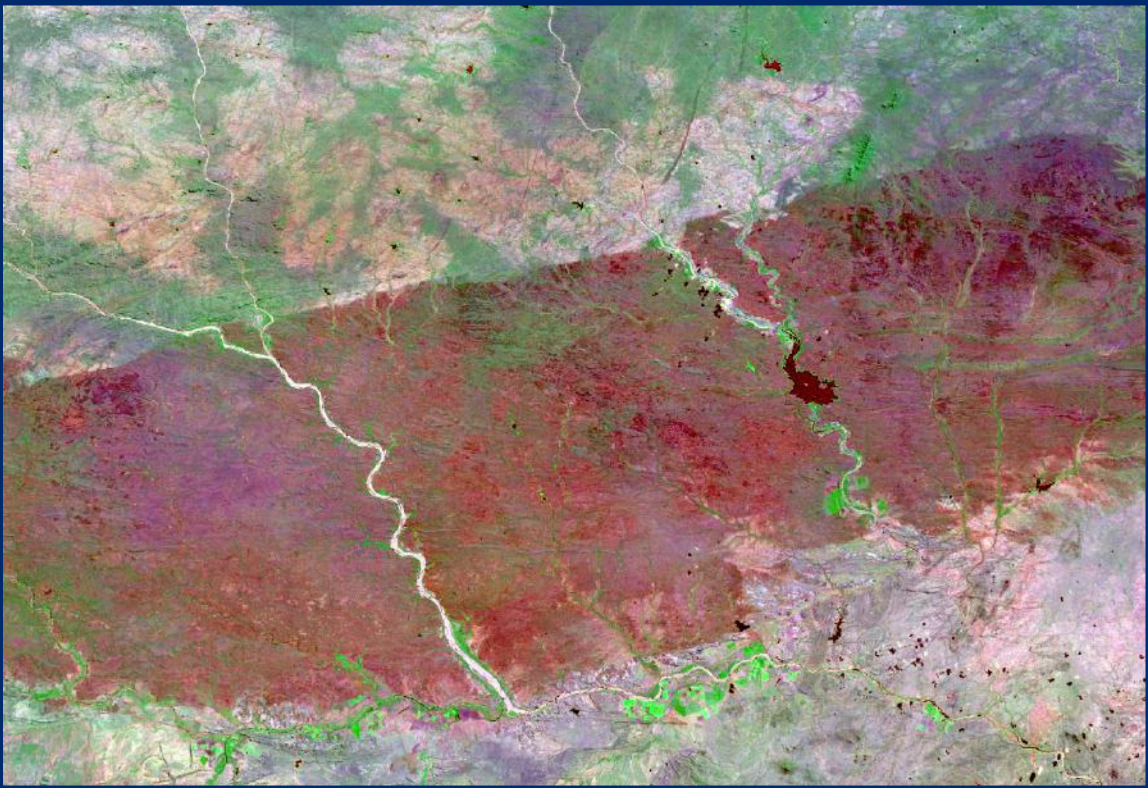
Transboundary Diagnostic Analysis (Baseline Report) for the Tuli Karoo System



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Acronyms

AfDB	African Development Bank
AGWNET	Africa Groundwater Network
AMD	Acid mine drainage
BIOPAMA	Biodiversity and Protected Areas Management
BCL	Bamangwato Concessions Ltd
CMA	Catchment Management Agency
DWA	Department of Water Affairs
DWS-BW	Department of Water and Sanitation-Botswana
DWS-SA	Department of Water and Sanitation-South Africa
DoH	Department of Health
DWAF	Department of Water Affairs and Forestry
EFR	Environmental Flow Requirements
ET	Evapotranspiration
EMA	Environmental Management Agency
FDC	Flow Duration Curve
FAO	Food and Agricultural Organization
GDE	Groundwater Depended Ecosystems
GMI	Groundwater Management Institute
GEF	Global Environment Fund
GLEAM	Global Land Evaporation Amsterdam Model
GDP	Gross Domestic Product
GPS	Global Positioning System
HIV	Human Immune Virus
IB	Irrigation Board
IWMI	International Water Management Institute
IUCN	International Union for Conversation of Nature
IMERCSA	Musokotwane Environment Resource Centre for Southern Africa
IPCC	International Panel for Climate Change
IWRM	Integrated Water Resources Management
LIMCOM	Limpopo Watercourse Commission
LMB	Limpopo Mobile Belt
LULCC	Land Use and Land Cover Change
LGC	Limpopo Groundwater Committee
MLM	Musina Local Municipality
MAP	Mean Annual Precipitation
MBGL	metres below ground level
MCM	Million Cubic Meters
MoLAWCRR	Ministry of Land Water, Agriculture, Climate and Rural Resettlement
MoLMWSS	Ministry of Land Management, Water and Sanitation Services
MoMEWR	Ministry of Mineral, Energy and Water Resources
NDP	National Development Plan
NOAA	National Oceanic and Atmospheric Administration
NDVI	Normalized Difference Vegetation Index
NASA	National Aeronautics and Space Administration
NWPR	National Water Policy Review
NWP	National Water Policy
NWRSII	National Water Resources Strategy II
NWSMP	National Water and Sanitation Master Plan
NWP	National Water Policy

NCU	National Coordinating Unit
NAC	National Action Committee
PET	Potential evapotranspiration
RBO	River Basin Organisation
RSAP	Regional Strategic Action Plan
RWIMS	Rural WASH Information System
RQOs	Resource Quality Objectives
RDRM	Revised Desktop Reserve Model
SADC	Southern African Development Community
SANP	South Africa National Parks
SARDC	South African Research and Documentation Centre
SAP	Strategic Action Plan
TFCA	Transfrontier Conservation Area
TB	Tuberculosis
TDA	Transboundary Diagnostic Analysis
TDS	Total Dissolved Solids
UB	University of Botswana
USEPA	United States Environmental Protection Agency
UNCTAD	United Nations Conference on Trade and Development
VIP	Ventilated Improved Pit
VDC	Village Development Committee
WUC	Water Utilities Corporation
WASH	Water Sanitation and Hygiene
WMO	World Meteorological Organization
WARMS	Water use Authorization and Registration Management System
WFDs	Wetting Front Detectors
WDM	Water Demand Management
WE	Water Efficiency
WUAs	Water User Associations
WUC	Water Utilities Cooperation
WAB	Water Apportionment Board
WB	Water Boards
WSA	Water Service Authorities
ZINWA	Zimbabwe Water Authority
ZimVac	Zimbabwe Vulnerability Assessment Committee
ZMSD	Zimbabwe Meteorological Services Department

Executive Summary

Conjunctive Management of Transboundary Waters in Southern Africa: Taking the first step Responding to recognition of the importance of international river basins, there has been prolific activity in transboundary surface-water cooperation in Africa generally and in the Southern African Development Community (SADC) specifically. A growing body of work, however, has also now identified and delineated more than 30 transboundary aquifers in the SADC Region and many more in Africa as a whole. Managing shared aquifers cooperatively and conjunctively – i.e., linking their management with pre-existing cooperative surface water frameworks – can foster progress towards the region's development goals including strengthening resilience, improving agricultural production, enhancing water security and achieving sustainable growth. A critical first step toward achieving cooperative and conjunctive management is achieving a common understanding of the international watercourse system. Undertaking a Transboundary Diagnostic Analysis (TDA) enables countries, which share a watercourse, to reach this common understanding.

Approach to this TDA: This report builds joint understanding of the current state of the surface water and groundwater resources in the Tuli Karoo Aquifer and associated surface waters, shared among Botswana, South Africa and Zimbabwe. The main aims of this TDA are as follows:

- Gather, interpret, and synthesize information on the water-related context and issues in the shared Tuli Karoo Aquifer Area and associated river system
- Identify and prioritize major transboundary issues in the shared water system
- Assess data depth and data gaps related to the shared system
- Foster convergence toward a common understanding on the current state of the shared Tuli Karoo Aquifer and associated river system

Structured into ten sections and populated with data obtained through extensive search and engagement with the three countries, the report is an inclusive, joint effort that includes i) focus on areas contained by all three countries in the Tuli Karoo System, and ii) focus on both surface water and groundwater. The report includes focus on demography and socioeconomics, climate, groundwater and hydrogeology, surface water hydrology and quality, land use and land cover, water uses, and institutions and governance. Ultimately, the report is believed to lay a foundation on which water cooperation on the Tuli Karoo can grow.

The Tuli Karoo: Complexity yet Opportunity The Tuli Karoo System is a geography of food insecurity, climate vulnerability, poverty, unemployment and migration. In the context of shared groundwater systems in the SADC region that have received project focus to-date (Ramotswa, Stampriet, Shire), the Tuli Karoo appears on the complex end of the spectrum. It is shared by three countries. It is in a highly arid context. Some six surface water catchments intersect with the aquifer, and these catchments have been the focus of substantial water resources development in recent years. The aquifer itself has an alluvial layer that is heavily tapped in South Africa and a sandstone layer that receives substantial use in Botswana. Despite the stressed context in which the Tuli Karoo System finds itself, there remains substantial potential for more benefits to be tapped. If carefully undertaken, for example, there may be potential for water use in productive activities such as agriculture—particularly if efficiency gains are achieved. Further, the proportion of water stored is currently high in the three countries yet management of this storage infrastructure appears unilateral. Scope for generation of additional benefit may lie in closer collaboration in the management of such national infrastructure. Yet an additional, and perhaps the most promising, way to enhance benefits derived from this shared system may lie in better understanding and harnessing groundwater.

Five Key Issues Ultimately, review of conditions in the chapters of this report led to preliminary identification of five key issues. These five issues are as follows:

1. **There is a need for improved, joint monitoring and greater understanding of the system** While the volume of knowledge gaps on the Tuli Karoo can be overwhelming, addressing approximately three key areas can lay a foundation for informed decision-making and management. A first area is understanding river flow and groundwater recharge, presumably through an expanded and coordinated monitoring network. A second area is determining surface vs. groundwater use, perhaps through refinement to data collection methods in countries. A third area is understanding how surface and groundwater interact; focused investigations could be undertaken toward this end through use of chemical tracers.
2. **Potential for irrigation expansion can be explored if efficiency gains are achieved** Irrigation is simultaneously a means to enhancing food security, promoting rural development and mitigating effects of erratic rains. In the Tuli Karoo, there is likely scope to enhance the efficiency of existing schemes—particularly smallholder schemes and particularly in lower tech contexts outside of South Africa. Realization of such gains would likely free up water to enable potential for irrigation expansion to be considered.
3. **Suitable resilience interventions should be identified, assessed and implemented** The risks of climate variability and change in the Tuli Karoo are clear, and not unlike other regions in Africa. Interventions that strengthen resilience and are suited to conditions in the Tuli Karoo, can help to insulate communities from these climatic realities. It is critical to clarify suitability of approaches such as subsurface dams – already implemented in some portions of the aquifer area – and to identify new approaches such as pro-active alternation in the use of different water sources in a way that best ensures availability. Other managed aquifer recharge interventions can also be tested. Approaches determined to be successful should be more widely rolled out.
4. **Ways to achieve greater satisfaction of environmental flows and ensure GDE health through cross-border policy harmonization should be considered** A healthy ecosystem is key to continued viability of this shared system, and water is key to a healthy ecosystem. While other demands on water may constrain full satisfaction of environmental flow requirements, it is critical that provision of water to satisfy ecosystem needs – both conventional environmental surface flows and water for GDEs – be taken seriously. One way countries may be able to make progress toward this end is greater coordination on environmental flows. By aligning management approaches, it may be possible to more meaningful contributions to the ecosystem health in the context of reduced water contributions do not fully achieve optimal levels.
5. **Impacts of mining and inadequate sanitation on water quality should be understood and addressed** Pollution from mining and sanitation limitations have been prominently noted in earlier chapters of this TDA, in particular chapter 3 and 8. The pervasive risks associated with such pollution need to be remediated. Challenges with mines may be more manageable in some ways, as the source of their impacts may be more easily identified. Nonetheless, through community engagement and long-term change in practice including lining of pit latrines, risks associated with sanitation (e.g., nitrate contamination) may also be alleviated.

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1. Introduction

1.1 Background

Transboundary Waters in Southern Africa: Moving toward conjunctive approaches Responding to growing recognition of the importance of international river basins, there has been prolific activity in transboundary surface-water cooperation and River Basin Organisation (RBO) development in Africa generally, and the Southern African Development Community (SADC) specifically (Lautze and Giordano, 2005; Saruchera and Lautze, 2016). A growing body of work, however, has also now identified and delineated more than 30 transboundary aquifers in the SADC Region and many more in Africa as a whole (Altchenko and Villholth, 2013). While on the-ground cooperation on SADC's shared aquifers is currently low, managing them cooperatively and conjunctively – i.e., linking their management with pre-existing cooperative surface water frameworks – can foster progress towards the region's development goals including strengthening resilience, improving agricultural production, enhancing food and water security and achieving sustainable growth. The importance of both transboundary water management, and ground and surface water management, are recognized in the SADC Regional Strategic Action Plan (RSAP 2016-2020). Further, policies in most national governments in the region emphasize the need to cooperate on shared basins and aquifers.

Project Vision: Optimal transboundary cooperation results from taking conjunctive approaches that manage water across source and scale Conjunctive management, integrating management of surface and groundwater, expands the range of cost-effective and sustainable solutions which contribute to a range of positive outcomes such as water security and resilience (Blomquist et al, 2001; World Bank, 2005; Dudley and Fulton, 2006). The project's premise is that the potential to implement conjunctive solutions that realize these positive outcomes can and should be realized regardless of international borders. Aquifers can be used as a storage solution for capturing and attenuating floods in upstream areas or states, for example, which can mitigate risk of adverse outcomes in downstream areas or states. In addition, stored groundwater may serve to enhance water security for both drinking water supply and small-scale crop cultivation in dry spells and droughts. Importantly, conjunctive uses and conjunctive water storage management may be more cost-effective than traditional flood protection and diversion schemes, because they are heavily based on natural infrastructure, in effect reducing requirements for major grey infrastructure investments.

Transboundary Conjunctive Management: How to? Guidance on appropriate institutional frameworks for conjunctive management of diverse water sources in a transboundary context – and the scale to which they may apply – do not exist. This reality is somewhat paradoxical given that the most technically sound manner to manage water is to consider all relevant water sources and manage such sources conjunctively for optimal benefit. Limited guidance on conjunctive use of multiple water sources in transboundary waters may result, at least in part, from the reality that the scale at which transboundary ground-surface systems should be managed is not straightforward. A surface water focus lends itself to basin frameworks. A groundwater focus lends itself to aquifer frameworks. The scale of conjunctive surface-groundwater management, by comparison, calls for crafting innovative approaches that thoughtfully respond to issues most relevant to riparians and aquifer-sharing states.

Project Objectives The *Conjunctive Water Resources Management across borders in the SADC Region: Generating Principles through fit-for-purpose practice* project contributes to sustainable water management in the SADC Region, through transboundary cooperation on shared critical water resources. The broad objective of the project is to enhance the capacity in SADC and its member states to manage integrated groundwater and surface water resources. The project will seek to identify and apply innovative solutions for conjunctive water management in transboundary river-aquifer systems. In particular, the project will identify issues and solutions that support the achievement of equitable, sustainable and resilience-strengthening water use, based on conjunctive management through deriving lessons from in the Shire River-Aquifer (Malawi and Mozambique), Ngotwane River /Ramotswa Aquifer (Botswana and South Africa), and Tuli Karoo (Botswana, South Africa, Zimbabwe) Systems (Figure 1.1). Given the level of existing activities in the Shire and Ngotwane/Ramotswa, the project places primary focus on the identification and recommendation of policy changes likely to advance pursuit of conjunctive water management solutions in the shared Tuli Karoo Aquifer and associated surface waters.

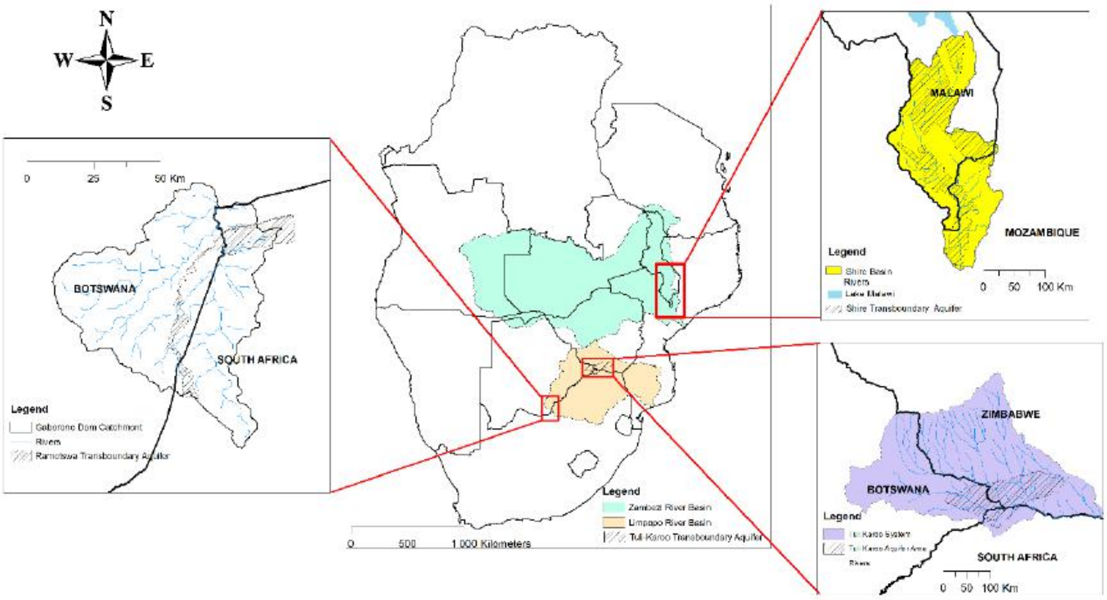

Figure 1.1: Shared Water Systems in SADC with conjunctively-oriented cooperation

Time Frame and Partners The project is intended to run from November 2018 through October 2021. The project is led by the International Water Management Institute (IWMI) and undertaken within the framework of the Limpopo Watercourses Commission (LIMCOM) and the SADC-Groundwater Management Institute (GMI). There are a broad range of involved organizations including: the Department of Water and Sanitation, Botswana (DWS-BW), Department of Water and Sanitation, South Africa (DWS-SA), South Africa National Parks (SANParks), Zimbabwe Water Authority (ZINWA), and the Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement, Zimbabwe, University of Botswana (UB), and Great Zimbabwe University. Finally, the US Agency for International Development (USAID) provided financial support.

1.2 The Transboundary Diagnostic Analysis

Aims of this Report This report presents the Transboundary Diagnostic Analysis (TDA), or baseline report, for the Tuli Karoo Aquifer Area and the surface water system in which it is situated. TDAs have been developed over time in projects on transboundary waters financed by the Global Environment Fund (GEF, 2013). The main aims of this TDA are as follows:

- Gather, interpret, and synthesize information on the water-related context and issues in the shared Tuli Karoo Aquifer Area and associated river system
- Identify and prioritize major transboundary issues in the shared water system
- Assess data depth and data gaps related to the shared system
- Foster convergence toward a common understanding on the current state of the shared Tuli Karoo Aquifer and associated river system

Approach to this Report This report builds an understanding of the current state of the surface and groundwater resources in the Tuli Karoo Aquifer, their uses, spatial and temporal variability, interactions, and impacts as well as human benefits derived from various ecosystem services and existing infrastructure. The report draws primarily on existing data from: (i) key government institutions in the Member States, such as DWS-BW, DWS-SA, and Zimbabwe Water Authority (ZINWA), (ii) key research institutes such as University of Botswana and Great Zimbabwe University as well as parastatals such as Botswana Geosciences Institute, (iii) remote sensing-derived data such as land use. Data were compiled and synthesized according to relevant themes including water resources and uses, environment, socio-economics (including gender equity), and institutions. Synthesising data in a shared water system is not straightforward, as countries tend to have different protocols for data collection and categorisation. Further, there tends to be many gaps in data. Ultimately, information collected as part of the TDA were synthesized to reveal a set of critical issues related to achieving water security, with specific attention to the opportunities that can be harnessed and challenges that can be addressed through conjunctive approaches.

Advances of this Report There has been very little investigation into the Tuli Karoo Aquifer or associated surface waters. One set of studies focused on specific topics in specific areas within the Tuli Karoo Aquifer System. Bordy and Catuneanu (2002) investigated sedimentology in one stratigraphic unit (Basal) in the South African portion of the Tuli Karoo. Hamer et al (2008) examined the seasonal duration of groundwater availability that follows drying up of a small dam on the Mnyabezi River—a tributary to the Mzingwane River in Zimbabwe. Love et al (2010) examined rainfall-runoff relationships on the Zhulube River – also a tributary to the Mzingwane River in Zimbabwe. Le Baron et al (2011) investigated sediments in one site in the South African side of the Tuli Karoo System. Love et al (2011) examined the storage potential of alluvial aquifers along the Mzingwane River; included in such aquifers were portions of the Tuli Karoo. Two scoping-type studies gave some focus to the aquifer as-a-whole. Owen (2011) gave some attention to the aquifer in his review of groundwater in the Limpopo Basin. Modo and Vermeulen (2017) applied a broad lens to the Tuli Karoo Aquifer, drawing on other experiences to question conflict potential on the aquifer. No report to-date has engaged the three countries to acquire and integrate data to provide an in-depth examination of the aquifer area and associated river system.

2. Methods

2.1 The Study Area

The Tuli Karoo Transboundary Aquifer The Tuli Karoo is a transboundary aquifer within the Limpopo River Basin (Figure 2.1). It is one of three known transboundary aquifers in the Limpopo Basin. The surface area of the Tuli Karoo Aquifer is just over 12,000 km2, and the population living within the aquifer extent is just over 120,000. The Tuli Karoo is shared among Botswana, South Africa and Zimbabwe. The greatest proportion of the aquifer's surface area is contained within Zimbabwe; the smallest proportion of the aquifer's surface area is contained in South Africa.

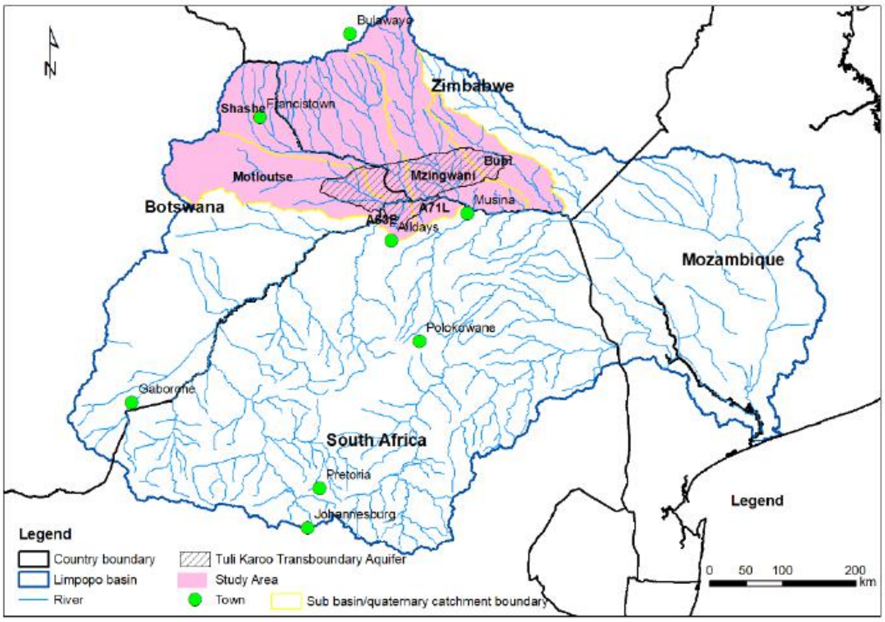

Figure 2.1: Map of the Tuli Karoo System in the larger Limpopo Basin

The Tuli Karoo System, including associated Surface Waters Six catchments cross the Tuli Karoo Aquifer. The largest of these catchments are the Shashe and Mzingwane. The aggregate area of the broader system of surface waters that encompass the Tuli Karoo Aquifer is just over 82,000 km2 (Figure 2.1). The largest proportion of this area is in Zimbabwe. The population living within this broader area of the Tuli Karoo Aquifer System is approximately 1.8 million.

The Study Area: The Tuli Karoo System The overall project – and this TDA – are focused primarily on conjunctive ground- and surface- water management in the Tuli Karoo Aquifer Area (shaded area in Figure 2.1). In order to understand conjunctive water management, it is necessary to understand surface water dynamics in the catchments that flow through, and encompass, the Tuli Karoo Aquifer. This broader set of encompassing catchments, shown in pink in Figure 2.1, is also considered in this report particularly related to surface flow and other parameters that can affect conditions in the aquifer area. This broader area is referred to as Tuli Karoo System. Notably, the main stem of the Limpopo River flows into the study area and needs to be acknowledged. Nonetheless, broadening the study area to include the entire was viewed to be too ambitious relative to the size of the specific area of primary focus, the shared aquifer.

2.2 Methods

Collaboration and Capacity-Building in TDA Development: Given the multi-dimensional dynamics of water and water management, production of a TDA for a shared surface-ground water system is by nature a multi-faceted effort. It requires insight into the hydrogeology of the aquifer(s), surface water flows, environmental issues, relevant socio-economic aspects of the system area as well as legal and institutional contexts in riparian countries. The multidisciplinary character of the assessment and the complexity of hydrogeological systems necessitate the involvement of several governmental bodies. At least two key governmental organizations were thus involved in the production of this document in each country: In Botswana; the Department of Water and Sanitation (DWS-BW) and Water Utilities Corporation (WUC), in South Africa; Department of Water and Sanitation (DWS-SA) and SANParks, and in Zimbabwe, the Zimbabwe National Water Authority (ZINWA) and Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement. Further, Great Zimbabwe University and University of Botswana were involved. To strengthen capacity of countries, five young professionals from three countries were involved in TDA development.

