of 2010 (GoN 2010). At the transboundary level, the National Action Plan for the sustainable use of the resources in the ORB provides the basin perspectives of water resources on the Namibian portion of the basin (OKACOM 2011d). In sections 56-63 of the 2013 Water Resources Management Act, there is a detailed focus on groundwater control and protection addressing areas such as drilling and borehole construction, licensing of boreholes, record keeping, groundwater wastage, and protection of aquifers (GoN 2013a). Nonetheless, the Act has not been given full effect, and it is unclear when all regulations contained in the Act will be implemented (Remmert 2016).

Zambia water resources legal and policy framework

Zambia's water resources are managed under the Water Resources Management Act of 2011(GoZam 2011). This legislation upholds the principles of equitable and sustainable use of water resources and establishes the Water Resources Management Authority as having overall control over all water resources in the country (GoZam 2011). Notably, Section 93 of the act addresses the protection of groundwater, specifically empowering the responsible minister to declare "…water resource protection areas around groundwater recharge areas and abstraction sources…" as well as "…measures that are necessary to mitigate saline intrusion into aquifers…" (GoZam 2011). Other sections of the Act (e.g., Section 53) delve further into borehole drilling specifying that permitting requires the establishment of permissible abstraction and keeping of records. The act also includes specific considerations of impacts of climate change on water resources, both quality, and quantity, and calls for climate change adaptation measures (GoZam 2011).

The 2010 Zambia National Water Policy indicates that the country has ample and well-distributed amounts of groundwater although not developed to its full extent (GoZam 2010). Nonetheless, the lack of data to substantiate groundwater availability is also highlighted. Unmanaged abstraction and pollution are cited among the potential risks to groundwater (GoZam 2010). The 2016 National Climate Change Policy calls for the protection of water catchment areas, including the development of environmentally-friendly infrastructure for bulk water transfer (waterways), storage, management, and utilization of water resources (GoZam 2016).

Zimbabwe water resources legal and policy framework

The National Water Act of 1998 (GoZim 1998) is the overarching legislation governing water resources in Zimbabwe. The Act declared river basins as units for planning and development and establishes catchment councils that are given the right to grant permissions for water use and to record and define the right to the use of water resources including aquifers. The Act recognizes the integrity of the hydrological cycle and hence the removal of the differentiation in the approach to the management of water between surface water and groundwater. However, there is no explicit reference to groundwater management or development, e.g., permissible abstraction rates. The 2012 National Water Policy points to conjunctive surface and groundwater management, highlighting the significance of groundwater and calling for more regulated abstraction of groundwater as the resource is increasingly exploited in urban areas (GoZim 2012). Lack of information on the extent and use of groundwater resources is indicated as a limitation towards efficient management of the resource. In addition, attention is drawn to unrestricted land-use changes as a challenge, which can impact groundwater recharge and quality. The 2016 National Climate Policy further emphasized the need to strengthen conjunctive groundwater and surface water monitoring, regulation, and assessment (GoZim 2016).

8.4.2 National conservation frameworks

Angola conservation legal and policy framework

Angola has a rich biodiverse landscape (World Bank 2019). The country experiences capacity deficiencies in natural resource governance as it recovers from the civil war that lasted from 1975 to 2002 (Rodrigues and Russo 2017). However, a sound legislative framework for conservation has been in place since 1998, i.e., from the 1998 Base Law for the Environment, the 2010 National Forest, Wildlife, and Conservation Areas Policy, and the 2017 Forest and Wildlife Act (Huntley et al. 2019, World Bank 2019). The earlier National Biodiversity Strategy and Action Plan (2007-2012) (GoA 2007) developed in accordance with the Convention of Biological Diversity requirements indicated that "*the legal framework of the country is innovative and modern as regards the principles of conservation and sustainable use of biological resources*."

Several subsequent strategic plans augment the legal framework such as the:

- National Biodiversity Strategy Action Plan 2019-2025 (GoA 2019b)
    - Serves as the implementation mechanism for the Convention on Biological Diversity
    - Defines priority actions on biodiversity conservation, e.g., ensuring minimum ecological flows and wildlife corridors during infrastructure development
- Plan for Expansion of the Network of Protected Areas (PLENARCA) (World Bank 2019)
    - Provides guidance on the expansion and enhancement of protected areas promoting climate change resilience in biodiversity conservation

Some of the legal and policy frameworks in place in Angola for conservation management include:

- Aquatic Biological Resources Act 2005
- Environmental Framework Law No. 9 of 1998
- Resolution implementing the Convention on Wetlands 2016 (No. 27 of 2016)
- Law No. 6/17 on Forest and Wildlife Basic Legislation

Huntley et al. (2019) argue that pressure from global conventions to increase land conversion to more protected areas (to meet a 2020 target of 17% of the national territory[55]) has not increased conservation activities in Angola due to limited capacity for park management. Generally, there is increasing international focus on the conservation versus economic development agenda in Angola, because of the central role Angola plays in the provision of downstream waters to systems like the Okavango Delta and the Kwando River.

Botswana conservation legal and policy framework

The Botswana 1992 Wildlife Conservation and National Parks Act among other functions, declare national parks and prohibits such actions as mining within park boundaries. It regulates the killing of wildlife - protecting 26 mammal species (GoB 2013). In 2013, the Wildlife Policy (GoB 2013) was adopted, updating the 1986 Wildlife Conservation Policy, which established Wildlife Management Areas (WMAs). The new Conservation Policy highlights the value of wildlife in Botswana's economy and of promoting CBNRM (GoB 2013). The 2013 Wildlife Policy further expounds on the institutional, regulatory and participatory framework for wildlife conservation, focusing on both the resources and development aspects (GoB 2013).

Due to increasing demand for pastoral and agricultural land, wildlife areas have come under threat and necessitated the establishment of national parks, game reserves, and WMAs (GoB 2013). Close to

[55] https://www.cbd.int/aichi-targets/target/11

20% of the country's land area is under parks and reserves and a further 20% falls under WMAs, which are primarily wildlife areas where only certain wildlife-related activities are allowed. WMAs form (i) buffers between parks and reserves and agricultural areas; and (ii) corridors that connect parks and reserves (GoB 2013). The policy upholds the formation of TFCAs and their recognition in land use planning and invites the private sector to play an active role in conservation through sustainable infrastructure and water development.