Chapters in this Report: The structure that would be adopted for the TDA was debated at the Conjunctive Water Management Joint Stakeholder Session in Musina, South Africa during the period 28-30 November 2018. Chapters aimed to capture context and key aspects of water management. Ultimately, a structure was adopted that drew on formats used in other TDAs, and is intended to capture key aspects of water management, such as water users and uses, threats to water availability, water's benefits and unintended impacts of water use. The structure is shown here:

1. Introduction
2. Study Area & Methodology
3. Demography and Socio-economic aspects
4. Climate
5. Hydrogeology and Groundwater
6. Surface Water
7. Land Use
8. Water Uses
9. Institutions and Governance
10. Key Issues

Selective Relaxation of Study-Area Boundaries: Consideration of various data that would be used to develop chapters led to realization that data was not always available at the basin or aquifer level. To adapt to this reality, relaxation of strict hydrologic boundaries was deemed a suitable approach when necessary, to enable presentation of data e.g. at a district level in or around the shared system, if data at an aquifer or basin level are not available.

2.3 Data Collection

Determining Data Needs: Data needs for each section were discussed at the Joint Stakeholder Session in Musina and further elaborated subsequently. These data include points like historic rainfall, borehole locations, and national water laws and policies in the three countries. A complete list of identified data needs, divided by section, are included in a table in Annex 1. To facilitate transition from identifying data needs to collecting data, a letter was sent by the Executive Director of SADC-GMI and the Executive Secretary of the LIMCOM to government focal points in Botswana, South Africa Zimbabwe, in March 2019.

Data Acquisition: To encourage swift data collection, IWMI staff followed up with the three countries to support their collection of data. Frequent follow-ups to facilitate rapid collection of priority data were made. Further, to accelerate data collection, three visits were made to Botswana and Zimbabwe in which meetings were held (Annex 2). A substantial amount of important data was obtained although some key gaps remained, likely resulting from the reality that some of the needed data simply is not in existence.

Data Limitations Attempts to understand the Tuli Karoo Aquifer is constrained by realities that i) there are often major limitations on availability of groundwater data, ii) the Tuli Karoo is located in fairly remote regions of the three countries, in which data tend to be thin. Further, when data do exist, they come in varying forms. At times, they are not digitized but remain in handwritten form in a physical folder in an office bureau. Other times, data quality can require extensive iteration to confirm the intentions of the data collector. The bottom line is data can be scarce and patchy. This TDA reflects an effort to mine that data to determine what it reveals and clarify data gaps.

2.4 Information Consolidation and Synthesis

Information Consolidation: Lead authors for each section extracted data and information relevant to their particular sections from the broader set of data collected. Attempts were made to structure the information in a logical way and harmonize data of different formats and depth, to enable depiction of a joint picture of the Tuli Karoo Aquifer System.

Information Synthesis: Write-up and presentation of key aspects of different topics were done according to the agreed structure. In concluding each section, a set of key messages were formulated. Such key messages are presumed to reflect the central points of each section and priority ways forward. Following draft write-up of each section, consultations were held in Botswana, South Africa and Zimbabwe in the window of 15-20 August 2019 to strengthen the level of collaboration in section development and overall quality of the report. A list of participants at such consultations is included in Annex 3.

TDA Revision The TDA was presented to representatives from the three countries, as well as other key stakeholders, at a project dialogue in Francistown, Botswana between 2-4 October, 2019. A set of revisions were requested by participants. These revisions were taken onboard in the course of October, 2019.

3. Demography and Socio-economics

Surface and groundwater abstraction are affected by population levels and trends. Similarly, socioeconomic development trajectories in the region drive and impact water use. It is thus important to account for the demographic and socioeconomic context of the Tuli Karoo System. This chapter of the TDA considers the socio economic and population dynamics in the Tuli Karoo since water use and management is ultimately impacted by these broader trends.

3.1 Population

Country populations Nearly 80 million people inhabit the countries that share the Tuli Karoo Aquifer. The total population of Botswana is currently just over 2 million (Statistics Botswana, 2018). In South Africa, the latest Community Survey results estimate the country population to be 55.6 million (StatsSA, 2016). Total population in Zimbabwe is estimated at 13.6 million, according to 2017 inter-censal data (ZimStat, 2017). South Africa therefore has the greatest population among the three countries, and Botswana has the smallest population among the three countries.

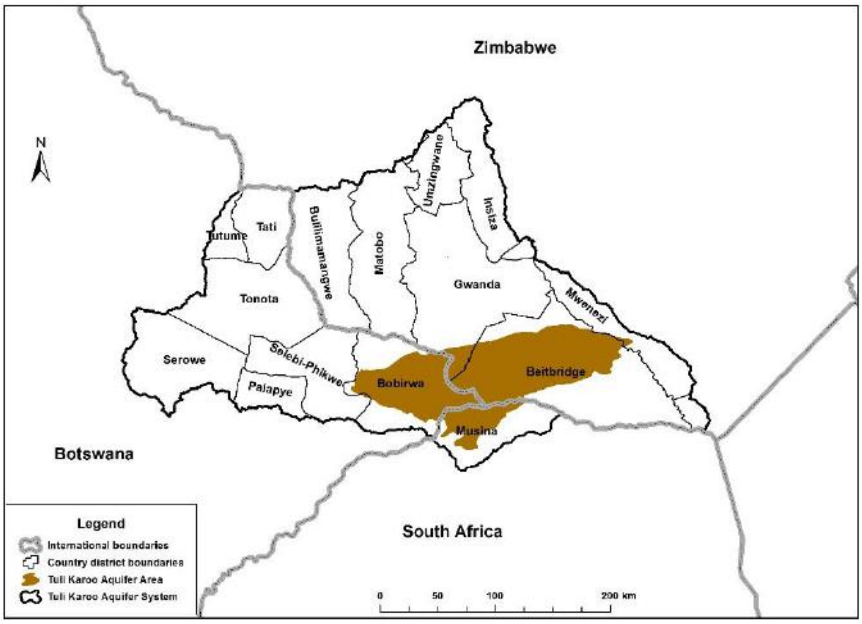

Figure 3.1: Administrative Districts in the Tuli Karoo System (Source: Governments of Botswana, South Africa and Zimbabwe)[1]

Administrative Areas in the Tuli Karoo System As outlined in Chapter 1 of this TDA, the focus of this work is the Tuli Karoo Aquifer Area as well as the broader Tuli Karoo System that encompasses the Aquifer Area. The Tuli Karoo System, reflected in the outer delineation of Figure 3.1, contains more than 12 administrative areas (alternatively referred to as sub-districts in Botswana, municipalities in South Africa, and districts in Zimbabwe) in the three countries. By contrast, the more specific focus of this TDA, shown in the shaded area in Figure 3.1, is mainly concentrated in just three administrative areas in the three countries: Bobirwa[2], Beitbridge, and Musina. In Zimbabwe, negligible portions of the aquifer also lie within the Gwanda and Mwenezi administrative areas.

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[1] Musina Local Municipality was re–delineated in 2016. The map is based on the pre-2016 delineations as an updated GIS shapefile containing the new boundary was not available.

[2] Please note that Bobirwa sub-district is referred to as Bobonong in some documentation. Following consultation with Botswanan authorities about the correct title, Bobirwa is used here to refer to the district and Bobonong is treated as the capital of the subdistrict.

Botswana In Botswana, areas falling within the boundaries of the Tuli Karoo System lie in seven administrative areas: Bobirwa, Palapye, Selebi-Phikwe, Serowe, Tati, Tonota and Tutuma. The combined population of these areas is more than 500,000. The Tuli Karoo Aquifer Area covers more than half of the Bobirwa sub-district. Population in Bobirwa has been growing steadily over the past decade, averaging more than 2% per annum, with the 2017 population estimated at 81 500 (Statistics Botswana, 2018). The average population density in Bobirwa is approximately 3.5 persons/km^2.

South Africa In South Africa, areas in the Tuli Karoo Aquifer, and Tuli Karoo System, fall entirely within Musina Local Municipality, which has a total population of 132,100 in 2016 (StatsSA, 2016; MLM IDP, 2018). Musina Local Municipality experienced a sharp increase in population from 2001 to 2016, with a more than 5 % average annual increase over the 10-year period of 2001-2011 and an even greater average annual increase in the 5-year period between 2011 and 2016. The intensity of growth in the second period may be partially explained by municipal border realignments that took place in 2016, absorbing the Mutale local municipality into Musina local municipality (VDM, 2017). Population density in the municipality is roughly 12 persons/km^2.

Zimbabwe The largest proportion of the Tuli Karoo System falls in the southern parts of Zimbabwe, in the Matabeleland South Province. The Matabeleland South Province is made up of 12 Districts which include Gwanda, Beitbridge, Umzingwane, Matobo, Bulilima, Mangwe and Insiza (Figure 3.1). According to 2012 census data (ZimStat, 2012), the total population in the Matabeleland South Province was 683 900, which increased to 810 100 in the 2017 Inter-Censal survey (ZimStat 2012; ZimStat, 2017) indicating an average annual increase of more than 5% over the 5-year span. The Aquifer Area falls mainly in the Beitbridge district, with smaller portions in the Gwanda and Mwenezi districts. Population density in Beitbridge district is 4.5 persons/km^2.

Calculating population in the Tuli Karoo To calculate present population in the Tuli Karoo, year 2019 district-level populations were first estimated using most recent data and district-specific population growth trends. Data in each district were weighted according to the fraction of each district contained by either the Tuli Karoo Aquifer Area or System. Population figures were then summed in each country to generate a total population for each country in the Aquifer Area, and System, in 2019.

Table 3.1: Estimated 2019 Tuli Karoo Population (Statistics Botswana, 2018; StatsSA 2016, ZimStat 2017)

	Tuli Karoo Aquifer Area	**Tuli Karoo System**
Botswana	42 000	597 600
South Africa	19 300	37 300
Zimbabwe	62 100	1 188 600
Total	123 400	1 834 500

Total population in the Tuli Karoo More than 1.8 million people currently live in the Tuli Karoo System and more than 120 000 people live above the Tuli Karoo Aquifer Area (Table 3.1). Zimbabwe contains about half of the population in the Tuli Karoo Aquifer Area, and nearly 2/3 of the population in the System. Despite possessing the smallest population and land area, the South African portions of the aquifer and broader system are the most population-dense and fastest growing.

3.2 Demographics

Age structure: National Context The population of the Tuli Karoo countries is young. According to 2017 inter censal data (ZimStat, 2017), Zimbabwe has a relatively young population with 40 percent under the age of 15 years and approximately 6 % aged above 65 years. In Botswana, 2017 data (Statistics Botswana 2018) indicates that children under the age of 15 comprise 42% of the population while the population above 65 years of age is less than 8% of total population. This suggests a similar age distribution across the two countries of Botswana and Zimbabwe. In South Africa, 42.5% of the population is made up of persons below the age of 19 and 3.6% above the age of 65 years (MDB, 2018). While data on age structure in the Tuli Karoo was not available, age distribution of national populations are believed to be broadly consistent with that of the Tuli Karoo.

More women than men in the Tuli Karoo. General trends in southern Africa indicate that rural – urban migration (AfDB, 2019) tends to increase the proportion of women in rural populations; such realities appear consistent with conditions in the Tuli Karoo. In Botswana, Bobirwa sub-district has about 91 men per every hundred females (Statistics Botswana 2015). Matabeleland South province of Zimbabwe recorded a sex ratio of 92 men for every 100 females in 2012, while the Beitbridge rural areas recorded a sex ratio of 88 men for every 100 females (ZimStat, 2012). The population in Musina, however, is split fairly equally between females (50.1%) and males (49.9%; DEMACON, 2019).

The population in the Tuli Karoo System is largely rural in South Africa and Zimbabwe. In the Matabeleland South Province, 88% of the population lives in rural areas (ZimStats, 2012). In South Africa, Musina Local Municipality comprises mainly of commercial farming areas and communal areas. Urban areas represent just 0.08% of total land use in the local municipality (MLM IDP, 2017). In Bobirwa sub-district of Botswana, by contract, just over 50% of the total population lives in urban areas[3] (Statistics Botswana, 2015).

Migration patterns The Tuli Karoo System encompasses the border towns of Musina, Beitbridge and Francistown. The Beitbridge-Musina border post forms a gateway into South Africa for a number of African countries, putting strain on the Musina Local Municipality through high volumes of immigrants, refugees and traders (SDF, 2018). Bobirwa sub-district, Botswana does not, by comparison, receive as many immigrants, as documented in the demographic survey of 2017 Botswana mostly experiences in-migration across districts, while less than 10,000 people per year emigrate across its borders. (Statistics Botswana, 2018). By comparison, over 600 000 people left Zimbabwe as emigrants to different countries in 2017 (ZimStat, 2017; ZimStat 2018).

3.3 Socio-economic Context

National Context

Gross Domestic Product (GDP) At a national level, Botswana is the wealthiest country on a per capita basis, of the three countries sharing the Tuli Karoo (Figure 3.2). Both Botswana and South Africa, with GDP per capita above $US 6000 per year, are middle income countries. There is nonetheless a marked gap between income levels in Botswana and South Africa on the one hand, and Zimbabwe on the other. Per capita GDP in Zimbabwe has generally hovered in the $US 1000-2000 in the last decade, roughly 1/3 or less of per capita production in Botswana or South Africa (World Bank, 2019).

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[3]Urban settlement definitions in the three countries: Botswana '… any human settlement with at least a population of 5000, and 75 percent of those engaged in non-agricultural economic activities' (Statistics Botswana, 2015). Zimbabwe 'designated urban areas, and which had all the following characteristics (i) 2 500 inhabitants or more (ii) A compact settlement pattern (iii) The majority (more than 50 percent) of the employed persons engaged in non-agricultural occupations (ZimStat, 2011). South Africa 'a classification based on dominant settlement type and land use. Cities, towns, townships, suburbs, etc., are typical urban settlements. EAs comprising informal settlements, hostels, institutions, industrial and recreational areas, and smallholdings within or adjacent to any formal urban settlement are classified as urban' (StatsSA, 2011).

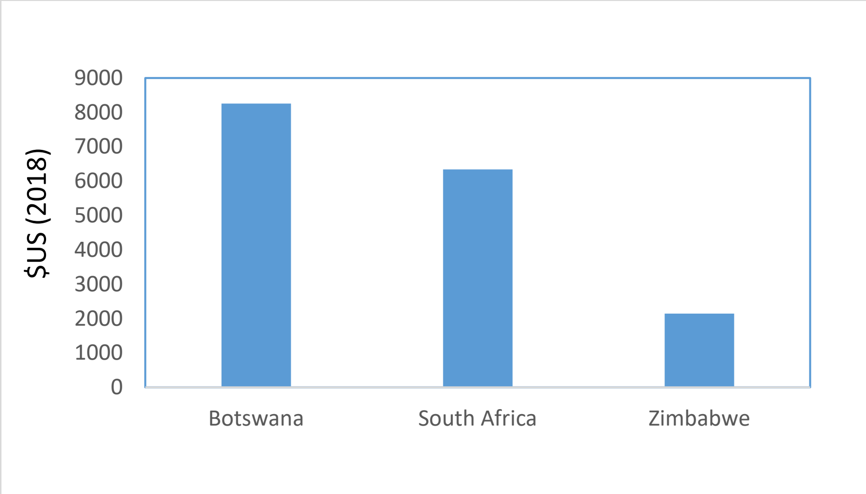


Figure 3.2: GDP per capita, $US in 2018 (Source: World Bank, 2019)

GDP Growth There has been substantial volatility in GDP growth in the three countries over the last decade. GDP growth has been most stable in South Africa, which has experienced a steady decline in growth rate (Figure 3.3). In Botswana, growth levels have typically been quite positive despite challenges in 2015 and 2017. In Zimbabwe, growth has quite positive before 2013 and after 2016; in between there was minimal development. The bottom line is that there seems to be considerable variation across years and countries that share the Tuli Karoo.

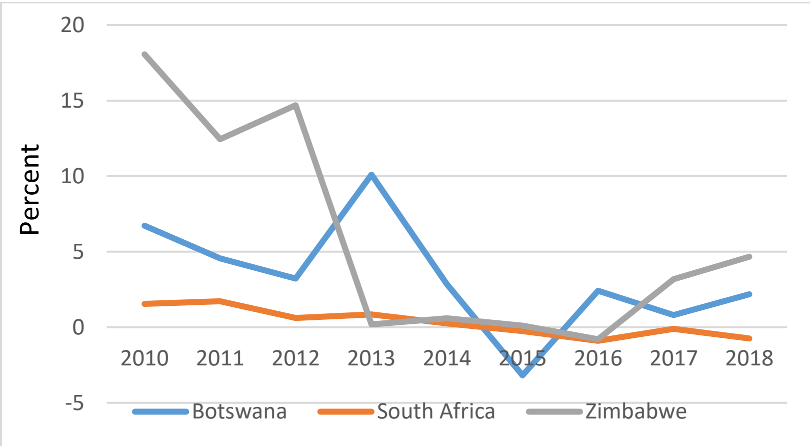


Figure 3.3: Annual GDP Growth (Source: World Bank, 2019)

Sectoral contribution to Gross Domestic Product (GDP) All three countries rely heavily on services – the services sector comprises the hospitality industry, financial services such as banking and insurance and educational services among others (Figure 3.4). Botswana's economy is strongly supported by the diamond mining industry (Mogalakwe and Nyamnjoh, 2017). However, the volatility of the global market has impacted diamond production contribution to GDP, which continues to decline (World Bank Group, 2015; NDP 11, 2017). Trade hotels and restaurants (services) are gaining momentum in Botswana as a significant sector contributor to GDP (NDP 11, 2017). South Africa's economy has been stagnating over the past decade although its service sector is well-established.

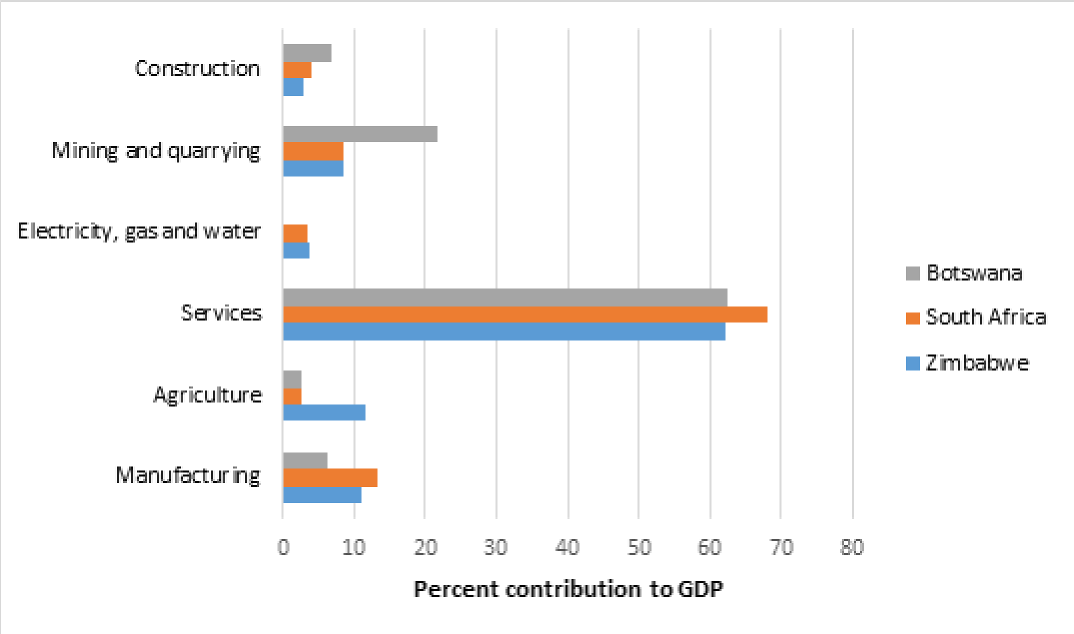


Figure 3.4: Sectoral contributions to GDP 2010-2018 (Source: AfDB, 2019)

Economy and Livelihoods in the Tuli Karoo

Local economic activities in the Tuli Karoo System. The Tuli Karoo System encompasses a range of economic activities in the areas of mining, agriculture and eco-tourism (MoFDP, 2006; DEMACON, 2019; Pers. Comm BBRDC, 2019). The region contains substantial deposits of coal and other minerals. It is rich in biodiversity, enabling game reserves and conservation activities. Commercial irrigated farming exists in Botswana and South Africa (Sithumule, 2014; DWS-BW, 2011). Communities also engage in smallholder agriculture, both rain fed and irrigated, especially in Zimbabwe (Pers. Comm BBRDC, 2019). Related, livestock farming is important, especially in the Botswana and Zimbabwe portions of the Tuli Karoo system (Masundire et. al., 2018; EMA, 2019).

Mining There are a number of coal mines operating in the Tuli Karoo System including Vele Colliery, Tuli Coal Mine, Beitbridge Colliery with exploration underway in the Tuli Coal fields (MoMMD, 2019). However, a number of mine closures that have been reported in Botswana, which include the Tati Nickel mine near Francistown and the BCL nickel/copper mine in Selebi-Phikwe (MoFDP, 2006). The closure of BCL mine is estimated have caused approximately 15 000 job losses and consequently more than 30 000 people lost their livelihoods (MoFDP, 2006; Makoni, 2015). Illegal small scale mining activities have been reported in the Beitbridge area, raising concerns for environmental degradation (EMA, 2019). The general decline of the profitability of mining commodities (Makoni, 2015), places risk and vulnerability on the livelihoods of local communities who depend on mining activities for employment.

Agriculture Agriculture remains an important source of livelihoods in the Tuli Karoo. Agriculture, forestry and fisheries contribute 35% to the local Musina economy, followed by mining (30%), transport and communications (15%) among other contributing sectors (MLM IDP, 2019). According to 2011 statistics, nearly 20% of the households in Musina were involved in agricultural activities (StatsSA, 2011). Statistics data for Beitbridge (2012), indicate that out of the employed population, 59% were employed in the agricultural sector (ZimStat, 2012). Matabeleland South is Zimbabwe's biggest livestock producing province due to its dry and arid nature, cattle ranching provides a source of livelihoods for local communities in the Beitbridge and Gwanda Districts (EMA, 2019). Botswana practices livestock, crop production both commercial and small scale (MoFDP, 2006). In 2015, cattle sales from subsistence farmers in Bobirwa made up approximately 5% of total sales in Botswana, similarly, maize produced by subsistence farmers in Bobirwa constituted 5% of total subsistence maize produced in Botswana in 2015 (Statistics Botswana, 2015). Commercial maize production constituted 68% of total maize produced while cattle production contributed 3% towards total commercial sales (Statistics Botswana, 2015).

Tourism Eco tourism, based on wildlife, is an important activity in the Tuli Karoo System. One of the notable wildlife reserves is the privately owned Northern Tuli Game reserve (NOTUGRE). NOTUGRE spans over 72000 ha on the Botswana portion of the Tuli Karoo (NOTUGRE, 2019; Sinthumule, 2014). In Botswana, the rich culture of the Babirwa augments the national heritage of the area, who are known for basket weaving. There are plans to further take advantage of and strengthen the tourism potential of the sub district (MoFDP, 2006). On the South Africa and Zimbabwe portion, game reserves and conservation areas including the Mapungubwe National Park, the Maremani Game Reserve, Musina Nature Reserve and Nottingham Estate are among some of the notable tourist attractions. The three countries share the Greater Mapungubwe Transfrontier Conservation Area (GMTFCA), known for its rich cultural and archeological significance, biodiversity and scenery, which are articulated in its 2010 Integrated Development Plan (GMTFCA, 2010). Potential for tourism in the GMTFCA has been well noted (GMTFCA, 2010). Nevertheless, tourist visits into the broader GMTFCA shared by Botswana, South Africa and Zimbabwe are generally low, despite speculation on the potential profitability of tourism in this area (Sinthumule, 2018).

Employment Rates The three countries – and the population of Tuli Karoo System – experience high levels of unemployment. South Africa has been rated highest in the world for youth unemployment with unemployment levels in the age group between 15-24 years recorded at 55% in the first quarter of 2019 (StatsSA, 2019). In Musina, South Africa, only 28% of the population are employed (StasSA, 2016). Employment estimates in Bobirwa sub-district, Botswana for the ages 25-64 years showed that 15 % of the labour force population is unemployed (Botswana Statistics, 2017). In Zimbabwe, only 27% of those 18 years of age and above depend on salaries and wages for their livelihoods (ZimStat, 2018). Nearly 4 million people in Zimbabwe are involved in informal activities – which are not captured in formal employment statistics. Most of such people active in the informal sector are women (ZimStat, 2018).

The Population of the Tuli Karoo System is largely literate According to the 2011 Census results, the Bobirwa sub-district recorded a literacy rate of 83%. Literacy was measured by having completed a minimum of standard 4 education in the population above 10 years of age. Matabeleland South province recorded a literacy rate of 94 % in the 2017 Inter-Censal study, almost similar the 95% recorded in the 2012 census (ZimStat, 2012; ZimStat 2017). Literacy rate was classified as the population of at least 15 years of age who had completed at least level of education grade 3. The levels of literacy were largely equal between males and females between 15-44 years of age, thereafter declining in favour of men (ZimStat, 2017). There was a 62% enrolment for primary school in the Matabeleland province in 2017 and an overall literacy rate of 95% for those 15 years and older. In South Africa, literacy rates were presented from a school attendance standpoint indicating that 18% of the population in Musina Local Municipality has received no form of education (StatsSA, 2016).

Poverty Rates in the Tuli Karoo are high The poverty rate in the rural areas of Beitbridge district were 62% (ZimStat, 2019). In Matabeleland South Province, there is an overall poverty rate of 62.8% (ZimStat, 2019). Botswana’s Bobobong sub district a poverty head count percentage of 13.9 % in the 2015/2016 period (Statistics Botswana, 2018). No poverty head count data was available for Musina. However, provincial data from Limpopo Province showed a poverty head count of 11.5 % in 2016 (StatsSA, 2016).

3.4 Domestic Water Supply and Sanitation

Water Supply

Water Supply varies across the Tuli Karoo In the Bobirwa sub-district, total access to water was estimated at 89.7% (Statistics Botswana, 2015). Piped water is an aggregate term for piped water indoors, outdoors, communal taps and neighbour's tap. The 'other' source comprises of water sources such as dam, pan, rainwater harvesting tank, spring water. Communities in the Musina Local Municipality are largely dependent on municipal water supply, with over 90% of the population accessing piped water whether individual or communal. The source of piped water supplying Musina Local Municipality is a combination of both surface and ground water (DWS-SA, 2016). Boreholes and deep wells constitute the major source of water for the local villages in Beitbridge. With the majority of the country population living in rural areas, a vulnerability assessment on rural livelihoods was conducted in 2017. The results of this assessment showed that 12% of the rural population are using unimproved water sources and untreated water for domestic use (ZimVac, 2017). Close to 15% of households in Beitbridge have their own water facilities while the remainder rely on communal and other unspecified sources. Of that 15%, the distribution of water sources is shown in Table 3.2.

Table 3.2: Domestic Water Source at Household Level (Statistics Botswana, 2015. StatsSA, 2016; Rural WASH Information Management System, 2019)

	Bobirwa sub-district (Botswana)	Musina (South Africa)	Beitbridge (Zimbabwe)
Piped (tap)	79%	90%	
Borehole	11%	9%	2.3%
River / stream	4%	1%	3.4%
Well	4%		2.2% (Protected) 7.1% (Unprotected)
Other	2%		

Sanitation

Varied types of Sanitation. In the Bobirwa sub-district, an estimated 75% of the households were using pit latrines as sanitation facilities (Table 3.3) including both ventilated improved pit latrines and ordinary pit latrines (Statistics Botswana 2017). In Musina Local Municipality, there have backlogs of rolling out improved sanitation infrastructure (MLM IDP, 2018). About 57% of the population in the Musina Local Municipality are connected to flush toilets while 34% and 7% use ventilated and unventilated pit latrines, respectively. In Beitbridge district, more than 80% of the population are reported to have no or unsafe sanitation types (Rural WASH Information Management System, 2019).

Table 3.3: Sanitation Type (Statistics Botswana, 2015. StatsSA, 2016; Rural WASH Information Management System, 2019)

Toilet Type		Bobirwa sub-district (Botswana)	Musina (South Africa)	Beitbridge (Zimbabwe)
Flush Toilet		24%	57%	0.4%
Pit toilet with ventilation	With ventilation	75%	34%	16.2%
	unventilated		5%	0.5%
Other toilet type		1%	1%	1.2%
None / unsafe sanitation type			3%	81.4%

3.5 Health

Health Challenges The low sanitation coverage, described above, may result in vulnerability and greater presence of conditions such as diarrhoea. The region is already believed to be a location of HIV and tuberculosis (TB) transmission (Statistics Botswana, 2018). These conditions often interact with one another to compromise human health. Children may be the most vulnerable. The bottom line is it is important to have accessible health care facilities to enable effective coping with such conditions.

HIV/AIDS Southern Africa has been widely noted for its high HIV and AIDS prevalence (SADC 2018). This trend has generally been decreasing over the past decades showing a decline in new infections by 32% between 2001 and 2011 (SADC, 2018). Zimbabwe has seen the HIV AIDS incidence rate decline from 18% between 2005 and 2006 to 13.8% in 2015 (Zimstat 2019). Botswana reported a HIV prevalence of 17.6% in rural areas and 8% in urban areas (Statistics Botswana, 2018). HIV prevalence in the Bobirwa sub district was 18.2 % in 2011 (DWA-BW, 2011). South Africa experienced an increase in people living with HIV and AIDS from 4.25 million in 2002 to 7.52 million in 2018, however incidence rates among the youth (15-24 years) have decreased from 6.7% in 2002 to 5.5 in 2018 (StatsSA, 2018).

Health care facilities Compared to other sub districts in the Vhembe District Municipality, Musina sub has the least number of public health care facilities as shown in Figure 3.5, this despite the increasing population trends in the area. This is likely putting a heavy burden on the health care facilities in the area (DoH, 2019).

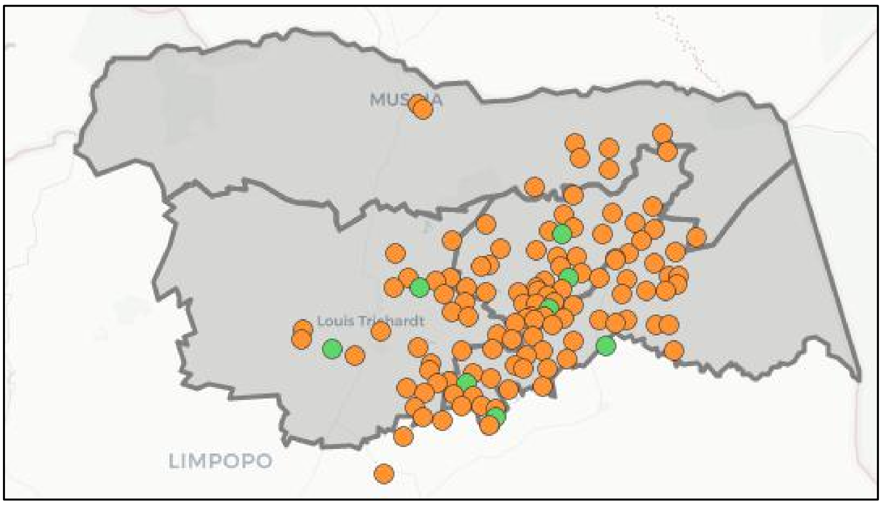


Figure 3.5: Public health care facilities Vhembe District (Source: Department of Health, South Africa, 2019)

Access to Health Care According to 2017 statistics (ZimStat, 2019), most people in Zimbabwe do not seek treatment in public health facilities when ill. Cost was cited as one of the biggest barriers to obtaining treatment. Table 3.4a shows that just over 50% of the extremely poor in urban Zimbabwe did not receive medical attention during illness compared to 33.4% in rural areas (Table 3.4b). It should be noted that private clinics include mission hospitals mostly found in rural areas. Botswana records that 95% of the national population (89% in rural areas) lives within 15km of a health care facility (Statistics Botswana, 2018).

Table 3.4: Methods for treatment of illness in Zimbabwe by poverty status

(a) Urban areas (Source: ZimStat, 2019)

Poverty Status	Public health facility	Traditional healer	Private clinic	None
Non-poor	42.8	0.5	22.0	34.7
Poor	52.7	0.6	10.1	36.6
Extremely poor	39.8	1.0	8.7	50.5
Total	45.7	0.6	17.6	36.1

(b) Rural areas

Poverty Status	Public health facility	Traditional healer	Private clinic	None
Non-poor	51.2	0.8	12.6	35.4
Poor	570	0.9	7.7	34.3
Extremely poor	59.8	1.1	5.7	33.4
Total		1.0	7.8	34.1

3.5 Key Messages

Review of the demographic and socioeconomic context of the Tuli Karoo generates at least four key messages:

- ***Tuli Karoo is a vulnerable socioeconomic context*** Unemployment, migration, and poverty combine to render the population of the Tuli Karoo vulnerable to instability and shocks. The population's livelihoods – consistent with those of many rural arid settings in Africa – have focused on agriculture though tourism and mining are also notable. Contributions of mines have nonetheless have been compromised by closures in recent years.
- ***Volatile economic context calls for water supply stability***. Compounding the rural development conditions in the Tuli Karoo, three the countries sharing the resource are experiencing a period of economic volatility due partially to global economic shifts and national political contexts. Further, much of the population of the Tuli Karoo, perhaps like other areas of rural Africa, are women and youth; men often serve in the migratory labour force elsewhere. Such realities are likely most acute in Zimbabwe. In this context, ensuring stable water supply would appear even more important in order to maintain community health and avoid the emergence of yet an additional impetus for out-migration (i.e., water shortage).
- ***Health Risks associated with prevalence of pit latrines need to be addressed*** Use of pit latrines is a common and concerning reality that cuts across the three countries in the Tuli Karoo System. Pit latrines, although affordable, put considerable strain on groundwater resources given the greater risk of contamination and increase in disease outbreaks. Access to health care facilities is generally low, especially in Zimbabwe.
- ***High Literacy levels suggest capacity for absorbing innovative, technology-based approaches.*** The reality that literacy levels are generally high in the Tuli Karoo System bodes well for future effort to capacitate and change ways of doing things. Interventions centred around technology, in particular, may find a receptive base.
- ***More data on local economic and livelihood realities could help tailor policy responses*** Quantitative data and information on economic production and livelihood conditions in districts of the Tuli Karoo was often not available. Securing such information would help target interventions.

4. Climate

This chapter provides the analysis and understanding of the climate of the Tuli Karoo System. The analysis is based on rainfall and temperature data obtained from weather stations in Botswana, South Africa and Zimbabwe. Long-term monthly precipitation (rainfall) data for 13 weather stations and monthly temperature data for 12 weather stations in the study area were provided by Botswana Weather Services (BWS), the South Africa Department of Water and Sanitation (DWS), Zimbabwe National Water Authority (ZINWA), and Zimbabwe Meteorological Services Department (ZMSD).

4.1 Precipitation

Spatial Distribution of Rainfall Stations. Data from thirteen rainfall stations across the Tuli Karoo System. (Figure 4.1). To in-fill gaps in data from such stations, e.g., certain months with missing data, satellite data from National Oceanic and Atmospheric Administration (NOAA) was used. Data from at least three stations were available in each country. Nonetheless, scrutiny of rainfall figures from Beitbridge and Bulawayo Goetz suggested issues with data reliability in places; such data were therefore excluded from short-term analyses.

Figure 4.1: Rainfall Stations, Tuli Karoo System

Rainfall Parameters In order to understand the rainfall in the Tuli Karoo System, the following parameters were considered for each station for years with data between 1980 and 2018 (Table 4.1): (1) total annual rainfall, (2) annual minimum and maximum rainfall, and (3) mean annual rainfall. In addition to annual variability analysis a further analysis on interdecadal variation was done over a period of 4 decades spanning from 1960 to year 2000.

Spatial Rainfall Variability Overall, the Tuli Karoo System is dry. Mean annual rainfall is in the 200 mm to 300 mm range. Annual rainfall is quite variable across the Tuli Karoo System (Table 4.1). The highest annual rainfall total (1074 mm) was recorded in 1999/2000 season at Bobonong rainfall station in Botswana and the lowest annual rainfall total of 5 mm at Tshokwe station. The high annual rainfall in Bobonong could be due to the station's proximity to the Lepokole hills located 15 km to the north of Bobonong district (Geoview, 2019). The hills may bring orographic type of rainfall.

High Temporal Variability in Rainfall Overall, rainfall Coefficient of Variation (CV) – the degree of variability in rainfall between years – is high in the Tuli Karoo System. The highest rainfall variability with CV of 81% was observed at Tshokwe station in Botswana with a mean annual rainfall of 173 mm. High CVs correspond to low mean rainfall (Moriniere, 2013). Data gaps were filled for Beitbridge using satellite data for the years 2006 to 2014. The satellite data was tested for correlation with ground data and found to have strong correlation (r^2 > 90%).

Table 4.1: Rainfall in 13 Stations, Tuli Karoo System

Rainfall Station	Minimum (mm)	Maximum (mm)	Mean (mm)	CV	Period of Analysis
Baines Drift	118	867	326	0.45	1980/81-2011/12
Bobonong	179	1074	369	0.49	1980/81-2013/14
Macuville	0.5	1010	320	0.63	1980/81-2003/04
Makhado_Alldays	167	682	339	0.40	1980-2018
Messina_Noordgrens	50	569	244	0.49	2003-2018
Messina_PP	14	560	263	0.65	2012-2018
Messina_Proefplaas	130	767	339	0.41	1980-2000
Pontdrift	191	611	386	0.35	2011-2018
Robelela	11	557	277	0.66	2000/01-2014/15
Selebi-Phikwe	190	639	376	0.32	1998/99-2013/14
Serule	50	692	338	0.44	1994/95-2015/16
Tshokwe	5	407	173	0.81	2000/01-2014/15
West Nicholson	48	119	101	0.41	1980-2001
Average				0.49	

4.2 Rainfall Trends

Weighting rainfall averages in the Tuli Karoo. The pie chart is used for apportioning average rainfall contribution for a catchment using point stations rainfall totals. For each portion the nearest rainfall station is assigned and the percentage contribution by each station is computed. The period of analysis used was 2000 to 2012 of the Hydrological calendar. Only 6 stations have overlapping data for the analysis period. The weights calculated expressed as percentages, are based on mean annual rainfall totals, and give an idea as to how each rainfall station in the watershed area contributed to the overall water balance calculation. In the present case, stations contributing disproportionately are Selebi-Phikwe, Serule and Bobonong stations with each accounting for 25.1 %, 24.6 % and 21.5 % respectively of the total weight. The calculated weights were used to construct a pie chart (Figure 4.2).

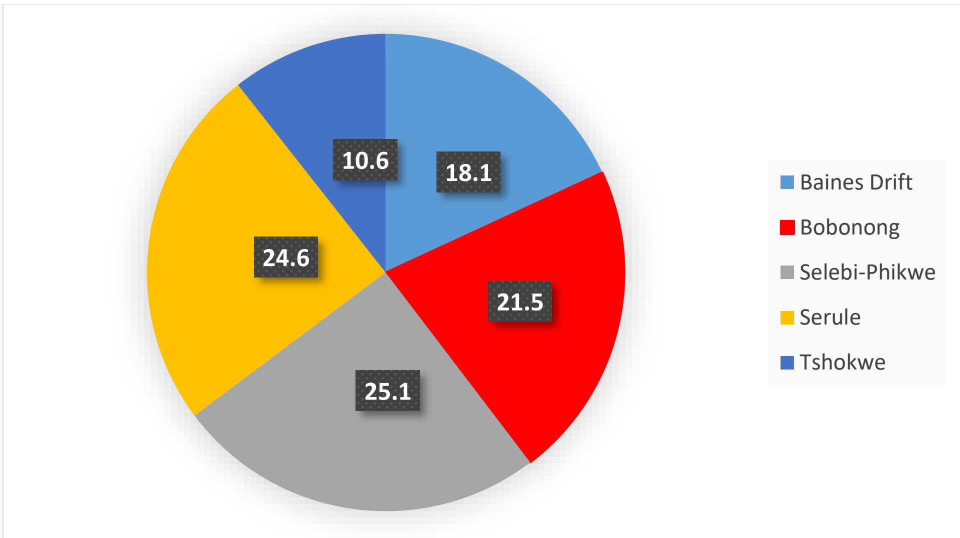


Figure 4.2: Weighting of Rainfall stations, Tuli Karoo System

Determination of significant trends The Mann-Kendall tests and confidence factor (CF) analysis were utilized to identify trends. CF is the measure of confidence for *rejecting* the null hypothesis of "no trend" vs. time. The Mann-Kendall analysis is a non-parametric statistical procedure that is used for analyzing trends in data over time (Gilbert, 1987). Non-parametric methods require no assumptions regarding the underlying statistical distribution of the data. Accordingly, the Mann-Kendall test neither requires a specific statistical distribution of the data, nor is the test sensitive to the sampling interval over which the monitoring data are collected. The outcome of the procedure depends on the ranking of individual data points and not the overall magnitude of the data points. Therefore, the Mann-Kendall procedure can be used for data sets that include irregular sampling intervals, data below the detection limit, and trace or missing data. The approach is particularly advantageous in cases where outliers in the data could produce biased estimates using parametric trend analysis. The method may be applied to track data trends for purpose of groundwater compliance monitoring, climate trends, sand monitoring of the performance of groundwater corrective actions (USEPA, 2009).

Identifying increasing or decreasing trends In order to test the existence and strength trend the *GSI Mann-Kendall Toolkit* (Connor, et. al *2012)* was applied. *GSI Mann-Kendall Toolkit uses two parameters to identify trend: S* Statistic (the *'S'* statistic is the sum of the differences between sequential sampling events), and CF (the confidence level) or the P value. The calculation of the CF value represents a minor modification of the approach to the Mann-Kendall test for trend, as published in Gilbert (1987) and elsewhere. Results for the conventional Mann-Kendall test include the designations of "No Trend," "Increasing," or "Decreasing" for the weather parameter vs. time at a given sampling location. Table 4.3 shows the statistical metrics used in GSI Mann-Kendall Toolkit. However, in order to develop a finer resolution of outcomes, consistent with the methodology set forth for the MAROS software (Aziz et al., 2003; AFCEE, 2004), the GSI Mann-Kendall Toolkit uses the Confidence Factor to identify less certain conditions that may correspond to "Probably Increasing" or "Probably Decreasing," depending on the level of confidence in the calculation. Technically, the CF is the measure of confidence for *rejecting* the null hypothesis of "no trend" vs. time. The null hypothesis (H_0) states that the dataset shows no distinct linear trend over time. The Mann-Kendall method tests H_0 against the alternative hypothesis (HA), i.e., that the data *do* show a trend over the specified time period. The probability (*p*) of accepting H_0 is determined from the Mann-Kendall table of probabilities (included in the software), which are based on the number of sample events (n, for $4 \leq n \leq 40$) and the absolute value of *S*. Specifically, *p* is the probability of obtaining a value of S equal to or greater than the calculated value for *n* events when no trend is present. In the GSI Mann-Kendall Toolkit, H_0 is rejected when $p < 0.1$ (corresponding to $\alpha = 0.1$, i.e. below a 90% CF).

Table 4.2: Annual total rainfall trends and Confidence factors for the period 1980-2018

Rainfall Station	Analysis Period	Mann-Kendall Trend Test	Confidence factor %
Baines Drift	1980/81-2011/12	S=-130, Decreasing	96.1
Bobonong	1980/81-2013/14	S=23, No trend	62.7
Macuville	1979/80-2001/02	S=10, No trend	60.6
Makhado Alldays	1980-2018	S=52, No Trend	88.2
Messina_Noordgren	2003-2018	S=6, No Trend	58.8
Messina_PP	2012-2018	S=0, No Trend	45.2
Messina_Proefplaas	1980-2000	S=26, No Trend	77.2
Pondrift	2011-2018	S=6, No Trend	72.6
Robelela	2000/01-2014/15	S=2, No Trend	52.4
Selebi-Phikwe	1998/99-2013/14	S=-22, No Trend	82.5
Serule	1994/95-2015/16	S=-85, Decreasing	99.2
Tshokwe	2000/01-2014/15	S=-1, No Trend	50
West Nicholson	1980-2001	S=-101, No Trend	89.5

Trends in Rainfall. From the trend tests conducted using GSI Mann Kendall trend test toolkit, all 13 stations were analysed. 2 stations showed statistically decreasing trends (Serule and Baines Drift), 4 stations are stable and 7 stations show no trend in annual total rainfall as illustrated in Table 4.2. With 2 stations out of 13 showing a decreasing trend there is no common trend observed. Nonetheless, this gives suggestive evidence of possible rainfall decreases in the Tuli Karoo System. An illustration of a decreasing trend is shown at Serule Station (Figure 4.3).

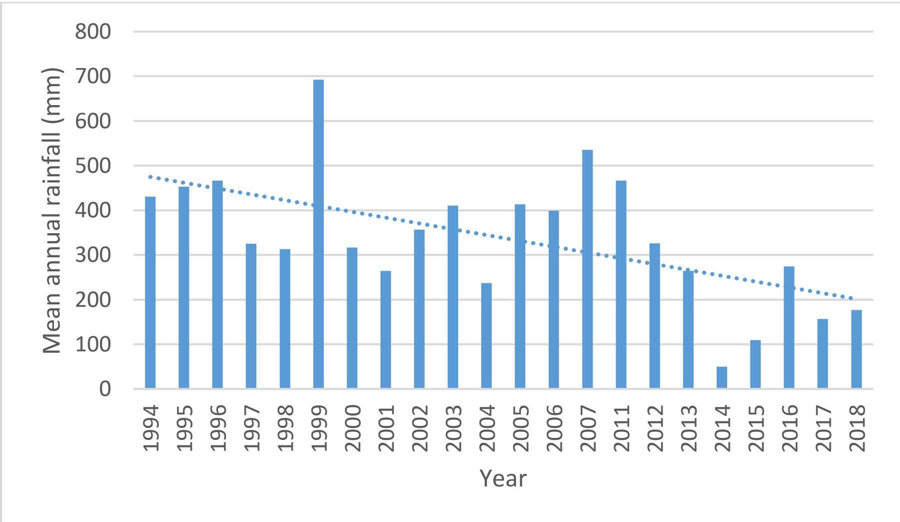


Figure 4.3: Annual rainfall trend at Serule station (annual rainfall data show statistically significant decreasing trend at S <0)

4.3 Temperature

Temperature data. Minimum and maximum temperature data was obtained from 12 weather stations in Tuli Karoo Aquifer System (Figure 4.4). At least three stations were located in each of the three countries. The stations are Francistown, Mahalapye, Selebi Phikwe, West Nicholson, Bulawayo Goetz, Beitbridge , Kezi, Messina Noordgrens, Messina Proefplaas, Messina PP, Pontdrift and Makhado

Alldays. Satellite Data for Kezi station (NOAA, 2019) from 1989-2014, and for Beitbridge between 2006 and 2014, were used.

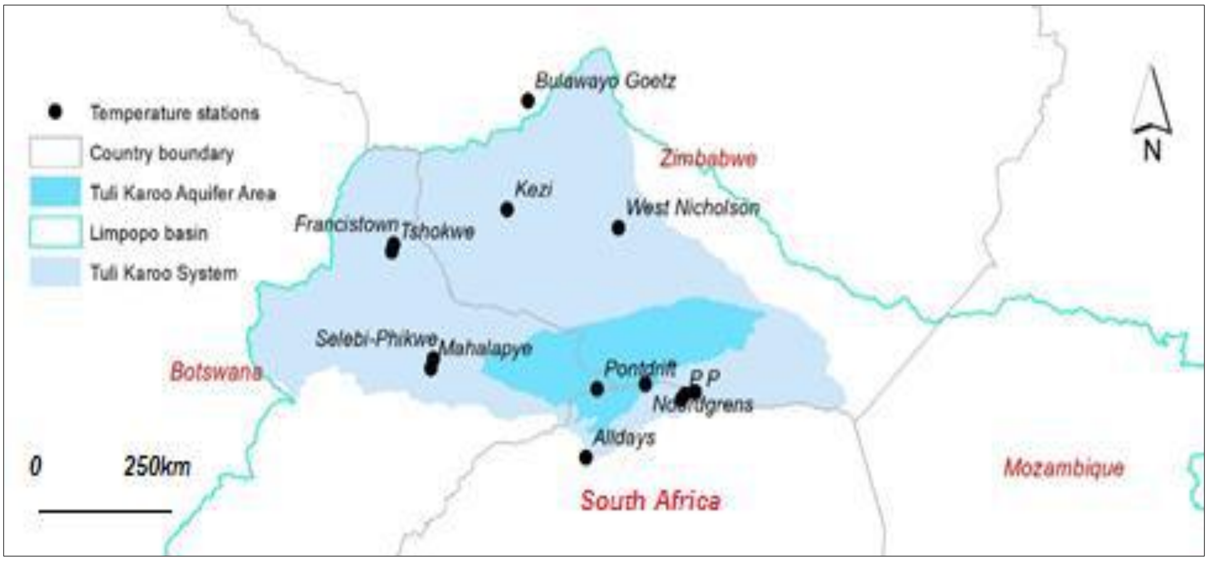


Figure 4.4: Temperature Stations, Tuli Karoo System

Mean Annual Maximum Temperature. Mean annual maximum temperatures for stations in and around the Tuli Karoo System is in the range of 29 to 33 ^{0}C (Table 4.3). In the particular years, the mean maximum temperatures range from 27.9 °C (1992) at Bulawayo Goetz to 34.5 ^{0}C (1982) at West Nicholson station. The average CV value is 0.03 which shows low variability in maximum temperatures.

Table 4.3: Maximum Annual Temperature

Station	Maximum Temperature (C)	Mean Max Temperature (C)	CV	Period of analysis
Beitbridge	32.4	31.0	0.02	1980-2014
Bulawayo Goetz	27.9	26.7	0.03	1980-2005
Francistown	31.1	29.3	0.03	1980-2018
Kezi	32.6	30.2	0.05	1989-2014
Mahalapye	29.8	28.5	0.02	1980-2018
Makhado_Alldays	31.9	29.7	0.04	2007-2018
Messina_Noordgrens	33.2	29.9	0.02	2003-2018
Messina_PP	33.7	32.9	0.02	2012-2018
Messina_Proefplaas	31.4	29.8	0.02	1980-2000
Pontdrift	33.5	32.7	0.02	2011-2018
Selebi-Phikwe	30.0	28.9	0.02	2000-2018
WestNicholson	34.5	31.2	0.07	1980-2013

Mean Annual Minimum Temperatures Mean annual minimum temperatures were examined across the weather stations for analysis period that spanned from 1980 to 2018 in and around the Tuli Karoo System (Table 4.4). Mean annual minimum temperatures from are in the range of 13 to 17 C. In particular years, the temperatures range from 7 °C at West Nicholson station to 18.5 °C at Beitbridge station. Temperatures for Beitbridge are consistently higher than for the rest of the stations.

Table 4.4: Minimum Annual Temperature

Station	Minimum Temperature	Mean Min Temperature	CV	Period of analysis
Beitbridge	11.1	16.7	0.07	1980-2014
WestNicholson	7.0	13	0.15	1980-2013
Kezi	13.0	14	0.05	1989-2014
Bulawayo Goetz	8.1	12.9	0.10	1980-2005
Makhado Alldays	14.7	15.7	0.04	2007-2018
Pontdrift	14.6	15.2	0.02	2011-2018
Messina_PP	14.6	15.2	0.04	2012-2018
Messina_Proefplaas	14.0	15.5	0.04	1980-2000
Messina_Noordgrens	13.3	15.1	0.10	2003-2018
Francistown	12.3	13.5	0.04	1980-2018
Mahalapye	12.4	14.0	0.05	1980-2018
Selebi-Phikwe	13.5	14.6	0.04	2000-2018

***Annual Average temperatures* are increasing.** Mean annual temperatures across the 12 stations, which collectively provide evidence that spans approximately 38 years (1980-2018), are increasing (Figure 4.5a). For 6 stations with an aligned period of data – namely, Beitbridge, WestNicholson, Bulawayo Goetz, Francistown, Mahalapye and Messina_Proefplaas stations for the years 1980-2000 – mean annual temperature is also increasing (Figure 4.6b). As such gradients for trendlines in both analyses show a steady increase in temperatures with time. Nonetheless, the Mann-Kendall test indicates that evidenced trends are significant only for the 38 year period (Figure 4.5b).