The Botswana National Biodiversity Strategy and Action Plan of 2016 highlights a vision: "by 2025, ecosystem, species and genetic diversity is valued, protected, and used sustainably and equitably, through the involvement of all sectors of society and the provision of sufficient resources for its sound management." (GoB, 2016). Other supporting policies for biodiversity conservation include:

- National Conservation Strategy (1990)
- Wildlife Policy (Draft of 2012 – although still a draft, it is included here, as an existing policy is in place which this will replace)
- National Forest Policy (2007)
- Botswana Threatened Species Management Action Policy, Implementation Strategy and Action Plan (2007)
- Predator Management Strategy (Draft of 2013)
- Community-Based Natural Resources Management Policy (2007) (GoB, 2016).

The HWCs between local communities in Botswana and the elephant population have fueled ongoing debate around the alleged benefits of elephant conservation (Perkins 2020). As a result, in 2019, the Botswana government took a stance to lift the ban on elephant hunting. A decision, which was fully supported by the KAZA TFCA Partner States. In the statement[56], the KAZA TFCA Partner States highlighted that while wildlife conservation is of importance, the livelihood and subsistence of local communities were of paramount importance. Combining water security, livelihoods enhancement, and conservation management, whilst managing HWCs, is essential to Botswana's rural development and national economy. For example, borehole provision has supported subsistence and commercial livestock expansion into the Kalahari over the last 50 years, with increasing use of artificial water points (AWPs) (Perkins 2020), the pros and cons of which are highlighted in Box 8.

Namibia conservation legal and policy framework

Conservation activities in Namibia are managed through the Ministry of Environment, Forestry, and Tourism via the Nature Conservation Ordinance of 1975 (GoN n.d). The Nature Conservation Ordinance has been amended several times such as on the establishment of conservancies by local communities, e.g., through the Nature Conservation Amendment Act, 1996 (No. 5 of 1996) (GoN n.d). The Nature Conservation Amendment Act, 2017 (No. 3 of 2017) broadly empowers the responsible minister to sustainably manage conservation areas, enhance biodiversity, as well as economically empower 'formerly disadvantaged Namibians' (GoN 2017). The 2013 policy on CBNRM details specific issues related to the implementation of community-based interventions, including land tenure rights, compliance monitoring, good governance, capacity building, and sustainability (GoN 2013b). Kanapaux and Child (2011) illustrate how such approaches need to be quite targeted toward the variable needs of communities due to various biophysical and other cultural and socioeconomic realities.

[56] https://www.kavangozambezi.org/en/news-public/item/35-kaza-tfca-position-on-elephant-population-management

Box 8. Artificial water points

Artificial water points (AWP) have been discouraged in wildlife conservation areas due to their tendency to cause increases in wildlife populations and disturbances to their natural migratory patterns, however it has also been highlighted that these can be designed in a way that imitate the natural system and rather ensure adequate movement (Perkins 2020) (Table 8.7).

Table 8.7 Advantages and disadvantages of artificial water points (AWPs) in conservation areas.

Advantages of AWP	Disadvantages of AWPs
Manipulate wildlife movements – to reduce drought-related mortality and HWC	Loss of migratory behavior as wild ungulates become sedentary around water points
Strategic positioning and pumping can be used to facilitate adaptation to climate change	'Canteen effect' enabling the populations of predators such as lions and hyenas to increase.
Focus for game viewing tourists – enables wild ungulates and predators to be viewed clearly	Loss of ecosystem resilience and adaptive behavior of ungulate and predator species (e.g., loss of mobility)
	Shifts conservation emphasis away from migratory corridors and is often accompanied by further land fragmentation and fencing
	Creates overgrazing around AWPs

Source: Perkins (2020)

The Namibian northeast national parks of the KAZA TFCA: Mangetti, Khaudum, Bwabwata, Mudumu, and Nkasa Rupara NPs constitute about 16% of the Namibian portion of the KAZA TFCA (Stoldt et al. 2020). Conservancies under communal tenure and subsistence farming are prevalent land-use practices in the Namibian part, particularly along the Okavango River, which offers favorable conditions for agriculture, both crop cultivation and livestock. Large irrigation can also be found within the Namibia portions of the KAZA TFCA, including within the Bwabwata NP (Stoldt et al. 2020).

The Namibia Second National Biodiversity Strategy and Action Plan for 2013-2022 highlights five key goals:

1. Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society
2. Reduce direct pressures on biodiversity and promote the sustainable use of biological resources
3. Improve the status of biodiversity by safeguarding ecosystems, species, and genetic diversity
4. Enhance the benefits to all from biodiversity and ecosystem services
5. Enhance implementation of the Second National Biodiversity Strategy and Action Plan through participatory planning, knowledge management, and capacity building (GoN, 2014)

The Strategy also calls for synergies across several Conventions including Ramsar, Convention for Biological Diversity (CBD), and the United Nations Convention to Combat Desertification (UNCCD).

Zambia conservation legal and policy framework

Over a third of Zambia's total land areas is under wildlife conservation due to historical colonial delineations of wildlife protection areas (Lindsey et al. 2013). This area is made up of 20 national parks, 2 wildlife sanctuaries, 1 bird sanctuary, 36 game management areas (GMAs) as well as other protected areas (GoZam 2018). Conservation activities in Zambia are managed through the Ministry of Lands and Natural Resources through legislation such as the Zambia Wildlife Act No. 14 of 2015 and other legislation relating to the management of fisheries, land, and the environment (GoZam 2018). The 2015 Zambia Wildlife Act establishes the Department of National Parks and Wildlife as well as Community Resource Boards to facilitate conservation management at the local scale (GoZam 2018).

The 2018 National Parks and Wildlife Policy (GoZaM 2018) highlights community development as one of the key policy strategies by devolving wildlife user rights as well as any costs and benefits realized (GoZam 2018). Community participation in conservation is well developed in Zambia, with programs such as the USAID-funded Administrative Management Design (ADMADE) for GMAs, which promotes integrated wildlife conservation and community development dating back to the 1980s (Sakala and Moyo 2017). ADMADE was implemented in the majority of Zambia's GMAs with mixed success with respect to socio-economic benefits for local communities, and external funding for its implementation ceased in 2002 (Matenga 2002; Milupi et al. 2020).

GMAs (which serve as buffer zones to national parks) allow for human settlements which are prohibited in national parks. As such CBNRM programs are implemented in GMAs (Lindsey et al. 2013; GoZam 2018). The success of such programs has been criticized for not achieving the desired socio-economic benefits for local communities due to a range of reasons including high poverty rates and poaching (Lindsey et al. 2013; Sakala and Moyo 2017).