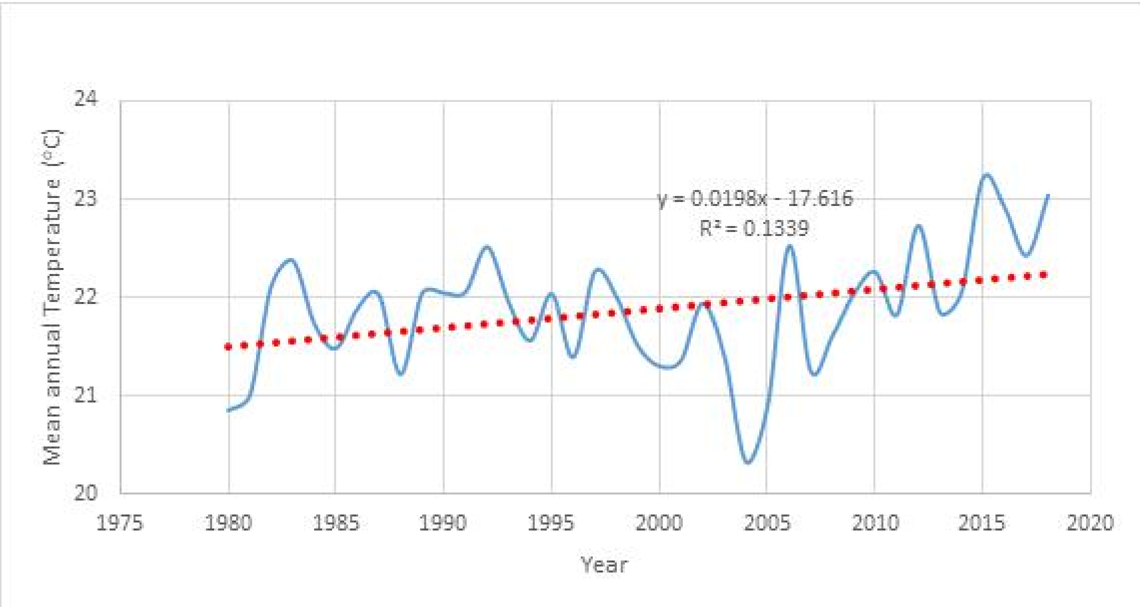


Figure 4.5a: Annual Mean Temperatures

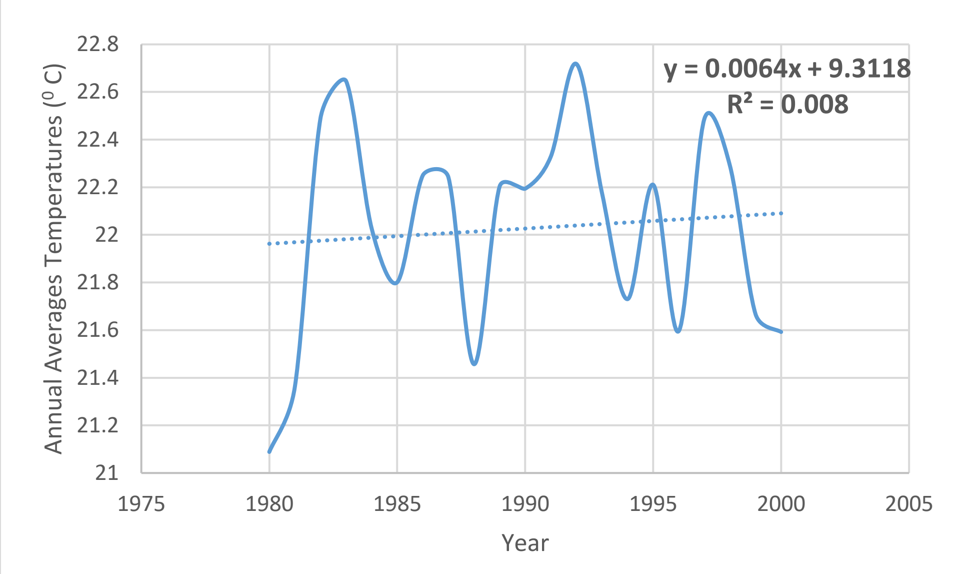


Figure 4.5b: Variation of Annual Mean Temperatures with time (overlapping data 1980-2000).

4.4 Evaporation and Evapotranspiration

Evaporation and evapotranspiration rates. Evaporation rates (Epan) records were obtained from a class A pan at dams in South Africa (Messina and Macuville stations) and a class C pan at Zhove dam in Beitbridge, Zimbabwe. The respective evapotranspiration rates derived from E pan were calculated using the pan coefficient (k) of 0.8, typical value for class A pans (AMS Glossary, 2010). Evapotranspiration rates for 12 stations namely Beitbridge, West Nicholson, Kezi, Selebi-Phikwe, Mahalpye, Bulawayo Goetz and Francistown were calculated using the Hargreaves method (Hargreaves et al. 1985; Subburayan et. al, 2011) which uses temperatures.

High Evaporation Rates evidenced. Mean Annual Evaporation rates range from approximately 1100 mm to more than 1500 mm (Table 4.5). West Nicholson has the highest evapotranspiration rate of 1532 mm/year for stations in the watershed area. Mahalapye station has the least evapotranspiration rate of 1337 mm/year for stations in the watershed area. Evaporation is highest during the rainfall season, and it significantly reduces effective rainfall, runoff, soil infiltration and groundwater recharge. Evaporation loss from dams is significant owing to the high storage-yield relationship and flat dam basins. Using the Hargreaves method, the calculated evapotranspiration was between 1132.11 mm/year for Messina_Proefplaas station and 1362 mm/year at Makhado Alldays. Daily Epan recorded at Zhovhe dam in Beitbridge for 3 months (January-March 2019) shows a monthly average of 89.5 mm/month or 1074 mm/year according to data available.

Table 4.5: Annual mean evapotranspiration rates derived from Temperatures using Hargreaves method.

Station	Period of analysis	Annual mean Evaporation (mm)
Beitbridge	1980-2014	1417
Bulawayo Goetz	1980-2005	1252
Francistown	2000-2018	1400
Kezi	1989-2014	1442
Mahalapye	1980-2018	1337
Makhado Alldays	2007-2018	1362
Messina Proefplaas	1980-2000	1132
Messina_Noordgrens	2003-2018	1139

Messina_PP	2012-2018	1247
Pontdrift	2011-2018	1240
Selebi-phikwe	1980-2017	1343
West Nicholson	1980-2013	1532

4.5 Aridity

Calculating Aridity The aridity index is calculated as the ratio of mean annual precipitation (MAP) to mean potential evaporation (PET) and is used as an index in classifying the aridity of climates. It is a measure which indicates the amount of energy which is available to evaporate water, relative to the amount of water received by that environment from precipitation. 7 stations namely West Nicholson, Selebi-Phikwe, Messina_Noordgrens, Messina_Proefplaas, Messina_PP, Pontdrift and Makhado Alldays had overlapping data for both precipitation and evapotranspiration for the period of 1980 to 2018 and were thus analyzed. Aridity categories in UNEP (1982) were used to classify the degree of aridity at each station.

Tuli Karoo System is Arid. Climate stations in the Tuli Karoo System suggest a context of arid to semi aridity (Table 4.6). West Nicholson has 0.10 on Aridity Index making it an arid area and Selebi-Phikwe and the rest of SA stations are semi-arid. According to FAO (2001), a large part of the Limpopo basin belongs to the arid to semi-arid).

Table 4.6: Aridity Status, Tuli Karoo System

Station	Mean annual precipitation (mm)	Evapotranspiration rate mm/year	Aridity	Aridity status
Makhado Alldays	339	1362	0.25	Semi-arid
Messina_Noordgrens	244	1139	0.21	Semi-arid
Messina_PP	263	1247	0.21	Semi-arid
Messina_Proefplaas	339	1132	0.30	Semi-arid
Pontdrift	386	1240	0.31	Semi-arid
Selebi-Phikwe	376	1343	0.28	Semi-arid
West Nicholson	101	1532	0.10	Arid

4.6 Climate Variability and Change

Climate Variability in southern Africa Climate variability refers to variations in the mean state of the climate on all temporal and spatial scales beyond that of individual weather events. Climate variability has long been a challenge in southern Africa, reflected in an abundance of droughts and floods in preceding decades (Table 4.7). In terms of recent floods, In 2014 the north-eastern parts of the South Africa experienced heavy and extended rainfall which led to extensive flooding and landslides. Limpopo Province was worst affected with the municipalities of Lephalale, Mogalakwena, Modimolle, Bela-Bela, Thabazimbi, and Mookgopong in Waterberg District hardest hit. Mogalakwena local municipality was declared a disaster area from 18 March 2014 (Red Cross, 2014). Zimbabwe have had its fair share of flooding with 5 events recorded between year 2000 and 2009 that resulted in substantial loss of life and property.[4]

[4] www.dlca.logcluster.org

Table 4.7: Droughts and floods in southern Africa (Ashton et al. 2001; SADC/IUCN/ZRA/SARDC 2000 in SARDC/IMERCSA/ZERO 2002; Red Cross 2014: World Vision 2019; Tyson, 1986; Preston and Tyson 2000;Ashton et al. 2001; SADC/IUCN/ZRA/SARDC 2000 in SARDC/IMERCSA/ZERO 2002)

Event	Period	Explanation
Drought	1962/63-1970/71	Dry over the entire sub-continent; <90% of mean rainfall.
Flood	1971/72-1980/81	High rainfall over much of southern Africa; 1974 the rainfall was >100 % the mean for throughout the region.
Drought	1982-1983	Dry over the summer rainfall region and most of sub-tropical Africa; ±68% of mean rainfall in northern South Africa.
Drought	1991-92	Dryer conditions over the region. Southern Africa, excluding Namibia experience severe drought.
Drought	1994-95	Many SADC countries were hit by the worst drought in memory, surpassing effects of the 1991-92 drought in some parts of the region.
Flood	1995/96	High rainfall throughout most of the SADC region
Drought	1997/98	impacts of El Nino were significant.
Flood	1999/2000	High rainfall and Cyclone Eline bring widespread floods to the region, significant flood damage is caused in all Limpopo basin countries.
Flood	2014	Major floods in South Africa in the Limpopo province
Flood	2019	High rainfall and Cyclone Idai bring widespread floods to Zimbabwe eastern highlands and Limpopo river basin Mozambique area.

Climate Change in southern Africa Current and future climate variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability) (IPCC, 2007). Climate change is a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer (IPCC, 2007) Climate has variability on all time and space scales and will always be changing (Easterling et al, 2007). For southern Africa, it is postulated that temperature will rise by 2°C in the next 30 years (IPCC, 2007) while some studies revealed that global temperatures will continue to rise by between 1.4 and 5.8°C by 2100 due to the emissions of greenhouse gases (Thomas et al., 2005; Bates et al., 2008).

***Climate Change in Botswana, South Africa, Zimbabwe*.** Evidence of climate change is found in the three countries of the Tuli Karoo. In Botswana, declining rainfalls and increasing temperatures have been the most obvious indications for changes in climate that continue to be observed over Botswana (Kenabatho et al., 2012). In South Africa, according to studies conducted by Thompson et al, 2012 based on four stations in the Limpopo province which are Mussina, Polokwane, Makhado and Tzaneen there is an increase in the maximum temperatures and a decrease in mean annual rainfall. Further, along the Mogalakwena and Sand rivers which form part of the Tuli Karoo System, there is evidence of shifting rainfall patterns in the past fifty years as first rainfall has moved from September to the October- December period (Rankoana, 2012). In Zimbabwe (UNCTAD, 2003), runoff may decrease significantly in the Umzingwane, Shashe, Nata, and Save catchments. In Zimbabwe the southeastern low veld with areas like Tuli and Beitbridge record a mean annual rainfall of less than 400 mm (Unganai, 1996).

Climate Change in the Tuli Karoo Climate change in the Tuli Karoo System is evident as indicated by increasing temperature which points to effects of global warming in the area. The results obtained in this chapter are in line with assertions of a rising temperature in southern Africa by Joubert and Kohler, 1996. Conditions of a rising temperatures and highly variable rainfall patterns are not sustainable and a cause for concern for the watershed area. Zimbabwe temperatures have been observed to increase by 0.1 ^{0}C (Unganai, 1996) per decade and global ambient temperatures have been observed to have increased by 0.5 ^{o}C between the years 1880 and 2000 (NASA, 2011). A lot of water in open water body surfaces will be lost to the atmosphere through evaporation. Analyses on rainfall trends were not entirely conclusive, with only 2 of 10 stations showing a decreasing trend.

4.7 Key Messages

The review of the climate of the Tuli Karoo System reveals important considerations for shared water management. Key messages are as follows:

- ***Rising temperatures and tentative evidence of declining rains highlight vulnerability*** Not unlike other areas of Africa, the Tuli Karoo faces high interannual variability in rainfall and limited water availability. Compounding matters is evidence of rising temperatures and potentially declining rain.
- ***High inter-annual rainfall variability calls for pro-active measures to strengthen resilience*** High inter-annual rainfall variability (CV: 51%) in the Tuli Karoo System has resulted in a notable rate of droughts and floods in recent decades. In response, there should be forward-looking planning to implement measures that strengthen resilience in the Tuli Karoo. Such measures can include subsurface dams, conjunctive management of water sources in such a way that minimizes risk, and pro-active management of surface water storage. Particularly in intensely-shared waters such as the Shashe Catchment and Tuli Karoo Aquifer, there are likely to be benefits through close coordination on implementation of such measures.
- ***Increasing temperatures bring urgency*** While trends in rainfall were not entirely conclusive, mean temperature showed a significant trend. The Tuli Karoo System is warming—likely associated with Climate Change. Such warming may amplify existing adverse effects of rainfall variability. Ultimately, this brings an urgency to act so the region's development aims can continue to progress in the face of growing biophysical challenges.
- ***Increase and modernization of rainfall stations may be key to conclusive ascertainment of rainfall trends.*** As noted in the preceding message, rainfall trends were inconclusive. Two stations showed a decreasing trend in rainfall, none had an increasing trend, and approximately eight stations showed no trend. Given the importance of understanding rainfall patterns for domestic water availability as well as food security, there is need for investment to increase and modernize the weather stations network in the Tuli Karoo System. There may be a role here for satellite or mobile phone based communication systems.

5. Hydrogeology and Groundwater

This chapter reviews the hydrogeology and groundwater of the Tuli Karoo Aquifer Area in order to assess groundwater availability, use and quality. The chapter relies on primary and secondary data from the three countries, which are sparse and variable across countries. The chapter nonetheless seeks to maximize findings from available data in the context of these constraints. The chapter is divided into three sections: i) Geology and Hydrogeology, ii) Groundwater Availability, and iii) Groundwater Quality.

5.1 Geology and Hydrogeology

Background

The geological evolution of the Karoo formations was driven by the first order breakup of the super continent Pangea, which formed Laurasia and Gondwana supercontinents. Two distinct tectonic regimes (bulk deformation of the supercontinent in two distinct symmetries and orientations) occurred in the northern and southern part of Gondwana respectively during a mid-Jurassic extensional episode. The southern tectonic regime was related to Late Palaeozoic-Early Mesozoic subduction (541 to 252 million years) and orogenesis processes that ultimately resulted in a foreland system (region of potential sediment accommodation) known as the main Karoo Aquifer area (Catumeanu et al., 2005). The system developed into the three aforementioned distinct areas (the northern marginal zone, central zone and the southern marginal zone) due to flexural warping of the lithosphere. The Limpopo drainage geological area, which overlaps with the Tuli Karoo Aquifer, contains geographic divisions that lie between Achaean to Mid-Mesozoic formations of South Africa, Botswana and Zimbabwe and Mesozoic to Cenozoic formations of Zimbabwe coastal basin (Environmentek, 2003). This geological aquifer drainage area is believed to form the western arm of a failed rift triple junction (point where the boundaries of three tectonic plates meet) that later extended in a north-south direction (Bordy & Catuneanu, 2002). The "Tuli Karoo" (Figure 5.1) is what we now refer to as the Tuli Karoo Aquifer or Tuli Karoo Aquifer Area.

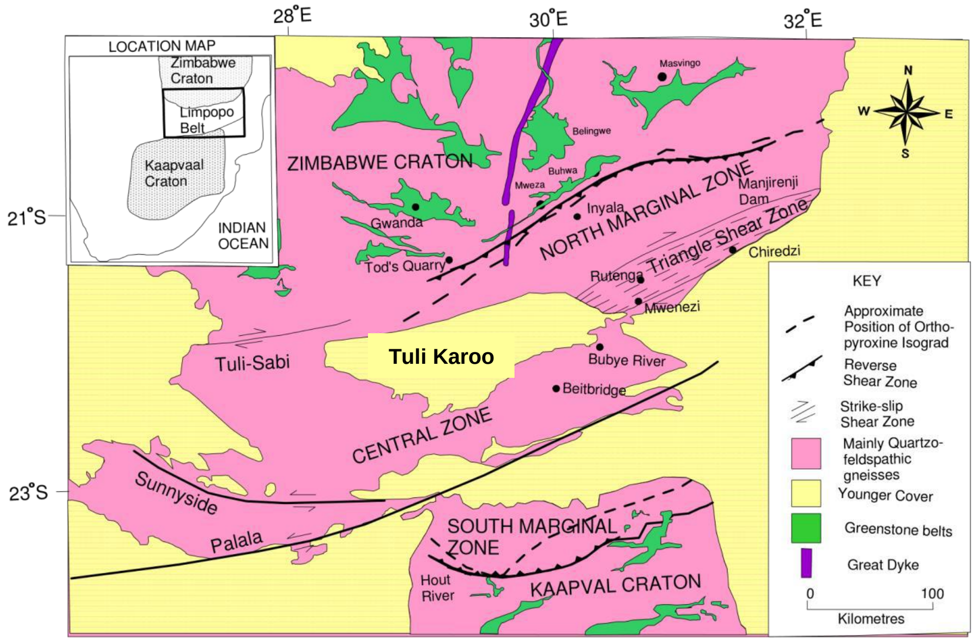


Figure 5.1 Simplified map of the Limpopo Mobile Belt showing its subdivisions, major shear zones and the adjacent cratons. (Source: Chinoda et al., 2009).

The Limpopo Mobile Belt (LMB) The Limpopo Basin is mostly underlain by the Limpopo mobile belt, a mega shear zone area with high deformation (Chinoda et al., 2009). The low lying belt is made up of Achaean early Proterozoic crystalline bedrock which is a product of the collision of Kaapvaal and Zimbabwe cratons (Water Surveys Botswana (Pty) Ltd, 2007).The Limpopo belt stretches in a near east to west orientation and cuts across eastern Botswana, Southern Zimbabwe and Northern part of South African in Limpopo Province. The belt has three distinctive subdivisions based on structural and lithological being the northern marginal zone, central zone and the southern marginal zone (Figure 5.1).

History of sediment deposition The sedimentary succession is made up of a series of mudstones, siltstones, sandstones and conglomerates overlain by Aeolian sandstones, with basaltic flood lavas overlying everything. The basalts are traversed by numerous faults trending east-north-east to north, and by easterly trending dykes which are the last phase of the Karoo igneous activity (Stour, 1995). The lowest part of the Tuli Karoo Aquifer's sedimentary sequence is the 60-metre thick Seswe formation belonging to the Ecca group. It is a coarse to conglomeratic sandstone containing feldspars and quartz pebbles within a fine grained silt matrix (Water Surveys Botswana (Pty) Ltd, 2007). The next sediments are windblown deposits that are well bedded, uniform and coarser red clastic sediments known as Korebo, Thuni and Tsheung, in order of succession (Table 5.1). The formations have a thickness of 33, 65 and 131 metres, respectively and are equivalent to the Ntane formation (Water Surveys Botswana (Pty) Ltd, 2007). The sedimentation was followed by extrusion of the Drakensberg lava showing a disconformity with the undulating Aeolian sand surface below it forming the Stromberg basalts. The lava was basaltic and formed lower and upper units. The upper unit is more extensive and constitutes silica saturated olivine free basalts while the lower unit is olivine tholites and limburgites. Both units have a combined thickness of more than 400 metres. The area has also been intruded by two main dyke Jurassic trends of west northwest and east north east. The latter occur south of the Tuli Karoo extending from Botswana into Zimbabwe and towards the failed triple junction.

Table 5.1. Summary of stratigraphy of the area. Source: Water Surveys Botswana (Pty) Ltd, 2007)

Group	Formation	Thickness (m)
Stromberg	Drakensberg Lava stage	
	Transitional stage	> 401
Lebung	Tsheung	131
	Thuni	65
	Korebo	33
Ecca	Seswe/	60
	Mofdiahgolo	5

Geology of the Tuli Karoo Aquifer

Geology of the Tuli Karoo The Tuli Karoo Aquifer straddles Botswana, South Africa and Zimbabwe. It is part of the larger Karoo Super group (Water Surveys Bostwana (pty) ltd, 2007). The lower part of the sedimentary sequence is coarse to conglomeratic sandstone containing feldspar and quartz pebbles embedded in fine-grained silty matrix (Figure 5.2). With upper units there are more uniform, well-bedded red clastic sediments and coarser windblown deposits. There are coal seams towards the upper portions of the sandstone layer. In places, the sandstone is not well sorted suggesting that, at least in part, the sediments were water lain. The more extensive upper unit are silica saturated olivine-free basalts, whereas the lower unit are olivine tholeites and limburgites (Water Surveys Botswana (Pty) Ltd, 2007).

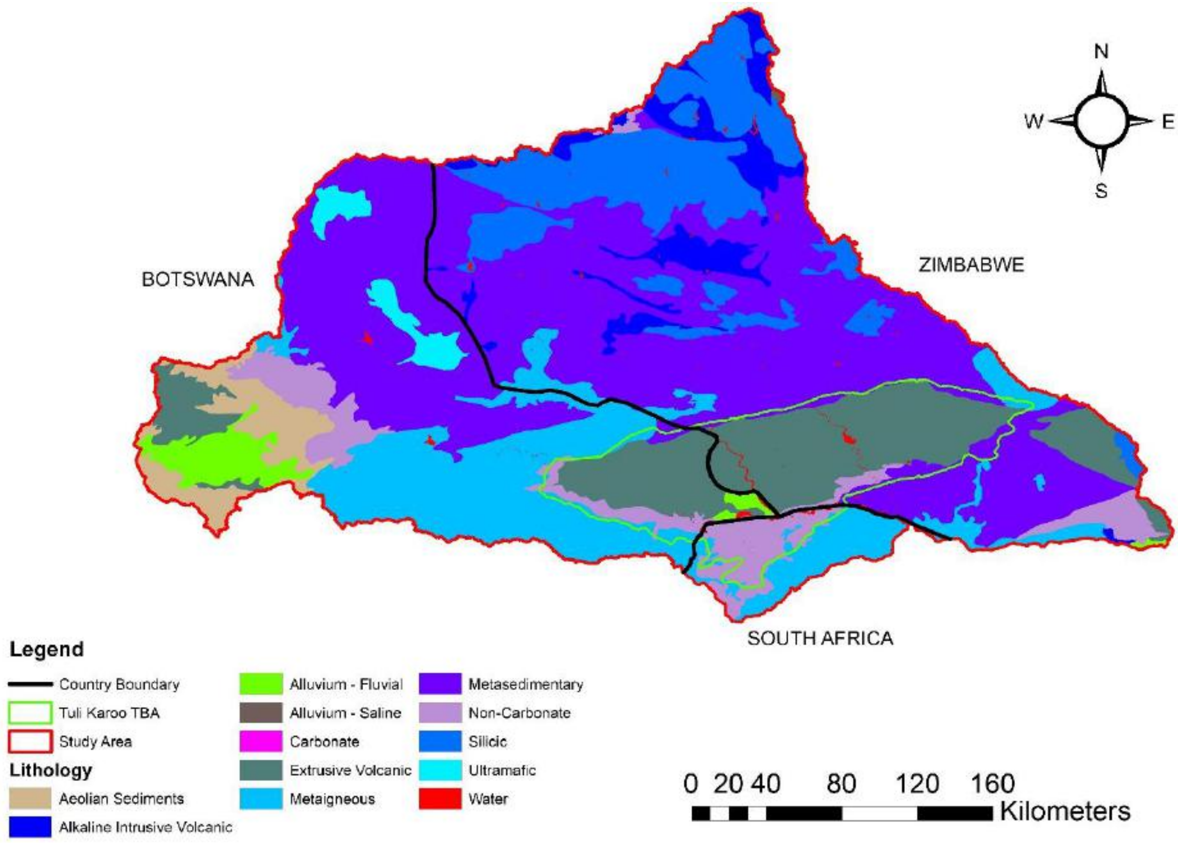


Figure 5.2: Lithology of the Tuli Karoo System (Environmentek, 2003)

Lithostratigraphy of the Tuli Karoo Aquifer Area The Tuli Karoo is situated between Achaean metamorphic rocks and the succeeding conglomerate-bearing middle unit. The 60-meter thick unit contains breccias, sandstones, mudstones and coal seams (Bordy & Catuneanu, 2002).The breccia and conglomerates are confined to lowermost part of the unit, and the units become finer upwards from sandstone with traces of conglomerates to mudstones (Table 5.2). The main coal seam of The Tuli Karoo Aquifer is primarily in the lower successions, with traces at the upper successions. The lowest unit is a basal unit with a thickness of about 30 metres (Table 5.2). The basal unit has two units when compared to the main Tuli Karoo Aquifer, which are the Dwyka group at the bottom and the thicker Ecca group, overlying the Dwyka group. The lower fining upward succession matches the Madzaringwe formation, while its upper counterpart matches the Mikambeni formation (Bordy & Catuneanu, 2002). Although Figure 5.3 is referenced from a study focused on the Botswana portion of the shared aquifer, the description of the stratigraphy likely reflects conditions throughout the aquifer area across the three countries due to uniformity of the stratigraphy.

Tuli Karoo Stratigraphy There are alternate descriptions and naming systems for the Tuli Karoo Aquifer Area formations based on the Karoo Supergroup strata across the three countries that share it (Table 5.2). Thick lines in Table 5.2 represent known unconformities. The Ecca Group is represented all over the aquifer area. In South Africa, it is composed of basal beds and the Fripp Formation (Table 5.2) with pinkish sandstones that have abundant conglomerate intercalations, interpreted as fluvial channel deposits (Chidley, 1985). The Beaufort Group is only described from the South African part of the aquifer area. It is represented by white, pink, green and khaki siltstones and very fine-grained sandstones, with grey mudstones of the Solitude Formation (Chidley, 1985). The Fripp Formation underlies the Beaufort Group's Solitude Formation. In Zimbabwe, the Ecca Group (Table 5.2) is named Fulton's Drift Mudstones (Thompson, 1975). It consists of grey to black argillaceous shales, mudstones, coal seams and a few discontinuous, lenticular white to light grey sandstones and pebble beds, especially near the base (Thompson, 1975; Watkeys, 1979; Cooper, 1980). In Botswana, the Ecca

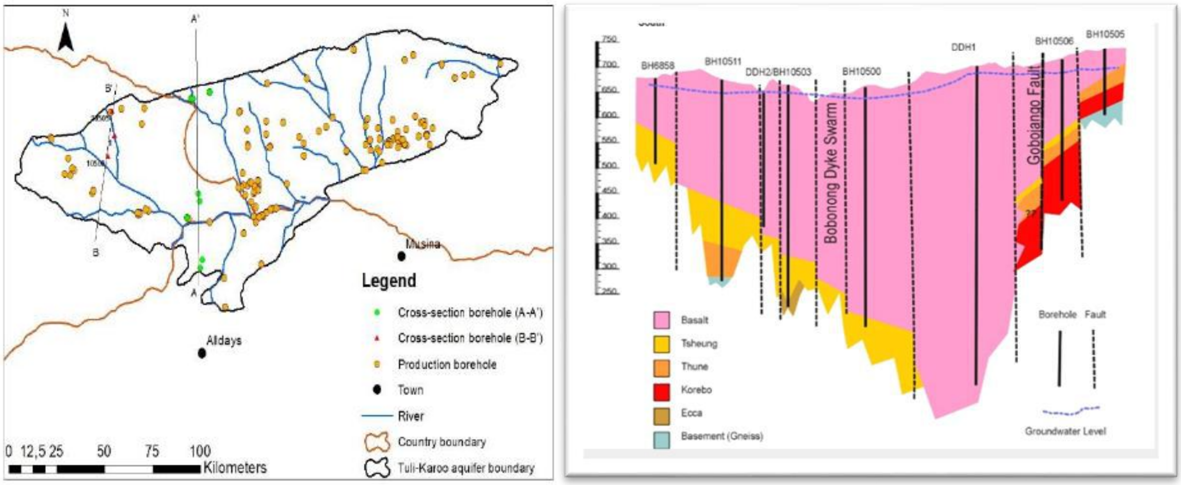
Group is represented by two formations: the Mofdiahogolo and Sweswe Formations (Smith, 1984). Importantly, sources of information utilized in Table 5.2, though somewhat dated, are still relevant as geology of the area does not change quickly and has not changed substantially since publication of the referenced documents.

Table 5.2 Stratigraphy of the Tuli Karoo Aquifer Area and correlation to the main Karoo Aquifer (Smith 1984; Water Surveys Botswana (Pty) Ltd, 2007)

<table>
<tr><th colspan="2">Main Karoo Aquifer (Johnson, 1994)</th><th colspan="2">Tuli Karoo Aquifer (South Africa part) (Chidley, 1985)</th><th>Tuli Karoo Aquifer (Zimbabwe part) (Thompson, 1975)</th><th colspan="2">Tuli Karoo Aquifer (Botswana part) (Smith, 1984)</th></tr>
<tr><td rowspan="5">Stormberg Group</td><td>Clarens Formation</td><td rowspan="2">Clarens Formation</td><td>Tshipise Sandstone Member</td><td>Forest Sandstone</td><td rowspan="4">Lebung Group</td><td>Tsheung Sandstone Formation</td></tr>
<tr><td rowspan="2">Elliot Formation</td><td>Red Rock Member</td><td rowspan="2">Red Beds</td><td>Thune Formation</td></tr>
<tr><td colspan="2">Bosbokpoort Formation</td><td rowspan="2">Korebo Formation</td></tr>
<tr><td rowspan="2">Molteno Formation</td><td colspan="2" rowspan="2">Klopperfontein Formation</td><td>Escarpment Grit</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td colspan="2">Beaufort Group</td><td colspan="2">Solitude Formation</td><td>X</td><td colspan="2">X</td></tr>
<tr><td colspan="2" rowspan="3">Ecca Group</td><td colspan="2">Fripp Formation</td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="3">Basal Beds</td><td>Mikambeni Formation</td><td rowspan="2">Fulton's Drift Mudstones</td><td colspan="2">Seswe Formation</td></tr>
<tr><td>Madzaringwe Formation</td><td colspan="2">Mofdiahogolo Formation</td></tr>
<tr><td colspan="2">Dwyka Group</td><td>Diamictites</td><td>Basal Beds (undifferentiated)</td><td colspan="2">X</td></tr>
</table>

Note: the cross in the box means there is no equivalent formation identified in that country.

Cross Section of the Aquifer A cross section of the Tuli Karoo was developed (Figure 5.3). There is an extensive basalt layer overlying the more productive sandstone or tsheung formation and its general curving shape due to the basalt weight overlying it. Even though the sandstone is laterally extensive its thickness is generally uniform compared to the basalt, which is deep (thick) towards the center and thins out towards the aquifer area edges. The sandstone is the main aquifer because of its double porosity and lateral extensiveness as opposed to its thickness. The basalt is thicker, especially towards the center but its secondary porosity is very localized and usually acts as an aquitard.



(a) **(b)**

Figure 5.3: Cross-Section of Tuli Karoo: (a) Boreholes on which cross section is based and (b) Cross-section of Tuli Karoo Aquifer Area (Adapted from Water Surveys Botswana (Pty) Ltd, 2007).

Hydrogeology of the Tuli Karoo

Aquifer Type The Tuli Karoo Aquifer is a sandstone unit of the upper Karoo that straddles the Botswana, South Africa, Zimbabwe triple junction. This is a dual porosity sedimentary rock aquifer but both the primary porosity and the fracture porosity are limited. The Tuli Karoo is made up of four types of aquifers (Table 5.3). A large proportion of the area is made up of intergranular and fractured aquifer types showing a double porosity formation. The Karoo Aquifer consists of the sandstone aquifer, overlain by Karoo basalts and underlain by low permeability mudstones and fine-grained formations. The aquifer may be confined and semi-confined in some parts of the basin. The most productive aquifer is the Karoo sedimentary aquifers/Tsheung/Forest Sandstone aquifers (Table 5.3). The undifferentiated rocks and various lithologies in the form of sedimentary, igneous and metamorphic rocks which cover a large part of the aquifer area and have low to medium water yields (Karoo sedimentary aquifers/Madikana beds). Fractured aquifer types in the form of predominantly Arenaceous sedimentary rocks (Karoo Igneous Aquifers/Basalt type) are found in the middle of the aquifer also with low to middle yields. The intergranular aquifer type in the form of unconsolidated sedimentary occurs at the northern part of the aquifer along the Limpopo river channel showing high water yields (Unconsolidated sedimentary aquifers/Alluvium aquifers in Table 5.3).

Table 5.3: Summary of aquifers and their properties. Source (Stour Consultants (Pty) Ltd, 1995; Water Surveys Botswana (Pty) Ltd, 2007)

Aquifer Type	Occurrence in Basin	Lithology	Depth (m)	Productivity (yield-m^3/hr)	Transmissivity(m^2/day)	Storativity
Unconsolidated sedimentary aquifers/Alluvium aquifers	North	Clastic sedimentary rock	12-23	3.6-36	200-500	
Karoo Igneous Aquifers/Basalt type	South west	Basalt	52-746	5-8	0.1-100	

Karoo sedimentary aquifers/Tsheung/ Forest Sandstone aquifer	Central	Sandstone	8-228	10- 100	9-121	0.00006 – 0.03
Karoo sedimentary aquifers/Madikana beds	Intercalated with basalt	Basalt/Sandstone	1-10	7-40	5-23	

Alluvium associated aquifers. They form the topmost part of the Tuli Karoo with an average thickness of about 20 metres and occurring around the Limpopo River that passes through it and its main tributaries (DWA Botswana/South Africa, 2013). It is extensively developed, having many boreholes with shallow water strikes. The total groundwater resource using the average aquifer thickness of 20 m has been estimated at 750 million m^3 (Water Surveys Botswana (Pty) Ltd, 2007). This water resource is heavily utilised at the downstream Musina mine in South Africa (DWS, 2011).

Basalt Aquifer Often overlooked as a potential aquifer due to absence of primary porosity, basalt has secondary porosity that developed along linear fracture zones associated with faulting and contact between individual basalt flows. The recharge is usually isolated to areas of river valleys where the basalt is exposed and usually localised to that area. Alternating layers of fresh and weathered basalt might hold potential for confined basaltic aquifers with more porosity. The transmissivity varies according to the amount of secondary porosity the basalt has developed and thus it can range from as little as 0.1 to as high as 100 m^2/day.

Tsheung/Forest Sandstone aquifer The aquifer is laterally extensive and generally hydraulically continuous. The main sandstone aquifer has a dual porosity with the primary and fracture porosity being limited (Water Surveys Botswana (Pty) Ltd, 2007). The aquifer dubbed the forest sandstone aquifer in Zimbabwe, it is overlain by Karoo basalts and underlain by mudstones and fine grained formations with low permeability (Africa Groundwater Network (AGWNET), 2011). As consequence, the aquifer is confined and unconfined at different parts of the basin. Furthermore, its basalt sandstone contact is a secondary porosity that is well developed at the indurated-basalt contact. A summary of the hydraulic properties of the aquifers is shown in Table 5.3. Transmissivities from this aquifer range from 9 to 121 m^2/day, while and storativity ranges from 0.00006 to 0.03, albeit for the Sandstone only (Water Surveys Botswana (Pty) Ltd, 2007). The wide range of values result from the various lava flow extrusions across the basin. More data on storativity is needed for other types of aquifers, and in other countries.

Madikana beds Drilling data in the area showed evidence of sandstone intercalations within the basalt with thickness of 1 to 10 metres. They were encountered as shallow as 49 metres below ground level (mbgl) and as deep as 193 mbgl with 5 to 15 metres of basalt between the beds (Water Surveys Botswana (Pty) Ltd, 2007). Their transmisivity has been calculated within a range of 5 to 23 square metres per day (Water Surveys Botswana (Pty) Ltd, 2007). Borehole yields in this aquifer formation are up to 40 cubic metres per hour but this is misleading as most boreholes are connected to Tsheung formation underneath which may be artesian thus giving the formation a water yield boost.

5.2 Groundwater Availability

Groundwater Recharge

Conceptual Model A conceptual model existing for the area was derived by Water Surveys Botswana (Pty) Ltd (2007). In general, the aquifer consists of Sedimentary rock (Tsheung sandstone) that is locally disconnected from the other hydrogeological units (Figure 5.4). The sandstone is regionally and laterally extensive and is continuous throughout the basin. Groundwater flow is mainly recharged around the edges of the Aquifer through the sandstone or near the basement-basalt contact. Recharge also occurs within exposed and weathered/fracture basalt outcrops. However, it is isolated and does not interact with the main groundwater flow existing as perched aquifers. Once, it enters the aquifer area it flows towards the centre of the aquifer area, the groundwater flows in the south-eastward direction to discharge along the edge of the aquifer area. The discharge is in the form of artesian flows in the basalt and Tsheung, which is ultimately lost to evapotranspiration in sites such as Lentswelemoriti in Botswana (Water Surveys Bostwana (pty) ltd, 2007). Along the sandy river channels, focused recharge to the alluvial aquifer also occurs during flows. Generally these alluvial aquifers extend to the flood plain and in some areas the deep boreholes (>100 m) drilled along the river banks connect the alluvial (top or shallow) and sandstone (bottom or deep) aquifers. This conceptual model (Figure 5.4) can be used to represent the aquifer area since the geology and lithology is similar across the three countries.

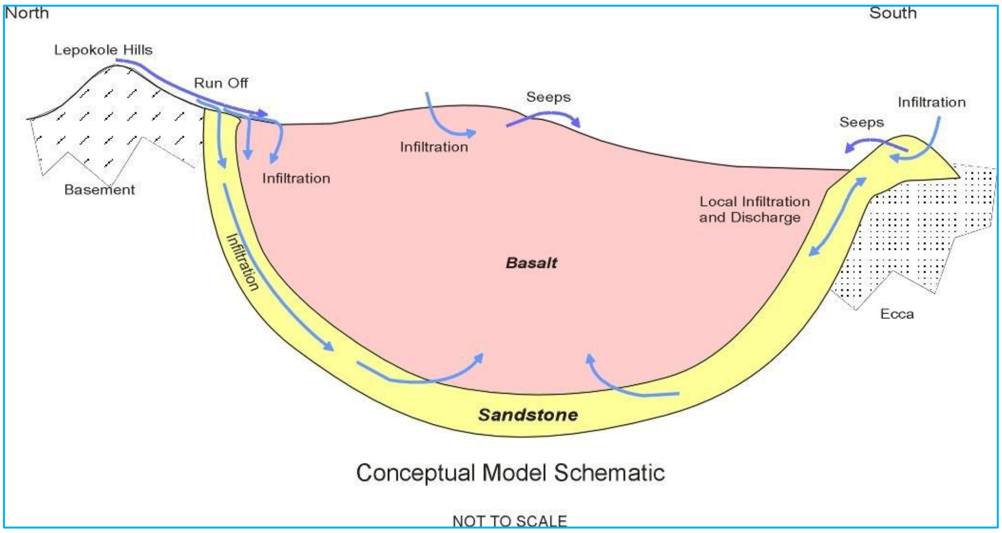


Figure 5.4: Conceptual Model of Groundwater Flow (Water Surveys Botswana (Pty) Ltd, 2007)

Groundwater Levels and Flow Direction

Borehole Distribution Zimbabwe has the highest number and density of boreholes (pumping) in the aquifer area (Figure 5.5). The borehole depths in the aquifer area ranged from 20 to 379 metres depending on whether they were located in alluvial aquifers or deeper sandstone aquifers. Zimbabwe had 55 boreholes with depths ranging from 13 and 133 meters. Botswana had 24 boreholes, with depths ranging from 17 to 379 meters that were monitored once a month for a period of nine years from 2011 to 2019. South Africa had 11 boreholes each with a depth of 110 meters. The static water levels from these 55 boreholes were used to construct a groundwater contour map.

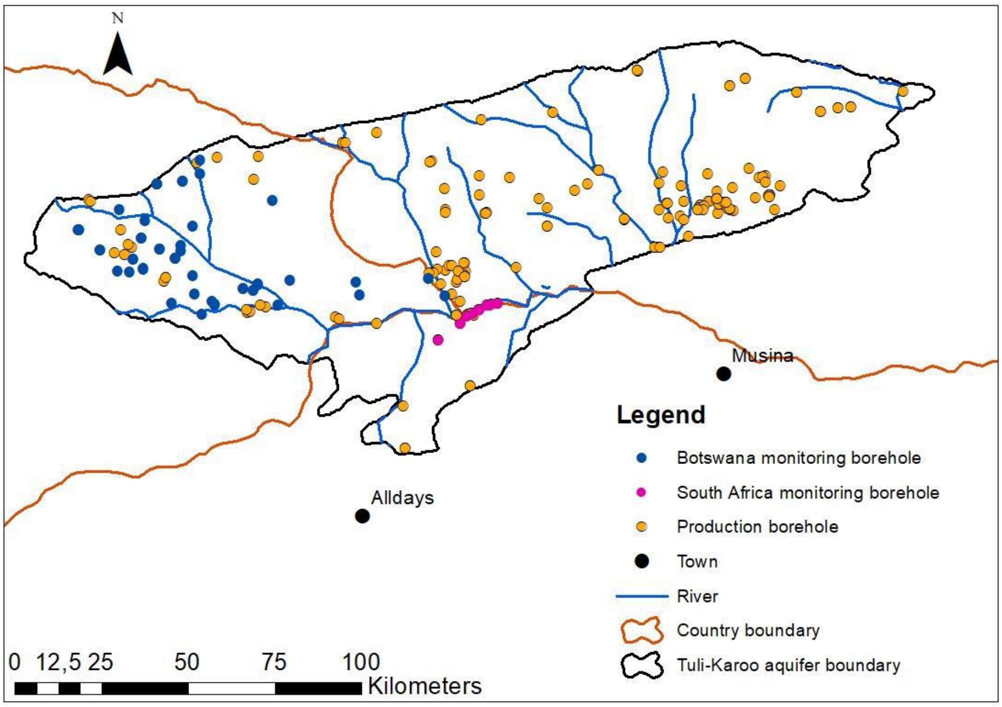
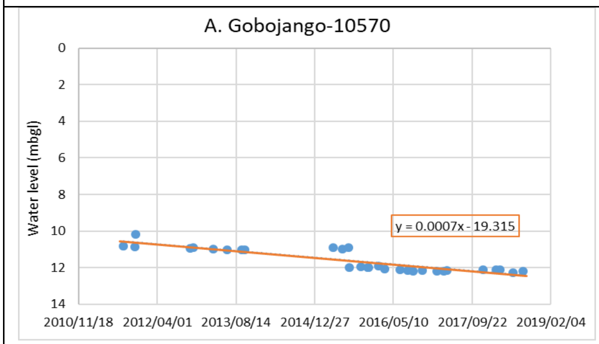
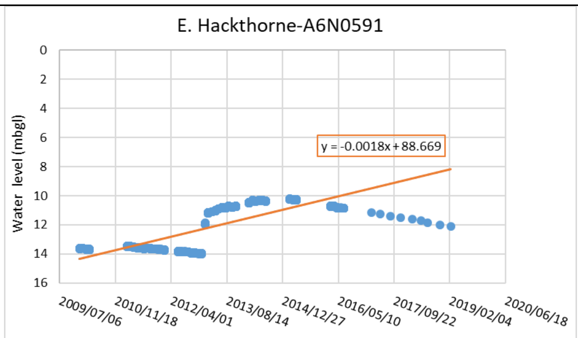


Figure 5.5: Borehole Distribution in Tuli Karoo Aquifer Area (Source: Data from DWS-Botswana, 2019; DWS-South Africa, 2019; ZINWA, 2019)

Groundwater level trends In Zimbabwe, no monitoring boreholes existed in the Aquifer Area. However, 25 boreholes had static groundwater level information obtained at drilling. In Botswana and South Africa, boreholes with groundwater levels existed and covered the same time period of 2011 to 2019. They were analysed to understand trends in groundwater levels. For Botswana, four representative boreholes were selected for analysis. They generally showed a gentle slope of a decreasing trend in groundwater levels (Figure 5.6). In South Africa, the groundwater level time series from these boreholes showed seasonal cyclic variation (e.g., A7N0630) which may indicate possibility of aquifer response and recovery to seasonal rainfall in South Africa. There is, however, also evidence of upward trends (e.g., A7N0603). Water levels in Botswana tend to be considerably deeper than those in South Africa.

Botswana	**South Africa**
	

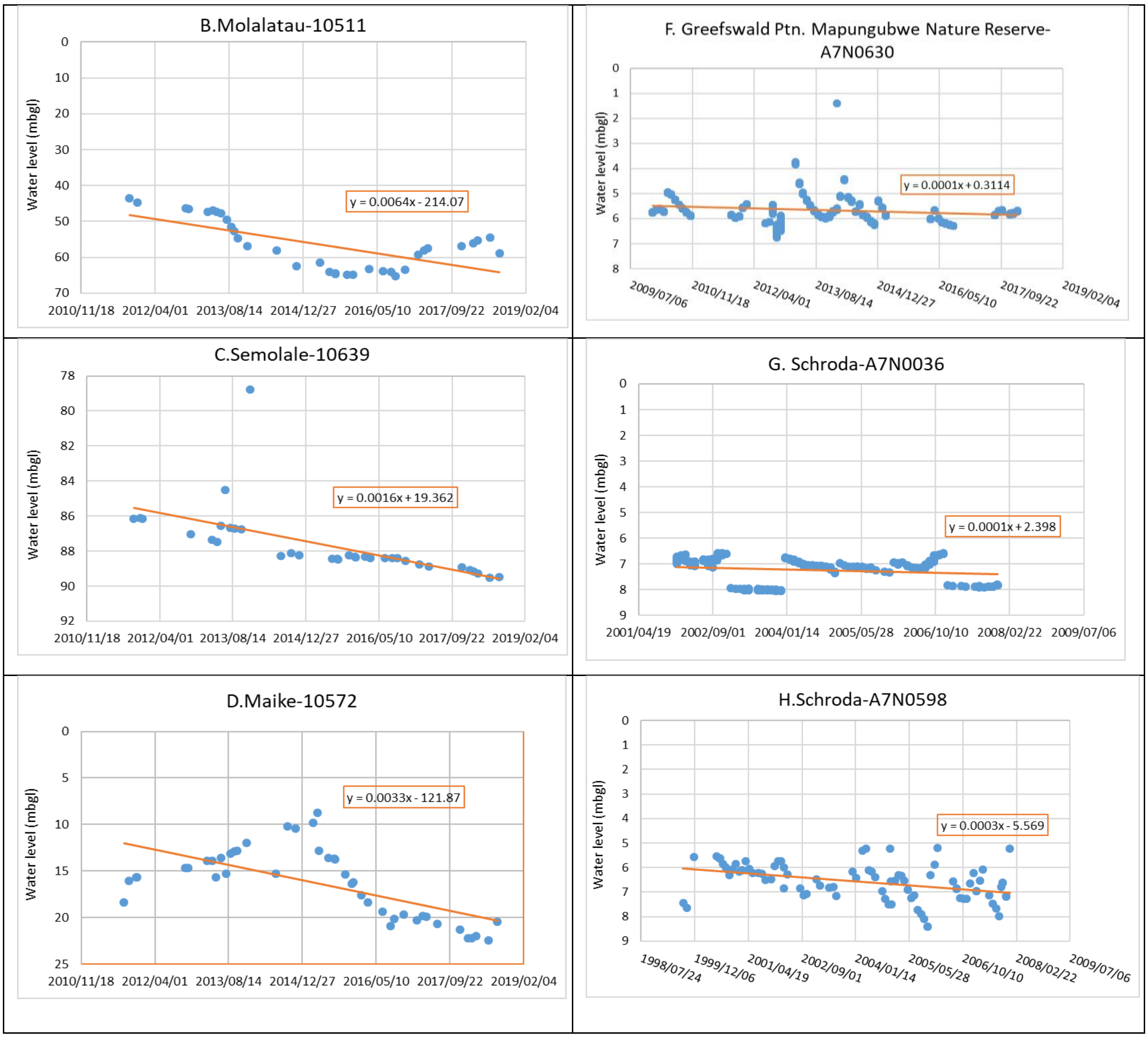


Figure 5.6: Groundwater Level Trends

Calculating Flow Direction Groundwater flow direction was based on data from differing time periods. The Inverse Distance Weighted (IDW) technique was used to interpolate the groundwater levels in the aquifer area based on 2016 groundwater levels. The data from South Africa was based on 11 observation boreholes (e.g., A7N0033, A7N607, AN0630) with static water levels as shallow as 4 to 12 metres above ground level (mbgl) and each at a terminal borehole depth of 110 mbgl, within the basalt formation. However, the boreholes were clustered near the northern part of South Africa's Tuli Karoo Aquifer Area which made interpolation towards southern portions difficult. Zimbabwe possessed data on 55 boreholes (BEIT-160, BEIT-247, etc.) with static water levels at drilling time in the range of 3.3 to 60 mbgl and terminal depths between 13 and 133 mbgl (average 60 metres). Botswana had static water level information from 24 boreholes (BH-10494-10640) between artisans to 87 mbgl and terminal depths of 17 to 379 mbgl. The boreholes terminated within the various hydrological units as shallow as the alluvium aquifers (~20 mbgl) and as deep as banded gneisses formations (> 200 mbgl) with a vast majority within the stromberg basalts at around 100 mbgl.

Tuli Karoo groundwater flow runs southeast The natural groundwater flow was observed to be from the northwest toward the southeast, i.e., towards the Limpopo River (Figure 5.7). The groundwater flow direction generally follows the natural topography of the area. The change in hydraulic head along a groundwater flow path is termed the hydraulic gradient. The velocity of groundwater flow is proportional to the magnitude of the hydraulic gradient and the hydraulic conductivity of the aquifer, which depends on the characteristics of the aquifer and pumping stresses imposed on the aquifer.

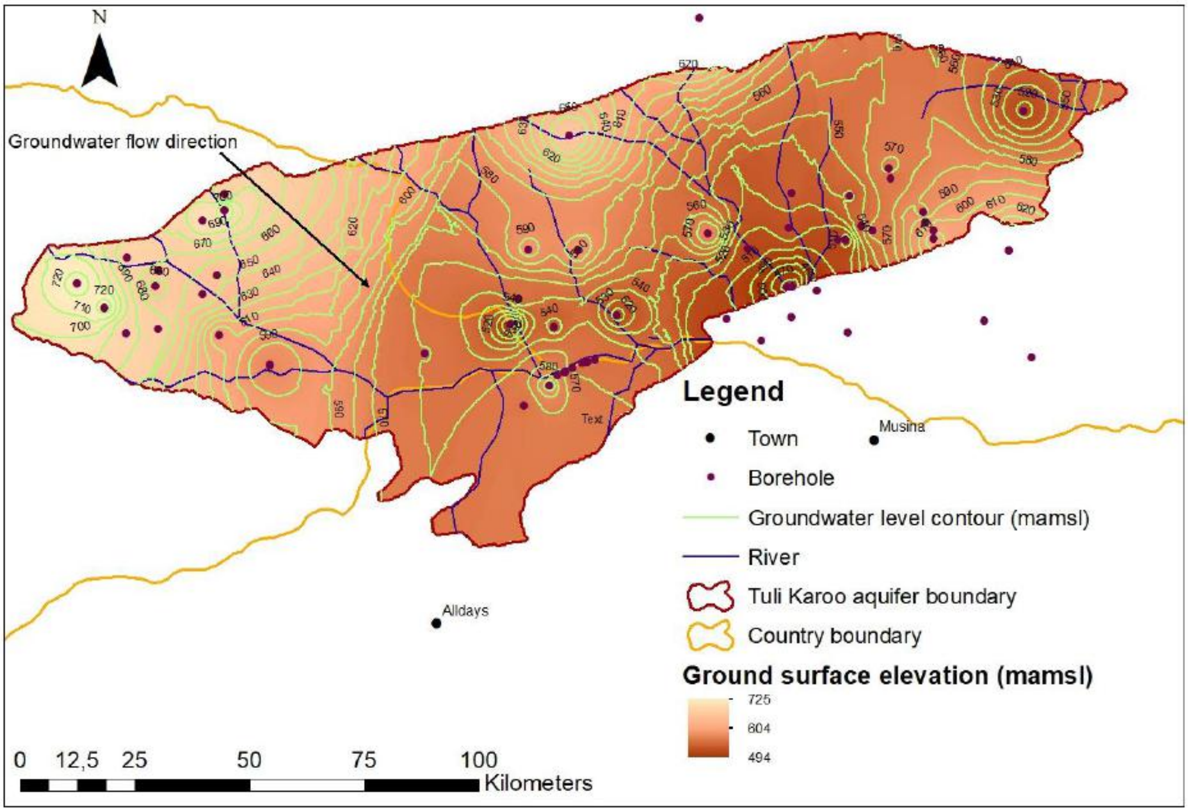


Figure 5.7: Ground surface, groundwater elevation and flow direction of the Tuli Karoo Aquifer Area based on water levels from 2016 dry season data. (Data source: DWS-South Africa, 2019; DWS-Botswana and DDF- Zimbabwe, 2019)

Soils

Soils and soil properties The three countries have different soil classification systems for the same type of soil thus the soil types discussed are based on the Food and Agriculture Organisation (FAO) system nomenclature. The soils in the area vary mainly according to the different parent/source material and climate. Low rainfall areas and hilly areas generally have less developed soils with thickness of at most 40 centimetres (Bangira & Manyevere, 2009), while high rainfall and temperature areas have highly developed soils that are at least a metre thick and comprise of leached clay and sandy soils (Bangira & Manyevere, 2009). The distribution of the soils in the study area as well as their subcategories shows the Tuli Karoo Aquifer as mainly having Eutric leptosols (Figure 5.8).