Zambia's Second National Biodiversity Strategy and Action Plan 2015-2025 states five key goals:

1. Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society.
2. Reduce the direct pressures on biodiversity and promote sustainable use.
3. Improve the status of biodiversity by safeguarding ecosystems, species, and genetic diversity.
4. Enhance the benefits to all from biodiversity and ecosystem services.
5. Enhance implementation through participatory planning, knowledge management, and capacity building (GoZam, n.d)

This strategy is supported by an extensive legal and policy framework across several biodiversity thematic areas including fisheries, land management, wildlife, energy, environment, mining, and water resources (GoZam, n.d).

Zimbabwe conservation legal and policy framework

Conservation activities are regulated through the 1975 Zimbabwe Parks and Wildlife Act (GoZim 1975) as well as the 2002 National Environmental Management Act (GoZim 2002). In addition to these two legal instruments, Zimbabwe currently runs the Communal Areas Management Programme for Indigenous Resources (CAMPFIRE), which allows local communities to manage wildlife on communal land and benefit from it. The program, which began in the early 1980s after Zimbabwe's independence, aimed to reverse colonial laws that had criminalized local communities, preventing them from hunting and benefitting from wildlife. An amendment to the Zimbabwe Parks and Wildlife Act gave the right to local communities to manage and benefit from wildlife in their locality (Alexander and MacGregor 2002). Although there have been positive outcomes of the CBNRM parts of the CAMPFIRE, in some cases it has led to conflict between local communities and local authorities. Alexander and McGregor (2002) therefore highlight the importance of considering historical legacies in the successful evaluation of such programs. Frost and Bond (2008) have drawn parallels between the CAMPFIRE and the Payment for Environmental Services (PES), concluding that while there are similarities, there is a need to strengthen local institutions for the success of CAMPFRE. CAMPFIRE in Zimbabwe is now registered as a Private Voluntary Organization and is funded by various interested donors.

According to the Zimbabwe National Biodiversity Strategy and Action Plan of 2014, the country's biodiversity is threatened by land-use changes from the expansion of agriculture, mining, and urbanization as well as by climate change (GoZim, 2014). Coupled with challenges in policy implementation, the strategy points to poor coordination as 'stifling progress and creating conflicts in biodiversity management despite comprehensive policies and legislation." (GoZim, 2014:19).

8.4.3 National Park management plans

One of the key management tools in the KAZA TFCA is park management plans. There are 20 national parks in the KAZA TFCA, and just over 70% of the total TFCA area is under conservation with the remaining portion used for agriculture and rangeland (KAZA TFCA 2014). Out of the 20 national parks, six are located in the KRWDA; the Luengue-Luiana and Mavinga NPs in Angola, parts of the Chobe NP in Botswana, the Bwabwata, Mudumu, and Nkasa Rupara (Mamili) NPs in Namibia, the Sioma Ngwezi in Zambia including respective conservancies and GMAs (Figure 1.3). Management plans for conservancies also exist but were not available during the time of this analysis.

The scope of park management plans is oriented towards conservation and tourism. Their temporal scope is short to medium term. However, they are useful tools, in which to highlight the role of (ground)water and how best the resources can be sustainably developed and tapped for specific economic development activities as well as water supply for communities, wildlife, and ecosystems. In the following, examples of plans for three key parks in the KRB and KRWDA are given.

Sioma Ngwezi National Park Management Plan (Zambia)
The Sioma Ngwezi ten-year General Management Plan (2019-2029) developed by the Government of Zambia's Ministry of Tourism and Arts through the Department of National Parks and Wildlife, provides guidance on the management of the Park's natural resources and development of tourism facilities (GoZam 2019). The plan identifies a number of local communities dependent on the Kwando River and open and shallow wells for water supply. The plan further highlights the vulnerability communities face from crocodiles in the river, advancing drilling boreholes as a potential solution to the HWCs (GoZam 2019). Medium-term plans are for the drilling and construction of boreholes (artificial water points, AWPs) to augment water supply. Nonetheless, the plan does not outline any groundwater management plans such as monitoring quality or quantity. A similar national park in the Greater Mapungubwe TFCA - the Mapungubwe NP - extensively outlines (in its park management plan) the role of groundwater within the park and has established a network for monitoring groundwater levels (SANParks 2019). The location of known existing wells in the Sioma Ngwezi NP is shown in Figure 5.26.

Bwabwata National Park Management Plan (Namibia)
Developed by the Ministry of Environment Forestry, and Tourism of Namibia, the Bwabwata NP Management Plan (2020/2021-2029/2030) outlines developments and activities that should take place around the park including the development of airstrips, campsites, and artificial water points (GoN 2020a). The main objective of water supply is to ensure that there is potable water for the park staff and visitors using water from both riverine and underground sources, although groundwater is the most preferred. There are several boreholes in the park to secure water to wildlife during the dry season (not shown in Figure 5.26 due to lack of data). However, the use of such AWPs is discouraged

and only to be used when necessary, so as not to disturb the natural wildlife dispersal patterns (GoN 2020a). Further, additional AWPs, although currently discouraged in the plan, are to be considered in as far as they contribute to vulnerable species support or economic development. The main objectives of managing the AWPs are (GoN 2020a):

- To maintain the current water availability with periodic evaluation of their use
- To protect vulnerable, rare, or threatened species
- To support tourism and trophy hunting in the park and neighboring conservancies, provided this does not adversely impact priority habitats or important species

Mudumu National Park Management Plan (Namibia)
The Mudumu NP is managed by the Namibian government through the Ministry of Environment Tourism and Forestry. Five communal conservancies are registered under the park following the Namibian government policy enabling their establishment (GoN 2020b). The Mudumu NP Management plan (2020-2030) is an official document, which guides proactive response and is reviewed every five years (GoN 2020b). One of the strategic objectives identified is to maintain regional conservation synergy through effective engagement with all park neighbors including those established by the KAZA TFCA, such as various basin water management initiatives, where the Kwando is the main source of water in the park (GoN 2020b). The park contains two AWPs to supplement natural water sources whose effects on wildlife should be regularly reviewed. The plan highlights that groundwater pollution should be monitored in collaboration with the relevant government departments (GoN 2020b).

8.5 Findings of national legal, policy, and institutional analysis

The results of the preceding analysis of the legal, policy, and institutional frameworks of the KAZA TFCA Partner States with respect to water and conservation (Section 8.4) are presented in Table 8.8. Based on this and the broader analysis of the regional and international legal and institutional landscape for water and conservation management (Section 8.1 to 8.3), the Transfrontier Groundwater Management Framework (TGMF) for the KAZA TFCA will subsequently be developed as a separate deliverable of the KAZA-GROW project. The conclusions and recommendations put forward in this and the following section (Section 8.6) aims to provide the basis or elements for developing such a framework supporting groundwater management within existing governance structures or if needed, supporting the co-development of new policies, taking into consideration the key challenges with respect to groundwater and conservation and the relevant scales in the KAZA TFCA.

National water policies and plans are fundamental instruments among the five KAZA TFCA Partner States and contain coverage of groundwater to varying degrees. The Botswana National Water Policy, for example, shows the importance of groundwater, available quantities, and recharge rates, while the Zimbabwe National Water Policy highlights the lack of groundwater data to inform management decisions. All countries highlight some level of a gap in terms of groundwater knowledge required to inform sustainable groundwater management. The Angola, Namibia, and Zambia water frameworks provide relatively larger coverage of groundwater management compared to the Zimbabwe and Botswana frameworks (Table 8.8). For all countries, the linkage between groundwater and ecosystems is relatively less well-addressed, although all countries highlight the importance of sustainable development and conjunctive management of surface and groundwater (Table 8.8). From the assessment of the national conservation frameworks, it is clear that water is generally featured as a key component of a conservation management framework, but not surprisingly, groundwater is less well represented. Having identified the critical role of groundwater for resilience and sustainable development in TFCAs and in larger and connected water and bio-ecological systems, it is confirmed that there is a gap in terms of addressing groundwater in these systems.

Table 8.8 Coverage of groundwater within national legal and policy frameworks for water and conservation.

Indicator[a]	Angola	Botswana	Namibia	Zambia	Zimbabwe
National Water/Conservation Law/Policy/Plan in place	+	+	+	+	+
Groundwater coverage in the national laws, policies, and plans	***	**	***	***	**
Groundwater development for enhancing climate resilience	*	*	*	*	*
Integrated groundwater and surface water management (conjunctive management)	*	*	*	*	*
Management and regulation of groundwater abstraction including identification and protection of recharge areas	**	*	**	**	*
Groundwater-dependent ecosystems (GDEs) in supporting conservation and livelihoods	–	–	–	–	–

[a] *** Focus covered with clear details
** Focus partly covered with limited details on implementation
* Focus covered, but not detailed
- Focus not mentioned within policy or legislation
+ Presence of focus in the national framework

The International Ramsar Wetlands Convention provides a good starting point, from a legal, policy, and institutional perspective, to take the TGMF forward, as it works in the cross-field between water and conservation management and does explicitly bring groundwater into its framework (Ramsar 2010). This is still at a more conceptual level, than at an applied management level, at least in the KAZA TFCA, but provides a strong entry point for the further development of the TGMF.

8.6 Recommendations for groundwater integration in legal and policy frameworks

The findings in Section 8.5 indicate the need to further integrate and expand groundwater considerations in existing legal, policy, and institutional frameworks for both water and conservation management related to TFCAs. Various important synergies present themselves in this regard:

1. Managing water resources and ecosystems are mutually reinforcing, and hence strengthening these links, especially on the groundwater aspects, will add great value to existing management frameworks.
2. The frameworks that apply to TFCAs have important significance for non-TFCA regions of SADC, and in essence, the focus of TFCAs is helping blur boundaries between management for conservation and broader sustainable development. Conservation and the socioeconomic values associated with it provide strong incentives for developing holistic and multi-criteria sustainable development across SADC.

At the various levels of governance in SADC, the following recommendations for how to better integrate groundwater into water and conservation frameworks are provided. These will support the development of the integrated Transfrontier Groundwater Management Framework.

SADC/regional level

Develop a generic Protocol for Transboundary/Transfrontier Conjunctive (surface water and groundwater) Management in SADC. While the SADC Revised Protocol on Shared Watercourses provides overall guidance on transboundary water resources, reference to groundwater and transboundary aquifers is limited. This could be because the watercourse definition encompasses aquifers, making their inclusion implicit. However, unique features of groundwater that necessitate specific management focus, are not clearly articulated, which may in the best-case result in the neglect of groundwater management or in the worst case undermine overall water resources management. The unique features of TBAs include their invisibility, unclear dynamics, and relatively slow movement, which call for better land use management, including protecting recharge and discharge zones, and the application of the precautionary principle, strong local engagement, and adaptive long-term climate-sensitive conjunctive management of surface and groundwater resources (Table 8.9). Given this backdrop, a specific protocol on transboundary aquifers or conjunctive water management may be a useful tool at the SADC level to allow for greater and more targeted adoption at the national and TFCA/RBO level (Figure 8.6).

Table 8.9 Characteristics of aquifers and implications for management of TBAs

	Special considerations/provisions needed in TBA management[a]								
Groundwater distinct characteristic	Joint user/use registration, regulation, monitoring and enforcement	Prior notification of development plans to other party	Precautionary principle	Conflict resolution	Stakeholder engagement	Long-term monitoring of resource	Flexibility in conceptual model and clear data- sharing arrangements	Land use and waste regulations	Prioritized protection
Open source	xx				xx				
Invisible and heterogeneous		x	x	x	x	x	x		
Vulnerable to land use impacts					x			xx	x
Slow reacting/delay in response		x	xx	x		xx			
Recharge/discharge is distributed and uneven								x	xx
Boundaries uncertain				x		x	xx		
Climate change impacts uncertain						xx	xx		
Blurred up- and downstream			x	x	x	x	xx		

Source: Villholth (2015)

River basin level

Strengthen the role of groundwater technical committees in basin organizations. And explore the designation of a (transboundary) Ramsar Site in the KRS. At the transboundary basin level, following the regional setup highlighted in the report (Section 8.3.1), groundwater technical committees of RBOs can serve as a vehicle to implement more specific tenets on groundwater as provided by the various protocols. Considering the geographic position of the Nata Karoo TBA, it will be critical that OKACOM and ZAMCOM work towards co-managing the shared aquifer, potentially with a strong role for the KAZA TFCA Secretariat with respect to shared conservation issues. Specifically for the KRS, the scope for establishing a (transboundary) Ramsar Site should be further explored. In Section 8.3.2, a potential site with a high likelihood of supporting regional groundwater recharge was identified (the trans-basin Moxico Water Tower in Angola).