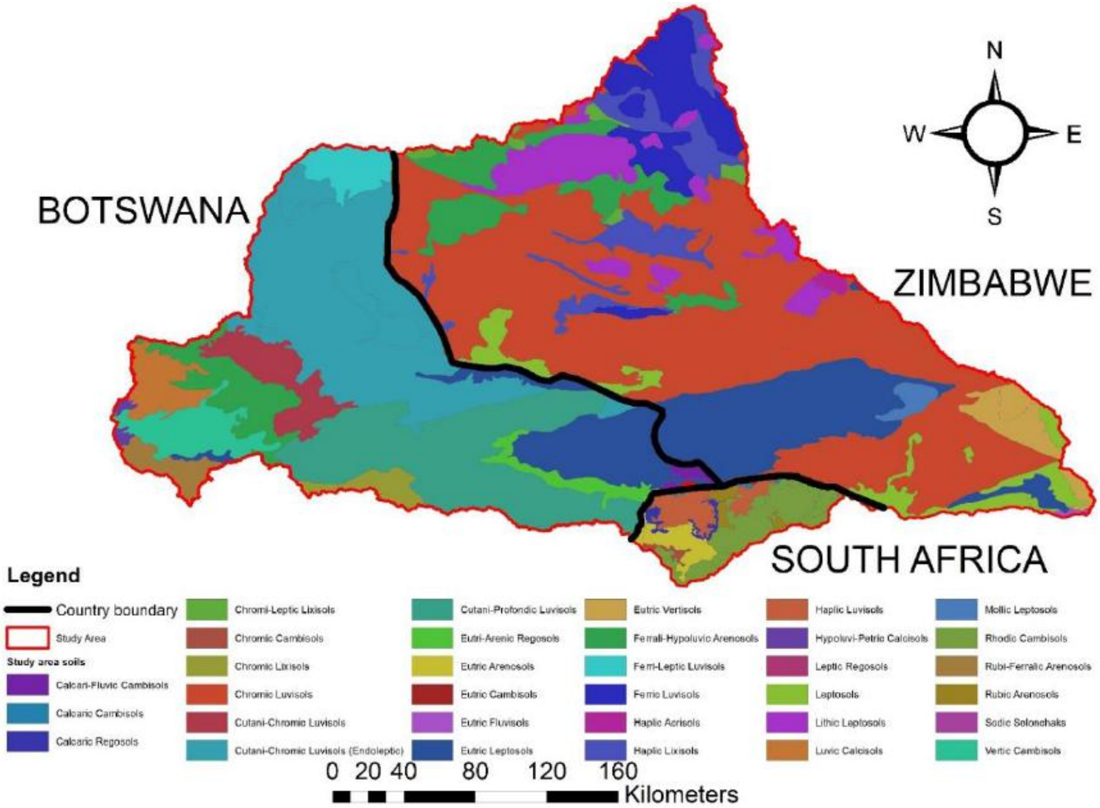


Figure 5.8: Dominant soils distribution in the system (Source: Dikkshoorn, 2003)

Soil Properties The aquifer area features three main dominant soil types: Leptosols cover the majority of the aquifer with a depth of less than 0.25 metres (Table 5.4). The two major types of leptosols include the euptic leptosols covering most of the aquifer and normal leptosols covering the south eastern part of the aquifer (Dikkshoorn, 2003). There are endoleptic luvisols with depths of 0.4 to 0.6 metres and Eutric fluvisols towards the centre of the aquifer (Dikkshoorn, 2003).

Table 5.4: Soils and morphological features. Source (Bangira & Manyevere, 2009)

Soil type	**Description**	**Approximate area (km^2)**	**Depth (cm)**	**Permeability and drainage**
Luvisols	Dark brown, coarse grained sandy loam to coarse grained sandy clay	46,000	40-60	Good permeability and well drained
Leptosols	Variable depends on climate and parent material	70,000	<25	Limited depth thus diagnostic horizons are lacking
Fluvisols	Dark to yellowish brown, Fine to medium grained sandy loam	7,800	>150	Good permeability and well drained

Drainage Properties of the Soil The majority of the soils are coarse grained sandy loam soils having generally good permeability and drainage. They are primarily from granites, gneisses and sandstones parent material, hence their coarse and gravely texture over the Tuli Karoo Aquifer had a limited depth, thus resulting diagnostic horizons were lacking. Fluvisols covering area near boundary of three countries and fluvisols towards the north east of the aquifer have good permeability and drainage (Bangira & Manyevere, 2009), and high groundwater recharge potential.

5.3 Groundwater Quality

Groundwater recharge generated in an area flows through the primary and secondary porosities of the rocks. This flow makes groundwater quality to vary spatially depending on the type of rock it penetrates, the area it passes through, where it accumulates and the environmental conditions of the locale. The main dissolved ions in 1-1000 mg/l of groundwater includes calcium, magnesium, sodium, potassium, chlorine, bicarbonate (Yani, Palupi, Bramantoro, & Setijanto, 2019). The anthropogenic contaminants of water in the area can be attributed to operating and non-operating mines in the area including Bamangwato Concessions Ltd (BCL), Venetia and Tati mine. Commercial farming prominent in the area especially along the Limpopo River such as the Tuli Block farms in Botswana and Pontdriff farms in South Africa lead to contaminants enrichment through leaching of chemical used by irrigation practices or precipitation. Finally, the area host different towns which have high population such as Francistown and home to industries such as abbatoirs, textiles and poultries that produce wastewater that can ultimately reach groundwater.

Groundwater quality data was available from South Africa and Botswana. Only an average Total Dissolved Solids (TDS) value was available for the Zimbabwe portion of the Aquifer Area (Table 5.5). Groundwater quality data in South Africa came from two groundwater quality monitoring boreholes: i) one located at Pontdrift border post along the Botswana-South Africa border, the other borehole located towards the southern point of the Tuli Karoo Aquifer Area in South Africa. In Botswana, there were water quality data from boreholes towards the north-western part of the aquifer near the border with Zimbabwe at Mabolwe and Gobojango, along the Thune River at Motlhabaneng, and upstream of Motloutse at Lepokole. The location of boreholes were groundwater quality was measured from 14 boreholes located in Botswana and two boreholes located in South Africa (Figure 5.9). Data available for South Africa was from 1995 to 2017 while for Botswana, data was recent from 2013 to 2019.

Table 5.5: Water quality parameters for Botswana, South Africa and Zimbabwe. (Source: DWS – Botswana, 2019; DWS – South Africa, 2019)

Parameter	Botswana (2013-2019)		South Africa (1995-2017)		Zimbabwe (2015)	Standards: WHO (2011)
	Range	Average	Range	Average	Average	
Total dissolved solids (mg/ℓ)	100 -1700	352.82	14-8800	2257.74	< 2000	600-1000
Nitrate(mg/ℓ)	0.1-464	46.54	0.12 - 61	4.88	-	50
pH	7 – 9.5	8.03	7 – 8.8	8.09	-	6.5-8.5
Calcium (mg/ℓ)	0.05-179.29	65.59	3.74-149.9	76.4	-	75-200
Magnesium (mg/ℓ)	0.71-321	85.49	7.9-57.6	25.89	-	50-100
Fluoride (mg/ℓ)	0.05-5.86	1.03	0.1-5.54	3.27	-	<1.5 m
Phosphate (mg/ℓ)	0.09-3.06	1.00	0.1-0.94	0.416	-	<15.3
Electric conductivity (µS/cm)	67.5-5030	549.81	2.3-230	208.97	-	700-3100
Potassium (mg/ℓ)	0.45-227.97	12.16	1.51-12.1	6.2	-	25-100

Sulphate (mg/ℓ)	3.825-867	83.67	3.24-1786.1	280.43	-	200-400
Chloride (mg/ℓ)	3.985-700.572	192.1	44.76-3506.8	580.56	-	200-600
Sodium (mg/ℓ)	0.02-667.8	170.50	17.5-1978.8	377.92	-	<500

Note: (-) no value reported

Salinity High salinity of 1,700 mg/ℓ was observed in parts of the Botswana portion of the aquifer. These levels decreased in Zimbabwe and north-western portions of the aquifer in Botswana, to values less than 100 mg/ℓ. The high salinity values can be linked to waste treatment plants in Botswana such as Robelela treatment plant. Furthermore, the population concentration of Selebi-Phikwe may lead to more waste being generated. In the southern parts of the aquifer in South Africa, salinity ranged between 1,000 and 2,000 mg/ℓ, with some extreme values of between 4,000 to 8,800 mg/ℓ recorded on three dates: 19/08/2016 (4,172 mg/ℓ), 06/04/2017 (7,527 mg/ℓ) and 12/09/2017 (8,801 mg/ℓ) at Pontdrift border post.

Nitrate may be high in South Africa, although there is no data in other countries. The data showed that nitrate values throughout the years fluctuated between below detectable limits and to an extreme of 61 mg/ℓ in 2000 in near Pontdrift border post. On average, nitrates at 4.88 mg/l were below the allowable limit of 50 mg/ℓ. Botswana showed much high values of nitrates having extremes of up to 464 mg/ℓ and an average of 46.54 mg/ℓ. The high nitrate values were found at Semolale borehole number 3587 and other boreholes located at Motlhabaneng. The main source of nitrates is from fertilizer used in commercial agriculture in the Tuli Block farms. Nitrates pose health risks and can cause eutrophication into surface waters that ultimately stimulate growth of weeds and reduce oxygen availability for aquatic life.

Slightly more basic pH. The pH of groundwater in the southern part of the Tuli Karoo Aquifer Area in South Africa varied from neutral to basic (pH 8.8). Groundwater from western part of the aquifer area in Botswana was similar to that in the southern part but with values becoming more basic towards the western part of the aquifer upstream of Motloutse, reaching pH levels of more than 9.5 due to dissolution of sedimentary calcite.

Calcium One of the main quality parameters for water that determine its hardness (DWA Botswana/South Africa, 2013). Calcium levels were on average within the allowable limits for both countries. The increasing levels of calcium might be coming from calcium carbonate discharged from the operating or abandoned mines such as the BCL mine and Venetia mine in Botswana and South Africa, respectively.

Magnesium Magnesium levels in Botswana and South Africa (towards the Pontdrift border) reached highs of more than 90 mg/ℓ and 340 mg/ℓ, respectively. In Evangelina game ranch, southern part of the aquifer area in South Africa, magnesium values of less than 60 mg/ℓ were observed.

Flouride The fluoride levels in Botswana on average were below the WHO standard, while South Africa had levels that were double the permissible WHO standard at 3.27 mg/l**.** The occurrence of high fluoride values may be attributed to shallow aquifers in arid areas experiencing high evaporation (Kimambo, Bhattacharya, Mtalo, Mtamaba, & Ahmad, 2019). Furthermore, high fluoride values may result from the groundwater reacting with young volcanic rocks such as the Stromberg basalts.

Potassium Although both countries on average have potassium values within WHO standards, Botswana has areas exceeding the limit by as much as 227.97 mg/ℓ. The high potassium may be because of NPK fertilizers leaching to the groundwater, commonly used in farming areas in the Tuli Block farms. Wastewater discharge from abattoirs and textile industries may also contribute to increasing potassium concentrations in the groundwater.

Sodium Average sodium levels were within allowable limits but Gobojango borehole in Botswana and Pontdriff borehole in South Africa were higher that WHO standard. The high values can be attributed enrich sodium through either irrigation or precipitation led leaching of soils high in sodium in the area. Furthermore, the presence of sewage effluent from towns within the vicinity of the aquifer from both countries can also contribute to increased sodium levels.

Sulphate Both Botswana and South Africa had areas that exceeded the WHO drinking standard. In Botswana, Gobajango area had high values, while in South Africa; the Pontdriff Border post showed very high values of 1786.1 mg/ℓ. The high sulphate values might be attributed to sulfide oxidation which is initiated by acid mine drainage (Toran, 1987). The dewatering of the BCL and Tati mines in Botswana and Venetia mine in South Africa could contribute to increased sulphate contaminant.

Pollution hotspot areas pose threat to quality and quantity of groundwater and surface water resources. Pollution hotspot areas of mines, industries, abattoirs and wastewater treatment plants exist in the Aquifer Area (Figure 5.9). The location of pollution hotspot areas in Botswana include Bamangwato Concessions Ltd (BCL) mine, Water Utilities Corporation Mambo water treatment plant, Nortex textiles, B and M textiles, Botswana Breweries Limited, Botswana Meat Commission Abattoir, Richmark Chicken Abattoir, Bobbsies Chicken Abattoir and Botswana Breweries Limited (Figure 5.9). In South Africa the hotspot areas include Vele coal mine (closed), Venetia Diamond mine and wastewater treatment in Weipe town and from Zimbabwe part of the aquifer area, the areas include wastewater treatment near Beitbridge, Manama area (Tuli Coal mine - closed opencast coal mine due to poor coal) and Shigwangana area (new coal mine opening soon). Acid mine drainage (AMD) from mines is a huge threat.

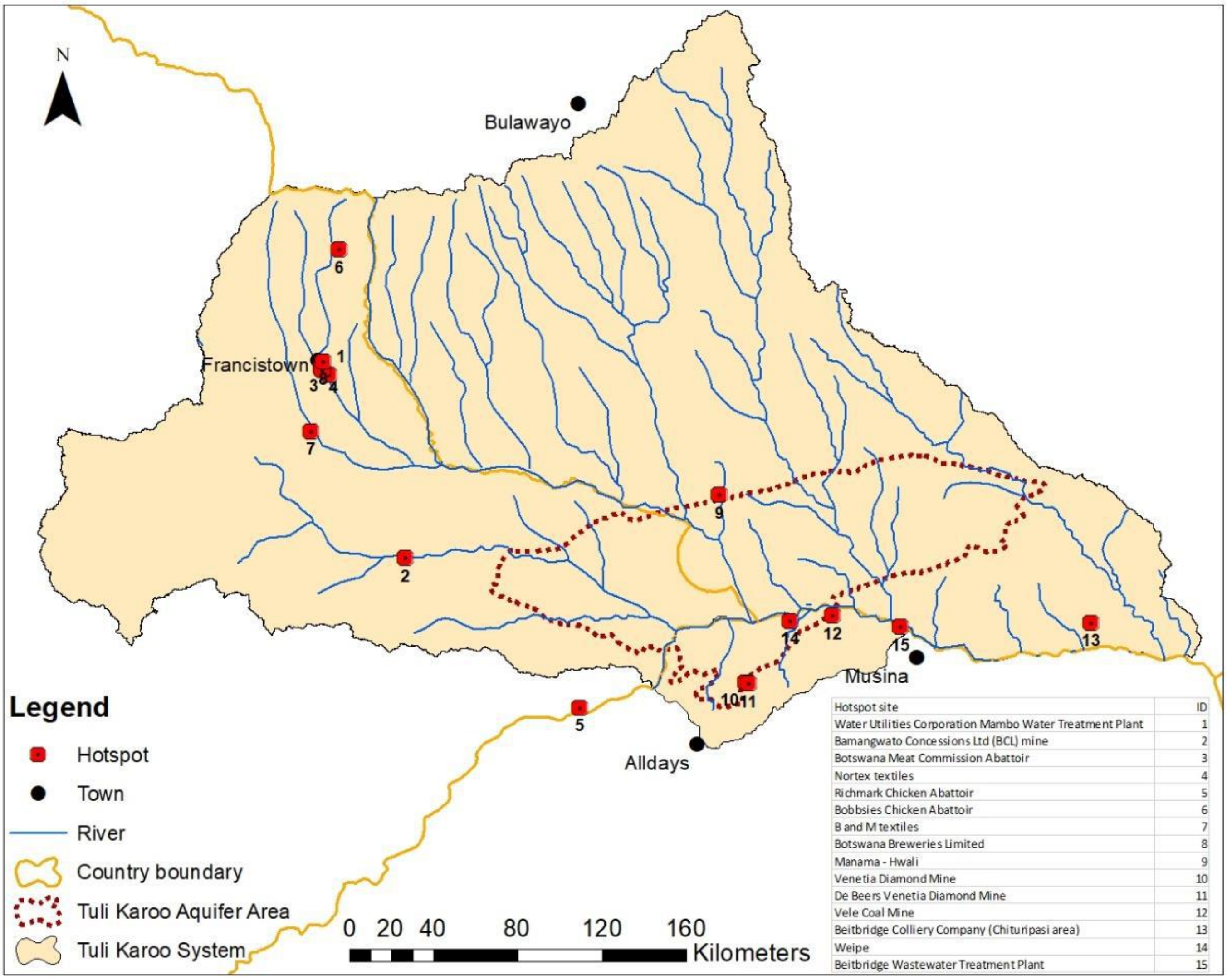


Figure 5.9. Pollution Risk Hotspots

5.4 Key Messages

Review of the hydrogeology and groundwater conditions of the Tuli Karoo Aquifer Area highlights important considerations for shared water management. Key messages are as follows:

- ***Flow direction indicates potential for transboundary impacts to be felt in South Africa and Zimbabwe*** While knowledge on the direction of groundwater flow in the Tuli Karoo Aquifer is limited, it appears to flow toward the southeast portion of the aquifer in South Africa and Zimbabwe—which renders these two countries somewhat vulnerable to changes in upstream portions of the aquifer in Botswana and to a lesser extent Zimbabwe.
- ***Current data provides no evidence of transboundary groundwater impacts*** 6 of the 8 groundwater hydrographs of boreholes in Botswana and South Africa had falling trends (four of them in Botswana and two of them in South Africa). No hydrograph data in Zimbabwe. While data from Botswana show declining water levels presumably due to increased water abstraction in the aquifer area, limited data on water levels in the South African portion of the aquifer showed no such trend. It may be that the current intensity of groundwater use, low transmissivities and consequent low borehole yields of the Karoo rocks across Botswana, South Africa and Zimbabwe mediate the transboundary impacts of groundwater abstraction.

It may also be that investigation based on a deeper data set produces a much fuller picture. Whatever the case, there is need to closely monitor the area so that potential impacts are well managed.

- ***Improved monitoring and targeted investigations are key to better understanding the shared aquifer*** There are four priority areas of focus to better understand the aquifer. First, groundwater levels in Zimbabwe should be monitored. Second, groundwater stable isotope investigations can be undertaken in order to establish sources and interaction of groundwater across the three countries. Third, aquifer response during periods of high rainfall can be investigated to clarify how these rainfall events contribute to local or regional groundwater recharge. With increasing frequency of such events, understanding their relationship to groundwater levels will be key to enable effective management.
- ***Although groundwater quality is generally good, albeit with very scarce data, hotspots mapping and monitoring are needed*** Limited data suggests that groundwater quality in the Aquifer Area is generally good, and does not appear to pose major health risks to the human population. There is a need for careful mapping and monitoring of potential hotspots (sources of contamination) to ensure their risks are mitigated. The Aquifer Area hosts several opencast, underground mines and industrial sites, for example, which may be releasing heavy metals, microbial pathogen, organics, radio-nuclides and radioactive material in the groundwater that is not being monitored. There are currently no aquifer area-wide heavy metals, microbial pathogen, organics, radio-nuclide or radioactivity monitoring programme therefore their abundance is not known.

6. Surface Water

This chapter contains three main sections: surface water hydrology, surface -groundwater interactions and surface water quality. In the first section, we describe the surface water hydrology of the Tuli Karoo System including drainage basins, runoff, and streamflow analysis. In the second section, we describe the ambient surface water quality parameters, erosion and sedimentation, pollution sources and water quality impacts. In the third section, we describe surface-groundwater interactions.

6.1 Surface Water Hydrology

The Limpopo Basin

The Limpopo River The Limpopo River is a natural sand river that forms the northern border between South Africa, Botswana and Zimbabwe. Its tributaries include the Ngotwane (Botswana-South Africa), Mzingwane (Zimbabwe), Shashe (Botswana-Zimbabwe), and Olifants (South Africa) rivers. The Limpopo River has a seasonal flow regime characterised by a wet season which recharges the alluvial aquifer and dry winter months where surface flows decline. Consistent with the climate context provided in chapter 4, the mean annual precipitation (MAP) in the Basin's upper reaches ranges between 400 and 500 mm in portions of Zimbabwe, decreasing to between 200 and 300 in the arid areas around the intersection of Botswana, South Africa and Zimbabwe; the far eastern portion of the Basin, in Mozambique, experiences rainfall in excess of 700 mm (Cobbing et al., n.d.). The length of the river has been estimated at 1 750 km (Nakayama, 2003). The Tuli Karoo System is situated in the upper Limpopo (Figure 6.1).

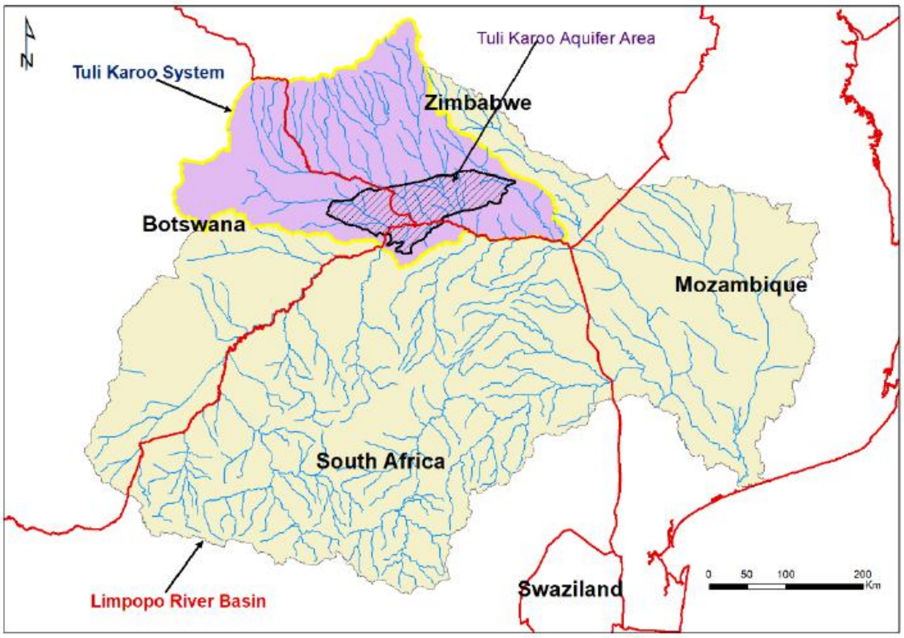


Figure 6.1: The Limpopo Basin and Tuli Karoo System

The Shared Limpopo Basin Overall, the Limpopo River Basin drains an area of approximately 408,000 km^2 with Botswana, Mozambique, South Africa and Zimbabwe covering 20%, 21%, 44% and 15% of this area, respectively. Its total mean annual runoff has been estimated at 5.5 million cubic meters (mcm). The greatest proportion of the basin's area and runoff is in South Africa (Table 6.1). Further, given the relatively high levels of water resources development, the greatest proportion of basin water use is in South Africa (Mohamed, 2014). More broadly, given the basin's level of water resources development relative to its renewable water resources, it is typically considered a "closed" basin (Molden, 2007).

Table 6.1 The Limpopo Basin (Source: Limpopo Awareness Kit, no date; Zhu and Ringler, 2012)

	Area (km2)	Mean Annual Precipitation (mm)
Botswana	81,400	420
Mozambique	79,800	750
South Africa	184,200	610
Zimbabwe	62,900	510

The Tuli Karoo System

Tuli Karoo System: Hydrologic sub-divisions The Tuli Karoo Aquifer Area lies underneath a somewhat diverse set of surface waters (Figure 6.2a). In total, the Tuli Karoo System is divided into six surface water catchments (Figure 6.2b): four sub-basins, namely Motloutse, Shashe, Mzingwani and Bubi, and two quaternary catchments[5] (A63E and A71L). In comparison to other transboundary aquifers that have received focus in SADC to-date (Ramotswa, Shire, Stampriet), Tuli Karoo intersects with the highest degree of surface water catchments. The others have been mainly contained by one sub-basin or catchment.

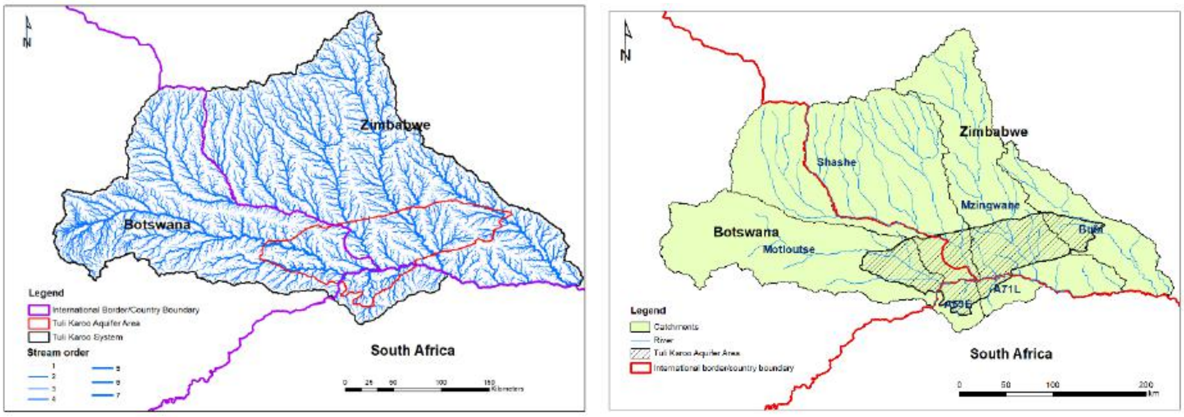


Figure 6.2: Stream Order (a) and Catchments (b) of the Tuli Karoo System

Area and Runoff in Tuli Karoo catchments The areas of catchments in the Tuli System vary considerably (Table 6.2). The Shashe is the largest catchment by area, followed by the Mzingwane. Together these two catchments cover more than 60 % of the Tuli Karoo System. Also important is the Motloutse, which covers more than 20 % of the area of the Tuli Karoo System. Runoff in the Tuli Karoo catchments, calculated in ARCGIS using Spatial analyst Tool called "Zonal statistics as Table" which summarizes the values of a raster (spatial variation in runoff) with in zones of another datasets (sub-basin zones) – shows that about 55% of the runoff in the Tuli Karoo System is generated from the Shashe Catchment. The next significant runoff is generated from the Motloutse sub-basin. It accounts about 27% of the total runoff generated from the Tuli Karoo System. The proportion of runoff generated from the Mzingwane sub-basin account for only about 14% of water in the system.