KAZA TFCA level

Highlight groundwater-related development plans in the KAZA TFCA Master Integrated Development Plan (MIDP), develop a JSAP related to groundwater and establish an expert or sub-Working Group on Groundwater in the KAZA TFZA Freshwater Working Group. The KAZA TFCA through its planning instruments, such as the KAZA TFCA MIDP, can further groundwater considerations related to how the resource can sustain ecosystems and wildlife and improve livelihoods in the wake of climate change impacts in the TFCA. This should be supported by a dedicated

JSAP for the Kwando River system, which may inform priorities and investments into groundwater assessment, development, and protection, building on existing TDA/SAP processes in the KAZA TFCA, e.g., by OKACOM (2011a,b). To inform such planning, it is recommended that the Freshwater Working Group under the Conservation Working Group under the KAZA Secretariat is strengthened through a dedicated Groundwater Expert or sub-Working Group. This will specifically address the information needs for groundwater development, e.g., for communities and Artificial Water Points (AWPs) in the national parks, and will facilitate cross-learning and harmonized and sustainable approaches for management. The Expert/sub-Group may also take on other tasks as TORs and needs to develop, for example, knowledge sharing and awareness-raising among stakeholders, knowledge management, citizen science, and database development related to groundwater/aquifers.

National level

Integrate freshwater management within park management plans. Park management plans have the potential to integrate freshwater management, including groundwater, with conservation management. Focus on the provisioning ability of groundwater can be integrated within park management plans to a greater extent than is currently observed. Issues that can be addressed at this level include local assessment of the resource potential, monitoring of groundwater abstraction, levels, and quality, and analysis of how groundwater can support conservation activities and mitigate against climate variability impacts. Furthermore, hydrogeological studies should be undertaken to identify and map the underlying aquifers, their connectedness with surface water resources in recharge and discharge areas, and the groundwater-dependent ecosystems (GDEs) they support within the national parks.

Local/community level

Integrate groundwater management into community-based natural resource management (CBNRM) frameworks. While CBNRM has brought about variable levels of success across the KAZA TFCA Partner States, the approach is promoted in regional and national policies as highlighted in the preceding sections. With this realization, it is important to integrate groundwater considerations into CBNRM frameworks that benefit both communities and wildlife for resilience and food and water security.

It is believed that these recommendations, based on consultation with stakeholders, will be developed and integrated as possible elements of the Transfrontier Groundwater Management Framework (TGMF).

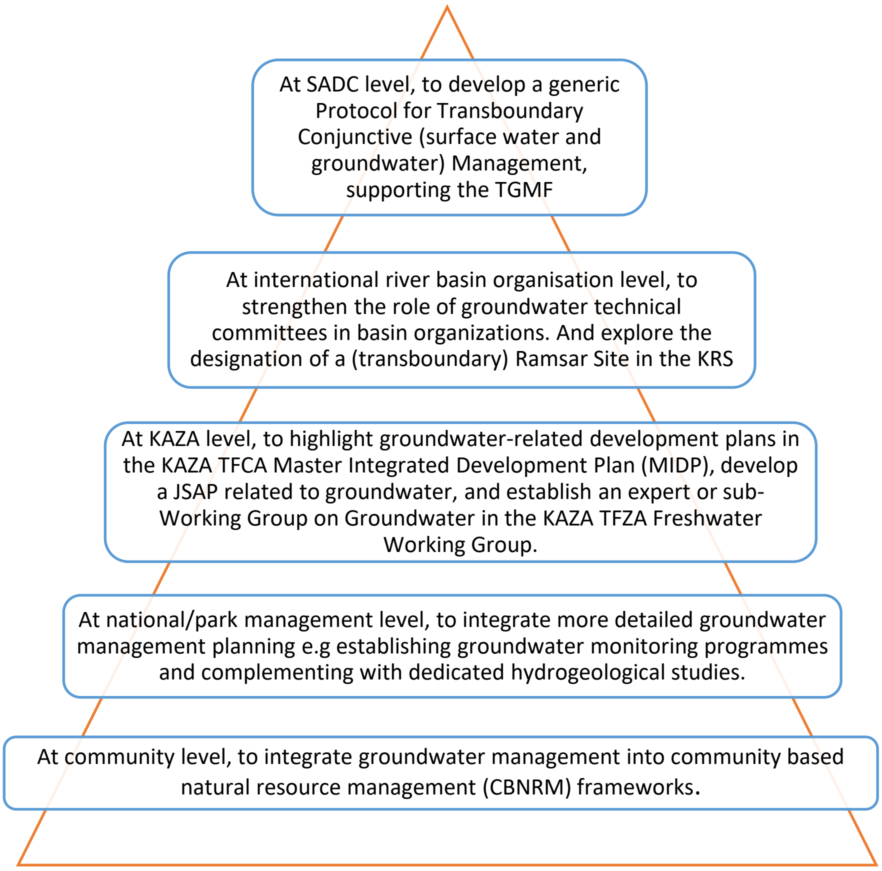

Figure 8.6 Possible interventions for groundwater integration into legal and policy frameworks in SADC with a focus on the needs of TFCAs.

9 LIMITATIONS OF THE STUDY

Limited and spatially skewed datasets across the KRS. There is a clear spatial skew in the distribution of various datasets. Most of the currently available datasets originate from the lower KRS, particularly the Western Zambezi region, Namibia. There are significantly fewer data from Angola and the upper parts of the KRB. The population density decreases in these upper regions towards the Angolan highlands and may partially explain why there is less monitoring infrastructure and thus recorded datasets. The TDA is based on secondary data and reflects an effort to compile information from data-scarce regions alongside the uneven distribution of data between the Partner States. Therefore, an emphasis on closing the data gap in a prioritized manner is critical in future interventions within the region. To support such a process, Appendix III lists priority missing datasets that future studies should provide to improve the knowledge and understanding of the region.

Limited available literature and unequal distribution of previous investigations across the KRS. A mix of qualitative and quantitative data was pursued to gather and present the relevant information as comprehensively as possible. This was complemented by relevant inferences and extrapolations to overcome limitations and provide a preliminary assessment of geographical regions with significant data scarcity. For example, there are multiple studies that relate to the Okavango River Basin (ORB) due to its international distinction and significance. This is not the case for the KRB, and it was essential to draw on these comparable studies and incorporate them with available datasets to the extent possible to build the preliminary conceptual hydrogeological model for the KBR. Similarly, working at nested scales gave an understanding of the context, e.g., from small to larger catchments, or from upstream to downstream areas.

The impact of the COVID-19 pandemic. Extraordinary factors, such as the COVID-19 pandemic, had an impact on the KAZA-GROW project implementation and the TDA. For example, the stakeholder consultation workshop was undertaken online rather than in-person. Implications of this are hard to monitor but could result in less effective engagement and feedback from stakeholders.

10 CONCLUSIONS AND RECOMMENDATIONS

The Transboundary Diagnostic Analysis (TDA) for the Kwando River system (KRS) linked to the Kavango Zambezi Transfrontier Conservation Area (KAZA TFCA) and with a focus on groundwater and aquifer resources, has provided a comprehensive interdisciplinary baseline understanding, based on available information, of the groundwater and aquifer context at various scales in the KAZA TFCA, and the roles groundwater plays in sustaining ecosystems and human health and livelihoods across the KAZA TFCA.

The aim was to underscore the criticality of proactively incorporating considerations of this resource into development and conservation planning. While the biophysical knowledge base is still rather limited and fragmented, it provides a solid basis for an overarching preliminary conceptual model of the subsurface system and its potential in serving biodiversity, ecosystems, and humans. As such, conclusions and general recommendations follow as to how to move forward in terms of improving the knowledge base as well as scoping out requirements to improve management of this resource and integrate it into broader, including transboundary, freshwater resources, ecosystem and conservation management, and cooperation structures.

Conclusions
From the TDA, the following general conclusions are brought forward:

1. The KAZA TFCA is a flagship transfrontier conservation area in Southern Africa, not only due to its size – being the biggest on the continent and globally – and its unique biome, but also because of the advanced cooperation mechanisms in place, with the KAZA TFCA Ministerial Committee at its apex and the KAZA TFCA Secretariat driving and coordinating the daily activities associated with the planning and development of the KAZA TFCA, and with support from local and Partner State (Angola, Botswana, Namibia, Zambia, and Zimbabwe) entities, National Governments, River Basin Organizations (OKACOM and ZAMCOM), as well as international donors, with a common long-term vision of prosperity and sustainability for the region.
2. Since TFCAs are focused on critical landscapes and ecological systems – not necessarily aligned with river basins – their remit related to river basin and aquifer system management is less prominent. However, with water resources coming under increasing stress, this, in turn, indicates the clear need for, and the synergy between, TFCA, RBO, and Partner State cooperation.
3. The groundwater resources, the subsurface hydrogeological and surface morphological setting and dynamics, along with climate, of the KAZA TFCA are to a large extent controlling the natural environment, e.g., with respect to the soil systems, vegetation, topography, catchment dynamics, and characteristics of ecosystems.
4. The Kwando River Basin, which is presently in a relatively pristine condition, is groundwater-driven, supporting perennial and relatively steady river flows downstream. Compared to the Okavango River system, the Kwando River is less seasonal given the maintained level of flow throughout the year, is less prone to larger floods and drought, and hence more climate-resilient.
5. To maintain the Kwando River Basin and associated conservation and wildlife dispersal areas in a healthy and climate-resilient state going forward, better groundwater management and understanding are required along with a better assessment of human and climate change impacts over the medium term.
6. The KAZA TFCA counts on five identified transboundary aquifers, while only two of them are presently associated with a certain level of knowledge, including the Nata Karoo TBA, located

within the KRS and possibly shared between the five Partner States. It cannot be ruled out that other TBAs exist, e.g., that the Nata Karoo consists of several distinct TBAs. It is also possible that a larger more regional aquifer system that ties upland headwaters and recharge areas in Angola to downstream discharge areas is present.

7. It is important to protect areas in the KAZA TFCA that are upstream of critical ecological sites, aquatic ecosystems, and potential Groundwater Dependent Ecosystems (GDEs), like wetlands and inland deltas. This is the case for both the Okavango and Kwando Rivers, which have significant deltas or flood plains downstream. This includes recognizing and possibly designating Ramsar sites in key upstream groundwater recharge areas maintaining pertinent upstream-downstream linkages, even with areas that lie outside of the KAZA TFCA, such as the Angolan highlands.
8. Groundwater will likely play a larger role in the KAZA TFCA, as populations grow, and urbanization and economic activities expand. This implies larger pressure on existing water and land resources for wellbeing, livelihoods, and economic growth, and climate change exerts larger variability in freshwater resource availability, implying larger demands for water during droughts (inevitably from groundwater). However, the legal, policy, and institutional frameworks are presently not robust enough to support the development and management of the envisaged demand on the resource (in-situ and ex-situ – i.e., for ecosystem services and abstraction for human needs) in the KAZA TFCAs, where conservation itself is an important water 'user'.
9. The KAZA TFCA represents a strong candidate for developing a Transfrontier Groundwater Management Framework relevant to the TFCA and possibly the Southern African Development Community (SADC) more broadly. Pre-scoping of such framework among the Partner States and relevant stakeholders as part of the TDA initiated a process towards consolidating such framework.

Recommendations
From the TDA, the following recommendations are brought forward:

A. ***Joint Strategic Action Plan***. It is recommended that the Transboundary Diagnostic Analysis (TDA) of the Kwando River system (KRS) is succeeded by the development of a Joint Strategic Action Plan (JSAP) for the KRS, with the aim to identify priority activities and investments related to groundwater that will support conservation, wildlife, and ecosystem protection as well as better water security and management across the Partner States. This should build on stakeholder recommendations and feedback for the TDA, the KAZA TFCA Master Integrated Development Plan (MIDP) processes, as well as other TDA/SAP processes in the TFCA, e.g., by OKACOM.

B. ***Groundwater assessments***. It is recommended that more in-depth and targeted groundwater assessments are carried out for the KRS. These studies, which should be done in transboundary cooperation, should focus on:
   I. The larger **Kwando River Basin hydrogeology**, river baseflows, surface water-groundwater interactions, recharge and discharge areas, and environmental flows
   II. Basin-wide **impact assessments** of climate change, socio-economic development, land-use change, and infrastructure development, including integrated hydrodynamic modeling
   III. **Hydrogeological assessment of the Nata Karoo TBA** includes improved delineation using geophysical investigations, selected exploratory drilling and isotopic studies, and 3D groundwater modeling to resolve the water balance and detailed flow dynamics
   IV. **Identifying and mapping GDEs** within the KRS and wider KAZA TFCA. These investigations would support the identification of potential (transboundary) Ramsar sites as well as critical approaches to their long-term management

C. ***Groundwater monitoring***. It is recommended to implement a coordinated groundwater sampling and monitoring framework across the KRS that is specifically and initially aimed at supporting activities under Point II Forward monitoring must be prioritized in particularly vulnerable areas and include efforts to assess both groundwater quantity and quality. It must be ensured that the data are captured, stored, and shared effectively for all partners to access.