[5] In South Africa, quaternary catchments (fourth-order) are used as the smallest water management units.

Table 6.2: Tuli Karoo System, Area and Runoff by Catchment

Catchment	Area (km2)	Proportion of Area (%)	Runoff (mcm)	Proportion of Runoff (%)
Mzingwane	20,160	24.6	358.85	11.82
Motloutse	19,590	23.9	818.65	26.96
Bubi	8,600	10.5	29.65	0.98
Shashe	29,950	36.5	1778.73	58.58
A71L	1,760	2.2	7.76	0.26
A63E	1,990	2.4	42.83	1.41
Total	82,940	100	3036.47	100

Spatial variation in runoff A spatial runoff map was created through the use of annual global precipitation data downloaded from CHRIPS (Climate Hazard Group Infrared precipitation with Stations V2.0)[6]. CHIRPS incorporate 0.05° x 0.05° (~5.4 km) horizontal resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring (Funk et al., 2014, Bai et al., 2018). Annual global precipitation data for 2000-2013 was downloaded and the mean long term annual precipitation was calculated using raster calculator. MODIS Global Terrestrial Evapotranspiration (ET) Product (MOD16 ET) data was then downloaded from University of Montana and annual long-term average actual ET data obtained for the period of 2000-2013. Many studies have reported that actual ET from the MODIS 16 product particularly in arid and semi-arid region shown significant underestimation (Wang and Zlotnik, 2012, Trambauer et al., 2014, Bhattarai et al., 2018). For instance, Bhattarai et al. (2018) found underestimation of 26 % in actual ET in mid-west, USA. The Tuli Karoo System water balance is treated as change in soil moisture storage = precipitation - ET- surface runoff –recharge. Long term change in soil moisture storage was assumed to be zero and recharge was assumed to be 5% of rainfall based on previous study estimate (Lombaard, 2016). The following procedure was then followed:

1. Binary raster data was created for valid range (value of 1) and for the others (value of 0)
2. Annual precipitation raster value was multiplied with the binary raster created in step 1 to exclude areas not included in ET calculation
3. Actual ET obtained from MODIS 16 is increased by 10% to account underestimation reported in literature. The 10% increment was decided after iterative comparison of runoff determined by water budget method using global data and measured streamflow data.
4. Recharge was obtained by multiplying annual rainfall in step 2 by 5%
5. The difference of annual precipitation and ET was calculated, this results negative values in areas where ET is exceeding Precipitation
6. Therefore, conditional statement was used to calculated surface runoff in areas where precipitation is greater than ET: if (annual precipitation minus ET> recharge) then Surface runoff= (annual precipitation minus ET minus recharge) or else Surface runoff=0
7. Step 5 assumes that recharge only occurs when the difference between precipitation and ET, exceeds 5% of precipitation.

Shashe Catchment is a major flow contributor Consistent with evidence presented on the preceding page using an alternate method, much of the runoff is generated from Shashe catchment (Figure 6.3). The Motloutse catchment also has good runoff. In general, the northern portions of the basin are areas of reasonable runoff. This may be due to high rainfall accompanied by step topography. However, the southern portion of the area which is relatively flat do not significantly contribute to

[6] ftp://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRPS-2.0

runoff volume. The Lower part of the Mzingwane and Bubi catchments generate only limited surface runoff.

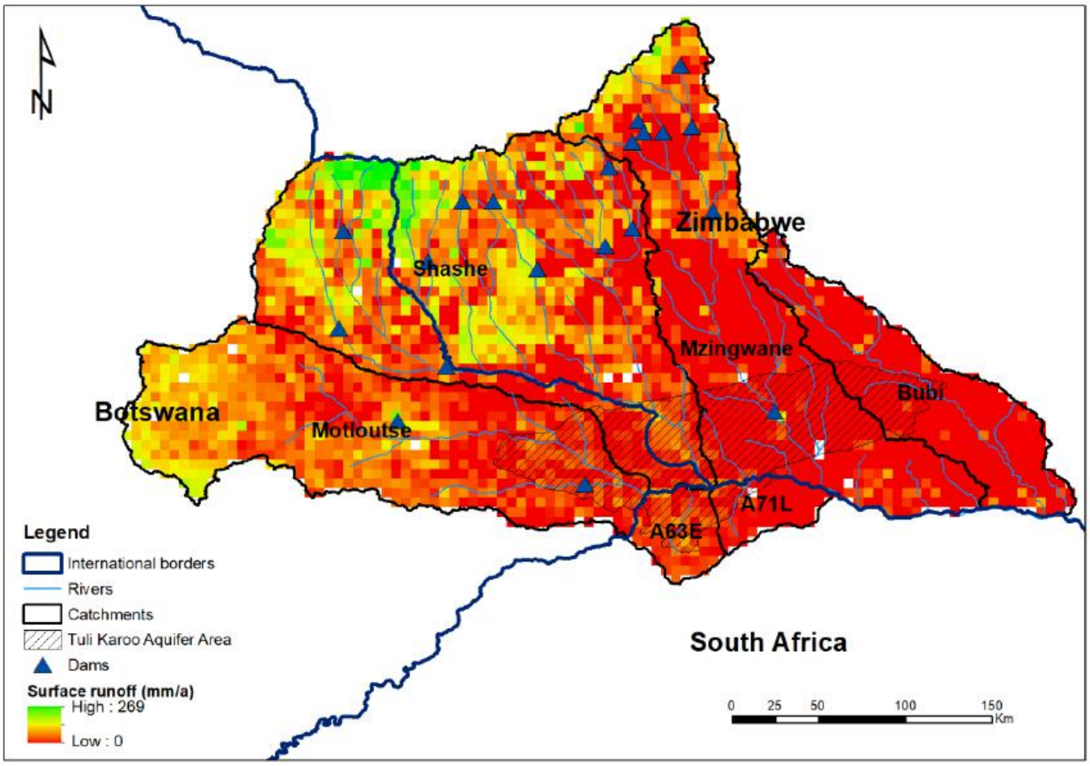


Figure 6.3: Surface Runoff in the Tuli Karoo System

Stream-flow Gauging Network There are 45 river gauging stations in the Tuli Karoo System (Figure 6.4), most of which are in Zimbabwe. The number of gauging stations in Botswana, South Africa and Zimbabwe, respectively, are 8, 2 and 35. Unfortunately, only a portion of these gauging stations are actively generating usable data. Among the 8 stations in Botswana, for example, only two currently generate data. Further, among the 35 stations in Zimbabwe, 26 generate only monthly data. South Africa has only two gauging stations both of which are located at Beit Bridge. To assess quality of data, streamflow gauging stations were classified into three classes based on record length, percentage of missing data and data availability (Figure 6.6). Stations with record length of greater than or equal to 30 years and percentage of missing data over the whole record period less than or equal to 25% is considered to be good and categorized as long-term continuous data. Except stations without data all the others are classified as stations with limited data. Among the 45 stations, 32 stations were classified as long-term continuous data. 25 out of the 32 stations are stations with monthly streamflow data[7]. There is a notable dearth of functional flow gauging stations near outlets of key catchments such as the Shashe, Motlouse, and Mzingwane.

7 Since streamflow in Botswana was only measured when the river is flowing and data is available for only for those days the following assumption was made during streamflow time series analysis: i) If no data is shown for a year (ie, entire year of blank cells) or long period extending beyond a year, we exclude that data for that period; ii) If there is data in a year but many blank cells, we assume those blank cells are zero flow.

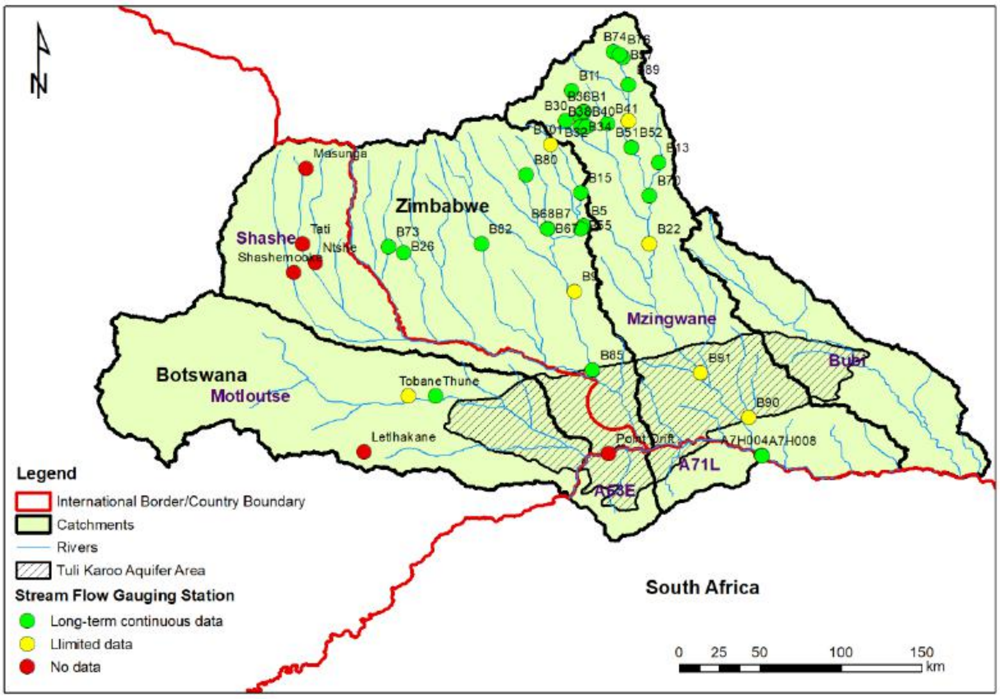


Figure 6.4: Streamflow Gauging Stations

Determining total runoff using observed streamflow data. Due to lack of streamflow gauging station at the catchment's outlet, estimation of total runoff was carried out using stream flow gauging station at the main stem of the Limpopo River (A7H004 and A5H008), at Beitbridge. The total runoff from the Tuli Karoo System is obtained as mean annual stream flow at A7H008 (downstream gauge) minus two points of inflow, just upstream of the study area (A5H006 and A6H005, not displayed as they are outside the study area) for the period of 2008-2013. This resulted in annual streamflow of 1243 million cubic meter (15.15 mm/a). Assuming baselow of index of 20% the total runoff from the Tuli Karoo System would be about 1502.88 mcm or 12.12mm/a. Since a portion of runoff generated in the catchment is impounded by surface reservoir/dams, the total runoff can be calculated as total runoff impounded (1402 million cubic meter) plus surface runoff computed as difference in in observed streamflow at the river gauging stations. The total dam storage capacity divided by catchment area results in runoff of 17.09 mm/a. Hence, the total runoff from the Tuli Karoo System is about 29.21 mm/a or 2645 mcm.

Comparison of surface runoff computed using global data and surface runoff determined from observed stream flow. The mean annual runoff for the Tuli Karoo System calculated in ARCGIS using Spatial analyst Tool called "Zonal statistics as Table based on spatial runoff shown in Figure 6.4 is about 37 mm/a or 3034 mcm. The total runoff computed using the observed streamflow data is about 29 mm/a or 2645 mcm. This shows that the runoff computed with the global data is roughly 27% higher than calculated surface runoff using observed streamflow data. This difference could be due to two reason: 1) underestimation of actual ET of MODIS16, 2) could be underestimation of surface storage like farm ponds, surface runoff to wetlands or depression storage etc. Even if the runoff calculated with global data show over estimation it provides spatial variability in runoff, which is not easy to find with measured streamflow data.

Flow Regulation and Water Resources Development There are currently 20 dams in the Tuli Karoo System, all concentrated in either Botswana or Zimbabwe (Figure 6.5). Five dams are located Botswana, and 15 dams are located in Zimbabwe. No dams are found in the South African portion of the system. Somewhat disappointingly, the level of coordination on planning and management of the dams in this shared context is not particularly high; dams are management to satisfy national objectives – typically irrigation and domestic water use. In Botswana, most of the water from two dams – Letsibogo and Digalthong – is channelled through pipelines called North-South Water Carriers, which transport water for domestic use in the urbanized southern portion of the country namely Gaborone, Palapye, and Mahalape. In Zimbabwe, irrigation is the more common use of stored water.

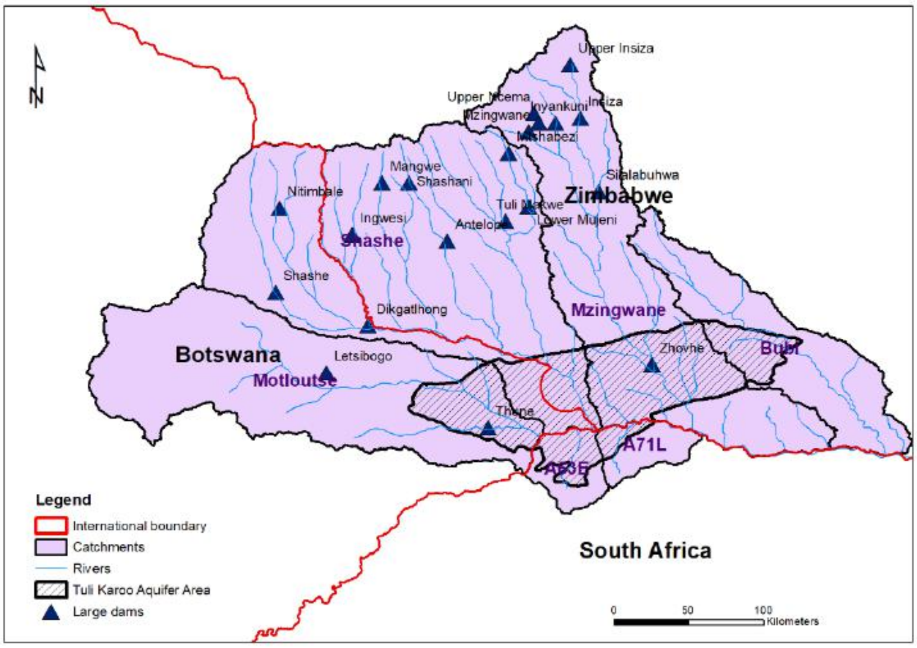


Figure 6.5: Dams in the Tuli Karoo System

Evolution of Dam Construction and Water Storage Dam construction began in the 1940s in the Tuli Karoo System (Figure 6.6). Through the 1980s, dam construction was exclusively to heavily concentrated in Zimbabwe. In the 1980s, the volume of water impounded in dams totalled just over 500 mcms. Between the 1990s and 2010s, most dam construction was in Botswana. By the end of the 2010s, the total capacity of water impounded in dams had nearly tripled from 1980s levels. The total volume now rests just under 15 000 mcms, divided about equally between water stored in Botswana and Zimbabwe. The magnitude of recent augmentation in storage spur questions about downstream impacts.

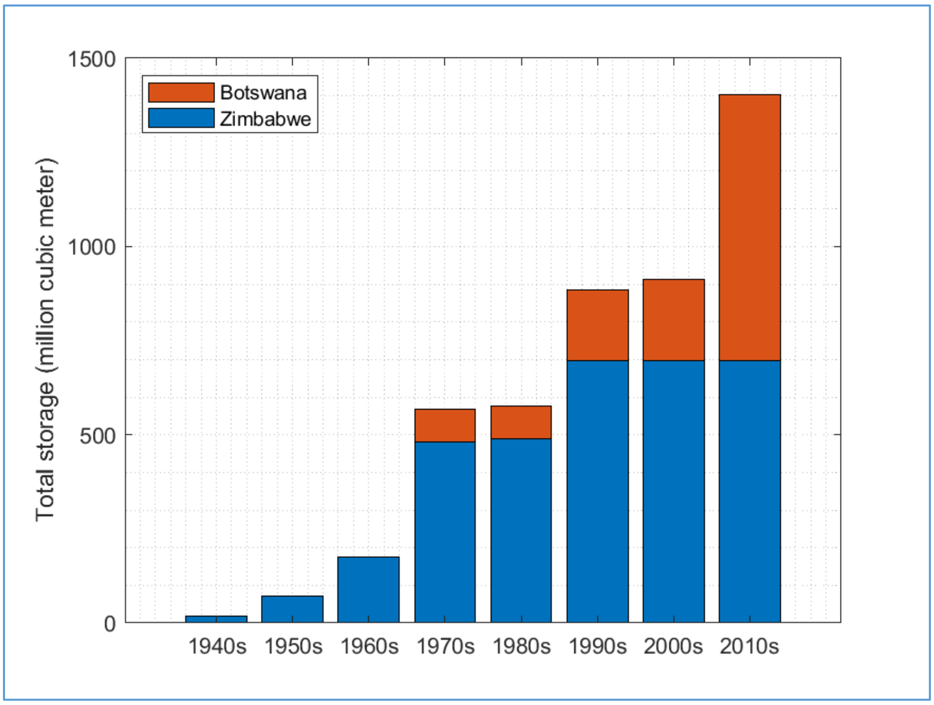


Figure 6.6: Volume of Water stored in dams in the Tuli Karoo System

Water Storage relative to Flow Overall, some 46 percent of annual runoff can be stored in dams in the Tuli Karoo System (Table 6.4). The Mzingwane catchment has the greatest proportion of runoff stored in dams, with more than 100% impounded. The Shashe catchment is able to contain about 39% of river flow, and Motlouse holds about 23%. No storage exists on the other three catchments in the system (Bubi, A71L, A63E).

Table 6.4: Water Storage Capacity relative to River Runoff

Catchment	Full dam capacity (million cubic meters)	Annual Runoff volume (million cubic meters)	Percentage of runoff stored in dams (%)
Mzingwane	514	360	140
Motloutse	190	820	23
Bubi	0	30	0
Shashe	698	1780	39
A71L	0	8	0
A63E	0	43	0
Total	1402	3040	46

Seasonality of Flow Mean monthly flows helps to illustrate typical seasonal variation in flow. Flow on the main stem of the Limpopo is much greater than the Shashe and Motloutse tributaries (Figure 6.7). The disparity in flow evidenced between that in the Limpopo and that on the two catchments, is likely explained by inflows from the Mzingwane and Shashe rivers. In a typical year, flow rates at most stations along the river begin to increase in November and December, and either remain high or continue to increase through April. Flow rates then decline between May through October. In Botswana streamflow, measurements are said to be carried out only when the river is flowing, hence all the other period flows were assumed to be zero. The seasonal variation is more pronounced in the Limpopo River, probably due to higher flow volumes. About 83% of the mean annual flow occurs between January and May.

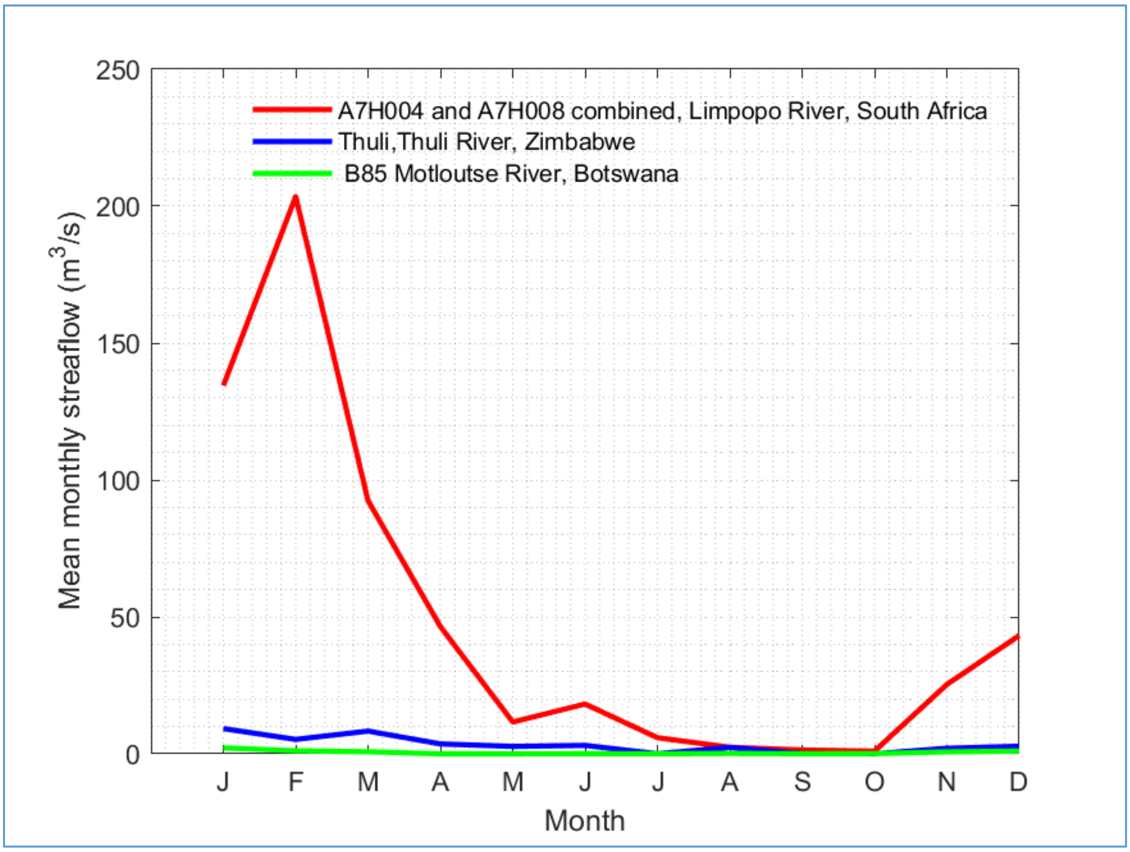


Figure 6.7: Mean Monthly Streamflow, 1995-2000.

Flow duration curve A Flow Duration Curve (FDC) is a graph that shows the percentage of time specified discharge were equalled or exceeded during a given period (Searcy, 1959). The shape of the FDC in the high flow regime indicate the type of flood regime the basin likely to experience and the shape in the low flow region shows the ability of the basin to sustain low flows during the dry seasons. The flow exceeded for 95% of the time is often used as the characteristic value for minimum river flow (Where abstraction is prohibited to guarantee environmental flow requirement). FDC is a key tool for the design of irrigation, hydropower and to determine minimum flow requirements in the river for dilution of domestic and industrial discharges (World Meteorological Organization, 2008).

Flow Duration Curve for Limpopo River shows flow reduction A FDC was constructed for Limpopo gauging stations near Musina (A7H004 and A7H008) using daily discharge data measured for the periods of 1955-1992 and 1992-2014, respectively (Figure 6.8). It is important to note that available data regardless of years with missing data was used for FDC construction. In the 1955-1992 period, 95% of the time, flow in the river is equal to or exceeds 0 m^3/s. 50% of the time the flow in the river equals or exceeds 2.13 m^3/s. 5% of the time flow in the river is equal to or exceed 319 m^3/s. in the 1992-2014 period, 95% of the time flow in the river equals or exceeds 0 m^3/s; 50% of the time the flow in the river equals or exceeds 1.26 m^3/s; and 5% of the time flow in the river is equal to or exceed 212 m^3/s. Comparing the two periods, the 5% and 50% exceedance shows a significant reduction (33 and 41%, respectively).

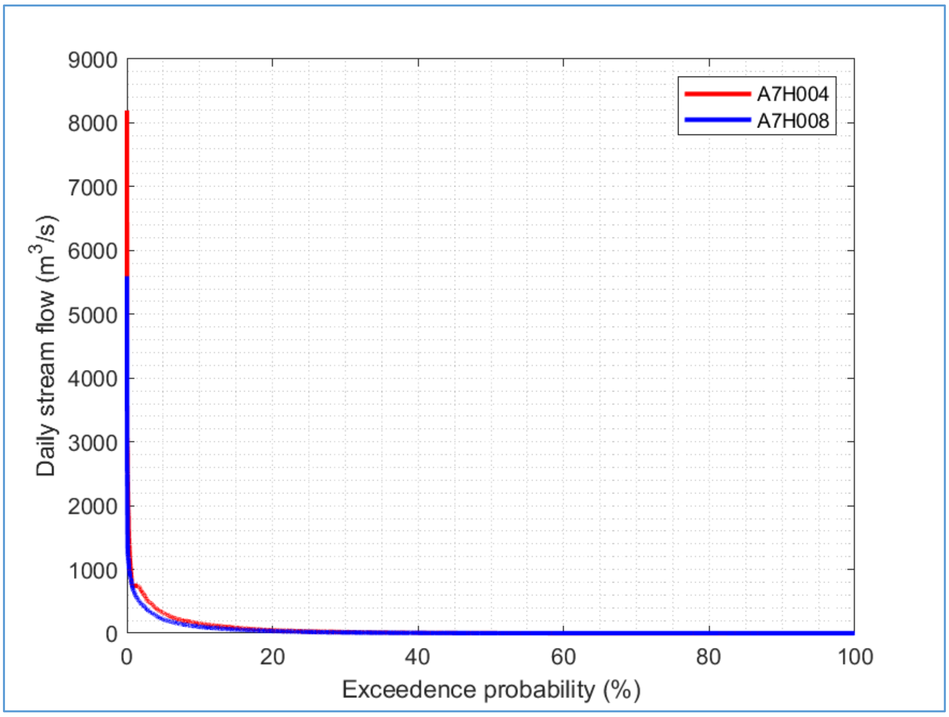


Figure 6.8: Flow duration curve at A7H004 and A7H008 Limpopo gauging station at Biet Bridge

Long-term Trends in Flow A non-parametric, rank-based Mann-Kendall Trend test was used to test the presence of trends in annual streamflow, and number of zero flow days in a given year. Trend analysis was conducted at 32 gauging stations. Among the 32 stations analysed, 8 stations showed statistically significant decreasing trend in annual streamflow and statistically significant increasing trend in number of zero flow days in a year at significance level of 5%. Figure 6.9 shows the location of the 8 gauging stations where trend is detected.