D. ***(Transboundary) Ramsar site designation and conservation*.** It is recommended to further investigate the options for designating the trans-basin Moxico Water Tower (Lisima Lya Mwono area) in Angola, or a larger part of the transboundary Kwando River Basin, as a (transboundary) Ramsar site. This would support the protection of source water areas that provide critical fresh water for downstream areas of the KRS, as well as the Cuito (Okavango River Basin) and other upper catchments of the Zambezi Basin. Models for its conservation including investments need to be put in place.

E. ***Groundwater potential development*.** It is recommended to further investigate and cautiously develop the resource potential of groundwater for sustainable water supply and small-scale livelihoods in the KAZA TFCA. Of particular relevance and importance is the provision of drought-resilient WASH facilities for local poor communities that will also cater to integrated small-scale productive uses as well as artificial water points (AWPs) for wildlife that enhance wildlife resilience to droughts while supporting natural migration dynamics. The installation of AWPs, and wider groundwater exploration, must critically assess the risks of Human-Wildlife conflicts and address nature-based solutions.

F. ***Transfrontier Groundwater Management Framework*.** It is recommended to further develop the integrated Transfrontier Groundwater Management Framework (TGMF) that will support the KAZA TFCA going forward in its integrated management of groundwater resources, in collaboration with SADC, Ramsar, RBOs, national ministries of water, as well as conservation and local stakeholder groups and community-based organizations. It is essential to integrate the TGMF across these various scales to ensure maximum cohesion between the different levels of governance.

G. ***Transboundary cooperation structures.*** In support of a successful TGMF, it is recommended to support and facilitate stakeholder and technical support platforms at the local to transboundary level with the aim to better incorporate groundwater for sustainable development and conservation in the KAZA TFCA, with an early focus on the KRS - for example, to maintain and strengthen pre-existing structures such as the Kwando Joint Action Group (KJAG) and to incorporate groundwater technical committees in the river basin organizations. Such structures will incentivize stakeholders to abide by the principles of international best practices for multi-country water cooperation, while in the long term potentially facilitating formalizing cooperation (into a treaty, agreement, or other).

H. ***Groundwater representation in the Freshwater Working Group in the KAZA TFCA organizational structure*.** It is recommended that best groundwater knowledge and recommendations are offered to the Freshwater Working Group under the Conservation Working Group under the KAZA Secretariat through a dedicated Groundwater Expert or sub-Group.

I. ***Knowledge Management Hub and related data sharing mechanisms for the KAZA TFCA*.** It is recommended that a Knowledge Management Hub is established for the KAZA TFCA, aggregating and harmonizing existing interdisciplinary data and information, which would enhance best knowledge sharing mechanisms e.g., National Partners, national parks, International Cooperation Partners, as well as local stakeholders. Such KAZA TFCA-wide data sharing mechanism would be linked to existing knowledge systems, like the OKACOM Decision Support System (DSS) and the ZAMWIS. An open-source online data-sharing platform for the KAZA TFCA (like the RIMS[57]) could be a component of the Knowledge Management Hub.

[57] RIMS (Ramotswa Information Management System) https://www.un-igrac.org/resource/ramotswa-information-management-system-rims

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APPENDIX I: SUMMARY OF STAKEHOLDER ENGAGEMENT PROGRAM

Stakeholder	Contact	Expertise	Date	Key Discussions/Outcomes
Peace Parks	Loraine Bewsher, Kuthadzo Nethengwe	Planner, Capacity Building	05/03/2021	- Details for collaboration with South African Wildlife College - Sharing of KAZA TFCA Park management plans
Peace Parks	Marina Faber	GIS	17/03/2021	- Created maps to use in stakeholder discussions, Data sharing agreement, Maps: Land use, soils, districts and wetlands
SASSCAL	Joerg Helmschrot	S. African climate database	01/04/2021	- CHIRPS rainfall datasets (1981-2020) - Navigating SASSCAL online portal
Peace Parks	Simon Mayes	Conservation, management	06/04/2021	- Conservation within Sioma Ngwezi NP
WWF	Mike Knight	Water resources	09/04/2021	- WWF (State of the basin report, Kwando activities)
WWF	Faith Chivava, Beauty Mbale	Hydrology	13/04/2021	- Discussions regarding hydrological modelling, sharing Kongoli discharge data - Invitation to KJAG meeting 27/05
Independent Consultant	Katharina Dierkes	GIS specialist, Namibian Hydrogeology	21/04/2021	- Key Namibian Hydrogeology report, assessment of Namibian GW archives
KAZA TFCA	Fritz von Krosigk	Park Conservation, management	26/04/2021	- Conservation issues/Management of Luengue-Luiana NP
Angolan Inst. of Water resources	Manuel Quintino	Water resources, governance	26/04/2021	- Role of Zamtech, key Angolan hydrology reports, transboundary issues
DWRD, Zambia	Namafe Namafe	Water resources	30/04/2021	- Discussion regarding key Zambian stakeholders/water quality and salinity issues
RAISON	John Mendelsohn	Water resources, socioeconomics	07/05/2021	- Kwando knowledge sharing, development prospects in SE Angola
Peace Parks	Willem Ponahazo	Conservation Park Management	07/05/2021	- Governance structures between regional parks, wildlife corridors in region
MAWLR, Namibia	Sakeus Ihemba & Anna David	Hydrogeologist(s)	02/03/2022	- Review of TDA and hydrogeological knowledge, collating BH data
DWS, Botswana	Keodumetse Keetile	Principal Hydrogeologist	04/03/2022	- Review of TDA and hydrogeological knowledge, collating BH data

APPENDIX II: KAZA-GROW META-DATABASE SOURCES

Online Databases		Institution	Links	Types of data available	Region
	International				
Ramsar Sites Information Service (RSIS)		Ramsar	LINK	Shapefiles, reports	World
Global Groundwater Information System (GGIS)		IGRAC	LINK	Online Maps	World
Quantitative Groundwater Maps for Africa		BGS	LINK	African groundwater maps download	Africa
Transboundary Water Assessment Programme (TWAP)		IGRAC/GEF	LINK	Reports	World
Gridded Population of the World (GPW), v3		UNEP/CIESIN	LINK	Raster files for southern Africa population densities	World
	Regional				
Peace Parks Foundation Open Data Portal		Peace Parks	LINK	Maps	Southern Africa
Land Cover monitoring KAZA- TFCA		KAZA TFCA	LINK	KAZA TFCA M&E, SMART Monitoring	KAZA TFCA
ZAMWIS		ZAMCOM	LINK	Integrated GIS, rainfall, river gauge, published reports	Zambezi River basin
SADC GIP		SADC GMI/IGRAC	LINK	Harmonized hydrogeological map for the SADC region, borehole data and associated information	SADC
CRIDF Resource Centre		CRIDF	LINK	Report database	Southern Africa
SASSCAL Data and Information Portal		SASSCAL	LINK	Climatic data and reporting from the southern Africa region	Southern Africa
OKACOM		OKACOM	LINK	Decision Support System	Southern Africa
	National				

APPENDIX III: TDA MATERIALS AND DATASETS USED

TDA Chapter	Description	Data requirements	Data gaps	Key Stakeholders
1	**Introduction**	**Regional maps, TDAs**		**Peace Parks, literature, GEF, IWMI, IR maps**
2	**The Transboundary Diagnostic Analysis**	**Regional Maps**		**Peace Parks**
3	**Physiography**			
3.1	Climate – present and historic	Climate – Precipitation (CHIRPS)	Full weather station data, actual ET data	SASSCAL
3.2	Climate Change Projections	Regional model results, IPCC SADC projections		WWF climate change KAZA TFCA report
3.3	River Basins	River basin: topographic data		ZAMWIS
3.4	Land cover / Use	Changing Land Use (GIS) Shapefiles, recent maps	regional/ KAZA specific / temporal evolution	Peace Parks (with
3.5	Geology	Geological maps / cross sections / stratigraphic charts / geophysical studies	Borehole logs of across the region, Angola more specifically	All partners, literature
3.6	Soils	Soil map shapefiles and maps	Local field data of soil profiles to verify large scale maps	FAO UNESCO Global Soil Map
4	**Socioeconomics**			
4.1	Demographics	Individual country data, river basin scale, downscaled within each region, OKACOM (2011a)	Population density throughout the KAZA	FEWSNET, only Zambia/Angola,
4.2	Transport infrastructure and water and energy services			

4.3	Economics, livelihoods and the SDGs	Individual country data, key industry, tourism, COVID impacts; Statistics regarding growth, SDG 6 progress reports	KAZA and regional specific, Further humanitarian reports	Peace Parks reports (see folder), CRIDF
4.4	WASH provisions	Statistics regarding access to water and sanitation		CRIDF reports
4.5	Water Use			
4.6	Recommendations to improve socioeconomic conditions	Regional development plans		Peace Parks Masterplan, KAZA TFCA
5	**Water resource assessment**			
5.1	Surface water			
5.1.1	River catchments	Long term river gauge records, seasonal flood records		ZAMWIS / Peace Parks / WWF
5.1.2	Wetlands	Location shapefiles, literature, World Heritage status	Role of GW in wetlands	RAMSAR website, UNESCO World Heritage
5.1.3	Water quantity and quality	Results of long-term river sampling, differences in wet and dry season	Hydrological modelling, Other: dams, dug wells	WWF, Mendelson and Martins 2018
5.2	Groundwater			
5.2.1	Aquifer systems (shallow and deep)	Aquifer maps, hydrogeological parameters	Geological model, GW ages, recharge estimates, flow paths	
5.2.2	Geological features	Geological maps; Lineaments/faults shapefiles	Detailed maps, accompanying field data, photos	National databases, BGS/BGR archives
5.2.3	Conceptual model of groundwater flow and surface water-groundwater interaction	Large scale geological cross sections	3D groundwater models	WWF- Zambia, Bäumle et al.

5.2.4	Groundwater potential			
5.2.5	Development potential (quantity and quality)	Compare to known aquifer systems, e.g., Okavango, more data-rich	3D groundwater models outputs	Map with subset of collected groundwater information
	Climate change adaptation	Wider literature review, CC adaptation in SADC	More detailed analysis w.r.t. GW	World Bank 2020 Drought report
	GW infrastructure	Peace Parks Maps		Combined BH sources Data sharing with WWF-Zambia
6	**Transboundary aquifers**			
6.1	Transboundary aquifers in SADC	Regional TBA maps and assessments, TWAP	Eastern Kalahari Karoo info	IGRAC / TWAP Nata Karoo / SADC GIP
6.2	Transboundary aquifers in the KAZA TFCA	Gap analysis		
6.3	The Nata Karoo Transboundary Aquifer in the KRB			TWAP
6.4	Ongoing assessment of other transboundary aquifers within KAZA TFCA			IGRAC
6.5	Data and knowledge gaps for the Nata Karoo Transboundary Aquifer			
6.6	Incipient transboundary aquifer cooperation in KAZA TFCA			
7	**Ecosystem services and environmental risks**			

7.1	Ecosystems and ecosystem services	National parks data and maps, consultation with Park managers, questionnaire, key water sources for wildlife	Veterinary fences, high risk fire areas, industrial activities and potential pollution sources	Peace Parks national park base-maps
7.1.1	Groundwater-dependent ecosystems	Definition of GDEs, recent Tuli-Karoo study		
7.1.2	Environmental flow requirements			In conjunction with WWF 'State of the basin' and 'Health Report card'
7.2	Wildlife and Biodiversity	Key conservation stats relating to challenges highlighted on Peace Parks website see: Key challenges in WDA	Success/failures of wildlife corridors, poaching data	Peace Parks Masterplan, KAZA TFCA
7.2.1	Human-wildlife conflicts	National parks data and maps, consultation with Park manager; Poaching data, Human wildlife corridors, Animal migration routes		Local government websites, check
7.3	Environmental and health risks	Effects of habitat loss, shared habitats and potential for disease transmission		Peace Parks national park base-maps, KAZA, TNC
7.4	Transboundary issues	Defining Kwando and relation to other basins		CRIDF, literature search
8	**Legal and Institutional framework**			
8.1	Significance of groundwater development and management in southern Africa			
8.2	Conservation governance in southern Africa			

8.3	Transboundary frameworks for freshwater governance			
8.4	Transboundary conservation frameworks			
8.5	Transboundary freshwater and conservational institutional and governance structures in KAZA TFCA			
8.6	Transboundary aquifer management instruments: Examples from SADC			
8.7	KAZA TFCA Integrated Master Plan and National Park Management Plans			
8.8	National freshwater and conservation policies and strategies			
8.9	Results of national legal, policy and institutional analysis and recommendations			
8.10	Recommendations for groundwater integration in legal and policy frameworks			
8.11	Key Messages			

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