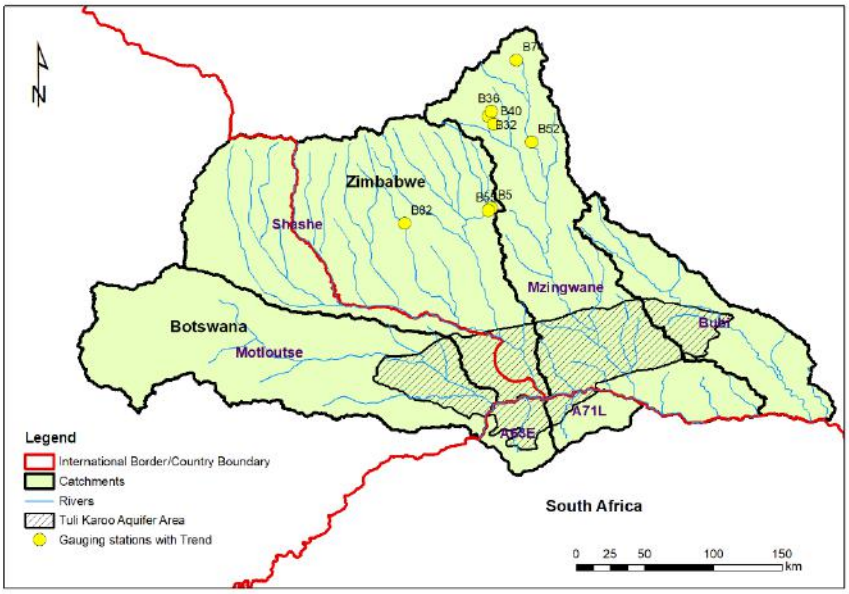
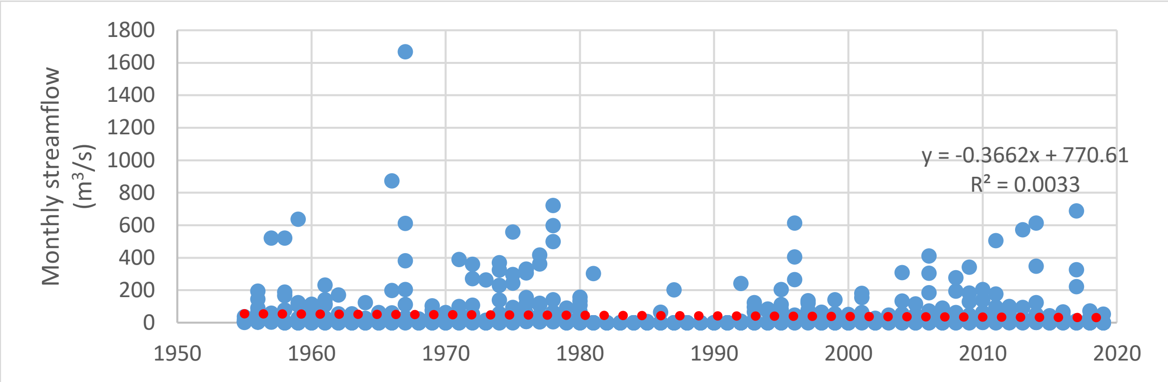
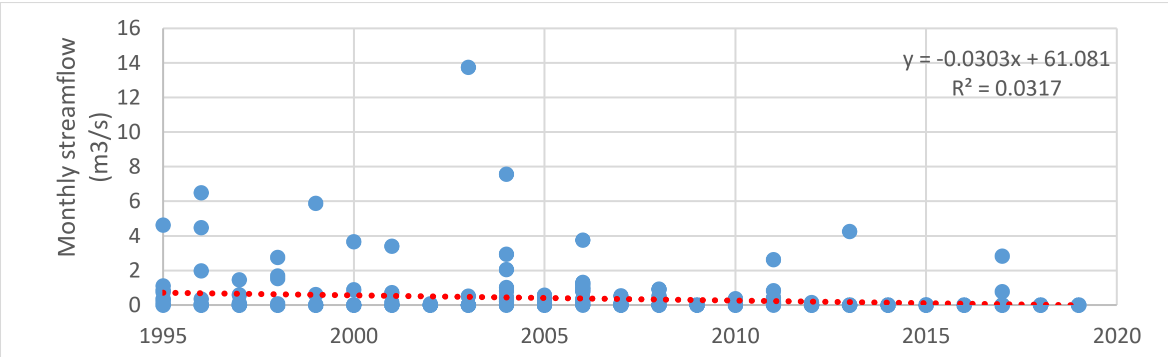


Figure 6.9: Location of gauging station where statistically significant decreasing trend in annual streamflow and increasing trend in number of zero flow days is detected

Trends associated with water resources development were difficult to detect Although a significant decreasing trend in annual streamflow and no-flow days is detected in upstream portions of tributaries in Zimbabwe, flow trends on the main stem of the Limpopo River at Biet Bridge or in the Motloutse catchment (Figure 6.10a and b) were – while decreasing – not significant. Lack of a significant trend may be explained by a strong influence of upstream inflow on the main stem at Beitbridge or, perhaps more likely, because the effects of reductions in flow on downstream portions of the Motloutse and Shashe tributaries, and subsequently along the Limpopo's main stem, have been most acutely felt by reductions in agricultural area cultivated upstream of the Musina/BeitBridge – allowing meagre yet stable volumes of water to continue to flow downstream.



(a)



(b)

Figure 6.10: (a) Flow on the Limpopo at Musina (A7H004 and A7H008 combined) and (b) Flow in Moutlotse Catchment at Thune

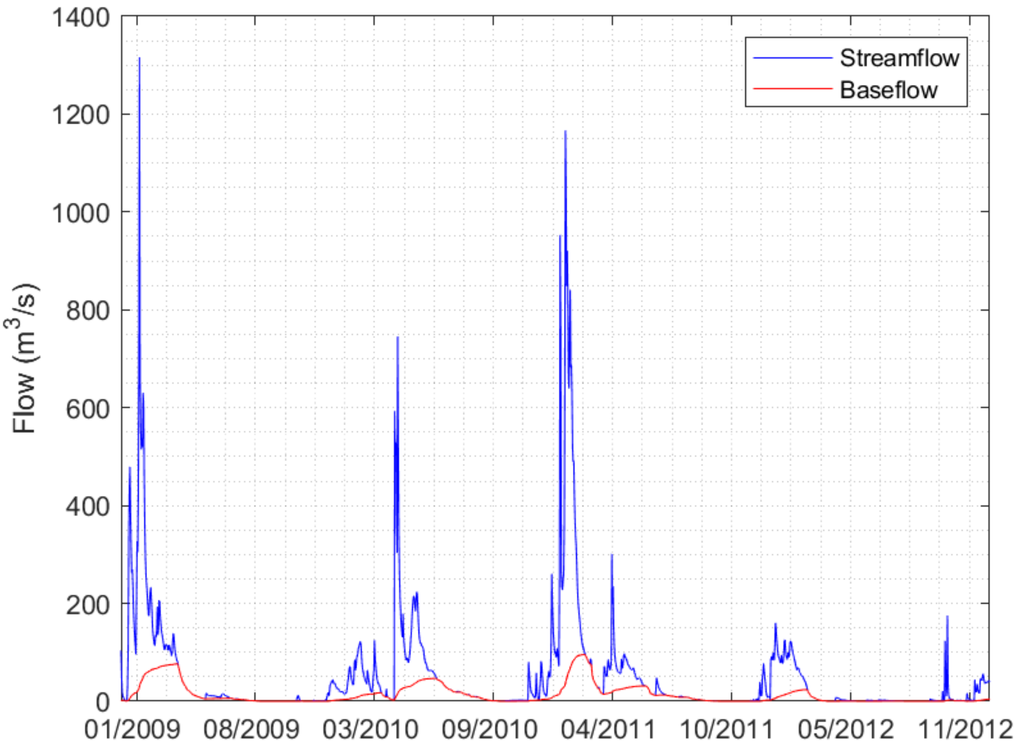
6.2 Surface-Groundwater interactions

Mechanisms of surface-groundwater interactions Groundwater and surface water are hydrologically linked. Groundwater discharge/ baseflow keep stream flowing during dry period. According to Winter (1998), streams interact with groundwater in three basic mechanisms: stream gain water from groundwater, stream loss water to the groundwater or stream gain water in certain reach of the river while losing in other. The elevation of the groundwater table in the vicinity of the stream must be higher than water level in the stream for a stream to gain water. If the groundwater at the vicinity of the stream is lower than the streambed elevation the river is losing water to the groundwater. If the groundwater level has large variations during a year a stream segment could receive water from groundwater for a portion of the year and loss water to groundwater at other times.

Understanding interactions Understanding surface-groundwater interactions has practical consequences in the quantity and quality of water in either system in the sense that depletion and/or contamination of one of the systems will eventually affect the other one. Quantifying surface-groundwater interaction can be very challenging due to significant time difference between the two processes. Surface water is temporally highly variable while groundwater is less variable in time. Estimating surface-groundwater interaction during flooding events require hourly to sub-hourly streamflow and groundwater level data (Ebrahim et al., 2013). Estimation of groundwater contribution to streamflow using hydrograph separation is one method of assessing surface – groundwater interaction (Kalbus et al., 2006). Environmental tracers such as stable hydrogen and oxygen isotopes and radioactive 222Rn are useful for analysing surface –groundwater interaction and hydraulic connectivity between the two systems. Since these data were not available surface-groundwater interaction is quantified using baseflow contribution to streamflow.

Defining Baseflow *Streamflow* in a catchment is composed of a rapid response component and a slow or baseflow component derived from groundwater (Brodie and Hostetler, 2005). A rapid response component often known as quick flow component occur due to overland runoff as a direct response of rainfall events, interflow- lateral movement in the soil profile and direct precipitation- direct rainfall on to the stream surface. Baseflow is the component of streamflow that can be attributed to ground-water discharge into streams (Brodie and Hostetler, 2005). Baseflow index (BFI) is the ratio of baseflow to total flow calculated from a hydrograph separation procedure (either on an annual basis or for an entire observation period, determined as the ratio of total baseflow volume to total streamflow volume (Smakhtin, 2001)). Information on BFI is required for many purposes including water use allocation, determining the assimilative capacity of streams, preservation of aquatic life, understanding groundwater-surface water interactions, and hydrological model calibration (Winter, 1999, Smakhtin, 2001, Gebert et al., 2007, Santhi et al., 2008b). BFI provides a systematic way of assessing the proportion of baseflow in the total runoff of the catchment (Abebe and Foerch, 2006). BFI value can be zero, if no baseflow (Smakhtin et al., 1995, Smakhtin and Watkins, 1997a) or range from 0.15 to 0.2 for an impermeable catchment with a flash flood regime to more than 0.95 for catchments with high storage capacity and a very stable river with a high baseflow proportion (Gustard et al., 1992, WMO, 2008).

Calculating Baseflow The recursive digital filter method introduced by Nathan and McMahon (1990) was used to separate the baseflow from streamflow. The technique is not physically based but provide an objective and automated solution for baseflow separation (Nathan and McMahon, 1990). Arnold et al. (1995) compared the performance of the recursive digital filter with manual separation techniques and baseflow separation with the PART model over 11 watersheds in USA. Their results showed that the annual baseflow estimated with the filter method was in good agreement with the baseflow obtained using the other two methods. The value of the filter parameter (β) needs to be determined for application of the algorithm. According to Nathan and McMahon (1990), the value of this parameter ranges from 0.90 to 0.95, while a β value of 0.925 is recommended as optimal. For the present study, we used a filter parameter value (β = 0.995) tested in previous studies in South Africa (Smakhtin and Watkins, 1997b). More recently, Ebrahim and Villholth (2016) applied the same value to assess BFI for 21 selected quaternary catchments in South Africa.



6.11 Baseflow relative to Streamflow, Limpopo River at Beitbridge

Potential Contributions of Groundwater to Surface flows in the Tuli Karoo System: Applying past approaches (Ebrahim and Villholth, 2016), BFI at the main stem of Limpopo River at Beitbridge gauging station A7H004 and A7H008 (Figure 6.11), Limpopo River South Africa, B85 Thuli River, Zimbabwe and Thune River, Botswana gauging stations. Results shows that BFI was 0.24, 0.22 and 0.01, respectively. This means aquifers are estimated to contribute between 0.1-24 percent of the total annual river flow. The low BFI signifies the contribution of groundwater to total streamflow is low. Streamflow is not sustained by groundwater discharge during dry period particularly in the Tune River Botswana. According to Love et al. (2010), studies in Zimbabwe the presence of an impermeable clay layer that limits percolation and depression storage results in low baseflow. Discharge is drops to zero very quickly after a flooding event. Santhi et al.(2008a) demonstrated that there was a strong positive correlation relationship between percentage of sand in the soil and BFI.

6.3 Surface Water Quality

Ambient water quality

Data to assess ambient water quality There was no data available to assess surface water quality on the South African side while for the remaining countries the data collection was fairly recent – as recent as 2019 with the oldest data being taken in 2013. Standard water quality parameters such as dissolved oxygen ,temperature, pH Electrical, conductivity, total dissolved substances, carbonate, chloride, sulphate, nitrate, potassium, calcium, magnesium, hardness and turbidity are monitored.

Data in Botswana and Zimbabwe 9 points were sampled in Botswana in December 2018 and forty eight (48) sampling points in the Zimbabwe were sampled in January to June 2019. The sample points were not assigned any coordinates but only the name of the source (surface water). The water quality parameters maximum and minimum values for the aforementioned periods were compared to the WHO water quality standard.

Table 6.5: Water Quality Parameters for Botswana (December 2018) and Zimbabwe (January 2019)

Constituent	Concentrations Zimbabwe (January 2019)			Concentrations Botswana (December 2018)			Recommended standard (WHO)
	Minimum	Maximum	Average	Minimum	Maximum	Average	
Temperature, °C	-	-	-	24.9	25.5	**25.00**	**Ambient** **-No guideline**
Dissolved oxygen, mg/L	14.1	78.5	53.38	-	-	**-**	**>5**
pH	6.67	9.16	8.1	6.74	9.56	**8.01**	**6.5-9.5 (for drinking water)**
Electrical conductivity, mg/L	69	1595	278.47	200.2	316.3	**188.17**	**700-3100**
Total dissolved solids, mg/L	2342	6820	3121	101.27	149.44	**104.89**	**500-1500**
Inorganic Macro-determinants							
Carbonate (as CO_3^{2-}), mg/L	-	-	-	-	-		**<500**
Bicarbonate (as HCO_3^{2-}), mg/L	-	-	-	-	-	**-**	**No guideline**
Chloride, mg/L	17	268	43	-	-	**-**	**<250**
Sulphate (as SO_4), mg/L	<1	14	3.33	-	-	**-**	**<250**
Nitrate (as NO_3), mg/L	0.14	2.05	2.02	-	-	**-**	**45-500**
Sodium, mg/L	-	-	-	5	205.81	**101.34**	**100-400**
Potassium, mg/L	-	-	-	1.77	6.83	**4.33**	**25-100**
Calcium, mg/L	-	-	-	24.61	118.22	**56.70**	**75-200**
Magnesium, mg/L	-	-	-	0.01	160.65	**13.45**	**30-150**
Total Hardness, mg/L	450	484	466	-	-	**-**	**<300**
Total Alkalinity, mg/L	76	432	240.5	-	-	**-**	**<300**
Turbidity, NTU	-	-	-	0.22	4.65	**0.37**	**<5**
Suspended sediments, mg/L	378	972	614	-	-	**-**	**<5.5**
Phosphate, mg/L	0.05	0.62	0.43	-	-	**-**	**15.3**

Water Temperature Temperature data which was only available for Botswana, ranged from 24.9 to 26.1 degrees Celsius (Table 6.5), the highest temperature being recorded at Selibi Phikwe raw water.

Temperature is an important water quality parameter since it influences water's ability to dissolve substances. Furthermore, it affects the rate of reactions within the water as well as biological activity.

Dissolved oxygen A measure of gaseous oxygen dissolved in an aqueous solution, is a requirement for natural stream purification that provides for aerobic life forms. The dissolved oxygen levels for January in Zimbabwe were between 14.1 mg/l and 78.5 mg/l which was higher than the minimum standard of 5 mg/l.

Total dissolved solids (TDS) Botswana had low total dissolved solids quantities compared to Zimbabwe whose values exceeded the maximum permissible limit. The TDS comprising of inorganic salts and small amounts of organic matter .The TDS values recorded were from water near Beit bridge colliery, which was likely the cause of the elevated values from water used in the mining operations.

Total hardness It is a measure of polyvalent metallic ions mainly calcium and magnesium, while expressed as milligrams of calcium carbonate per litre (World Health Organisation, 2011).Zimbabwe had a total hardness exceeding the standard quality parameters and classified as very hard. This implies the water might have been affected by acid mine drainage from the Beit Bridge coalmine as the samples were taken near that point.

pH Data from Botswana and Zimbabwe show pH values within the WHO water quality standard range. Botswana has a range of pH 6.74 to 9.56 in December, which is in the middle of its rainy season. Zimbabwe also shows a similar range of 6.67 to 9.16 in January which is also the rainy season time. The pH, which is a measure of hydrogen acidity/alkalinity of a water sample, has effects on the ionic and osmotic balance of aquatic life.

Electrical conductivity It measures the capability of water to conduct an electrical current which is a result of inorganic macro determinants (carbonates, nitrates, calcium) which carry an electrical charge. Electrical conductivity for Botswana and Zimbabwe was within acceptable limits, with Zimbabwe having values of up to 1595 µS/cm. Increase beyond the set standard has potential to alter the ecological structure of the ecosystems by eliminating species not suited for that increase.

Pollution Sources

Agriculture Commercial irrigation activities along the Shashe and Limpopo rivers rely on groundwater from alluvial aquifers. Irrigation return flow will typically have high levels of nutrients associated with fertilizers and contaminants from pesticides/herbicides. The aforementioned can find their way back to the river and ultimately the aquifer through groundwater-surface water interactions. Further investigations should target the sampling and analysis of soils and water in the irrigated farms. In South Africa, citrus farming on the banks of the Limpopo, which is a high production venture and is set to increase (Sikuka, 2019). Botswana has the Tuli block farms west of the Motloutse River as the main source of agricultural pollutants (UNDP/World Bank Energy Sector Management Assistance Program, 1987).

Mining Generally mining activities might reduce groundwater quantities and cause groundwater deterioration. Mine dewatering might cause cones of depression large enough to affect other states especially rural communities. Furthermore, mining activities are associated with various contaminants, which have a potential to affect shallow aquifers such as the alluvial aquifer system the mines intercept. Botswana has mines such as Tati and BCL mine, which are both no longer operational but the risk for pollution from mining last long after cessation of mining activities. Studies done on heavy metals and Sulphur concentration on soils especially on the downwind side of the BCL mine show elevated levels, which ultimately reach water sources through precipitation (Letshwenyo, 2016).

In South Africa, there is the Venetia diamond mine while Zimbabwe has the Beit bridge colliery company. Acid mine drainage a process were by substances such as iron sulfide are oxidized due to being exposed to air and water by mining leads to acidic waters containing heavy metals which pollute surface waters (Akcil & Koldas, 2006)

Textile industry Wastes and effluents from the textile industry contain heavy metals such as copper, chromium, cadmium, lead, nickel, molybdenum and arsenic (Sakamoto, Ahmed, Salma, & Huq, 2019). The Botswana side of the Tuli Karoo has textile industries in the form of B&M in Tonota discharging into the Shashe River and Nortex in Francistown discharging into mambo waste treatment plant, which ultimately discharges into Tati River.

Abbatoirs The environmental effects of abattoirs are a result of their operation and waste disposal. They have the potential to produce solid waste and wastewater that has a biochemical oxygen demand. Furthermore, the blood, manure ,hair, fat and bones common to the industry has a high likelihood of harboring diseases that might make it to water bodies and thus are classified as industrial wastes by UNEP (Olawuni, Daramola, & Soumah, 2017). The Botswana side of the study area has textiles in the form of Bobby's chicken abattoir discharging waste into Tati River, Richmark discharging into minor tributaries that lead to Thune River and Dudex discharging its waste into Mambo waste treatment plant, which ultimately reaches Tati River (Moreki, 2011).

Aquatic Weeds

Aquatic weeds Aquatic ecosystems in southern Africa have been under threat by aquatic alien invasive plant species such as the salvinia (Salvinia molesta),water lettuce(Pistia stratiotes) and water hyacinth(Eichhornia crassipes). The basin has been especially vulnerable to the water hyacinth which infested the Limpopo river in 2010 from the Hartbeesport dam in South Africa (Kurugundla et al., 2016). Indigenous to tropical Amazon basin in South America the water hyacinth is a free floating tropical plant that has spread throughout the world. The invasion and proliferation of these invasive species targets nitrate and phosphate enriched water as a result of eutrophication. During the off flood season of April to November it occurs in stagnant waters of small dams in the Limpopo river between Martins drift and Zanzibar. During the flood season of December and March flash floods wash it all the way through South Africa and Zimbabwe even up to the Indian Ocean (Kurugundla et al., 2016).

Impact of aquatic weeds Aquatic weeds disrupt water flow in river channels, canals, drains which ultimately derailing downstream irrigation, slowing drainage of floodplains, suppression of indigenous aquatic vegetation, navigation, entrap sediment and fishing impediments (Africa Groundwater Network, 2011). Despite the evidence of availability of invasive species and aquatic weeds in the Limpopo basin, there is little data specifying how the Tuli Karoo has been directly affected by invasion of these species.

Methods to mitigate aquatic weeds Discovery of the water hyacinth floating from Crocodile River led to the Botswana Department of Water Affairs alerting the South African department of environmental affairs. The two countries through joint workshops between 2010 and 2013 resolved to tackle the threat through the development of management plans. A pilot program was initiated in 2012 with a helicopter survey from Martins drift to Seleka farms. As a result of this survey between 2012 and 2014 dense manifestation of the invasive species were physically removed (Kurugundla et al., 2016). Despite these commendable efforts, there is still lack of data on the impact of invasive species and aquatic weeds on the environment, and how the current efforts have addressed the water quality problems related to invasive species.

6.4 Key Messages

The review of the surface water resources of the Tuli Karoo System reveals important considerations for shared water management. Key messages are as follows:

- ***There has been substantial recent (1990-) development on three main catchments in the Tuli Karoo*** Three catchments – Motloutse, Mzingwane, Shashe – contribute more than 90% of flow to the Tuli Karoo System. There has been considerable development on these catchments since 1990.
- ***Recently-undertaken water resources development may manifest a lost opportunity***. While the increased water availability generated through water storage augmentations is positive, it appears that development were undertaken unilaterally. Additional gains may have been able to be achieved through greater collaboration among countries sharing the Tuli Karoo System (e.g., through LIMCOM).
- ***Downstream impacts of water resources development are unclear*** While a significant and decreasing trend in annual streamflow was observed in some upstream portion of Mzingwane and Shashe catchments, flow trends on the Limpopo River at a relatively downstream point in the Tuli Karoo System – while decreasing – were not significant.
- ***Baseflow is negligible and rivers of the Tuli Karoo System are likely "losing"*** Based on baseflow analysis, rivers of the Tuli Karoo appear to contribute (or "lose" water) to groundwater. Surface flows are therefore key to sustaining groundwater levels, and reductions in surface flows may have impacts on groundwater availability
- ***There is need for improved monitoring*** Ultimately, there appear to be key changes in water storage and use in the Tuli Karoo System. Review of results based on current data provide clues of potential impacts, but more comprehensive monitoring program would allow for far greater clarity. In particular, streamflow gauging stations near the outlets of tributaries such as Motloutse, Mzingwane and Shashe – downstream of water storage infrastructure – would constitute an important step forward.

7. Land Use and Land Cover

Land Use and Land Cover in the Tuli Karoo This chapter is focused on assessing the land use and land cover across the Tuli Karoo System, with particular focus on the Tuli Karoo Aquifer Area. In the first section of this chapter, land use land cover data obtained from each country are integrated and discussed. In the second section, global land cover data was clipped to the Tuli Karoo to enable a harmonized picture of land cover in the Tuli Karoo System. In the third section, irrigated area is assessed based on global data. In the fourth and fifth sections, Transfrontier Conservation Areas and mining activities, respectively, are presented.

7.1 Land Use and Land Cover: Integrating Country Data

Distinguishing land use and cover Land use and land cover are often used interchangeably, but they are different. Land use refers to how land is utilized for different activities, such as human development which transforms the functional role of land for productive use (Lambin et al., 2003). By contrast, land cover represents natural and human features that cover the earth's surface such as natural vegetation, forest, wetlands, human construction such as building, roads and other infrastructures. Drivers of Land Use and Land Cover Change (LULCC) can be catrogized broadly into two groups: those relate to humana activites and those originating from natural forces (Cotillon and Tappan, 2016). Human activites related LULCC could be due to the following four reasons (Verheye, 2009): i) expansion of arable land in order to meet the increasing food demands for a growing population (agricultural intensifications), ii) rapid development of urban and suburban areas, iii) deforestation and loss of pasture lands in favour of (mainly) agricultural and urban areas, and iv) protection of the environment resulting in the creation of nature reserves.

Integrating data from the three countries To assess land use and land cover in the Tuli Karoo, maps (GIS shape files) were obtained and synthesized from the three countries (Figure 7.1). It is important to note that Figure 7.1 shows land use for Botswana and Zimbabwe, while for the South Africa land cover is shown due to lack of land use data. The land cover for South African portion of the Tuli Karoo system is obtained from National land cover map produced in 2014. For the land use data obtained from Botswana and Zimbabwe the map date is unknown. Due to incomplete national land use datasets (for example, the South African portion) and different method used by each country to create the land use data and legend classification it was not possible to make summary of the domain land use for the Tuli Karoo System based on data obtained from the member states. However, it was believed that providing summary of land use figures for Botswana and Zimbabwean side and land cover map for South African portion provides an idea of the dominant land use or land cover of Tuli Karoo System per country.

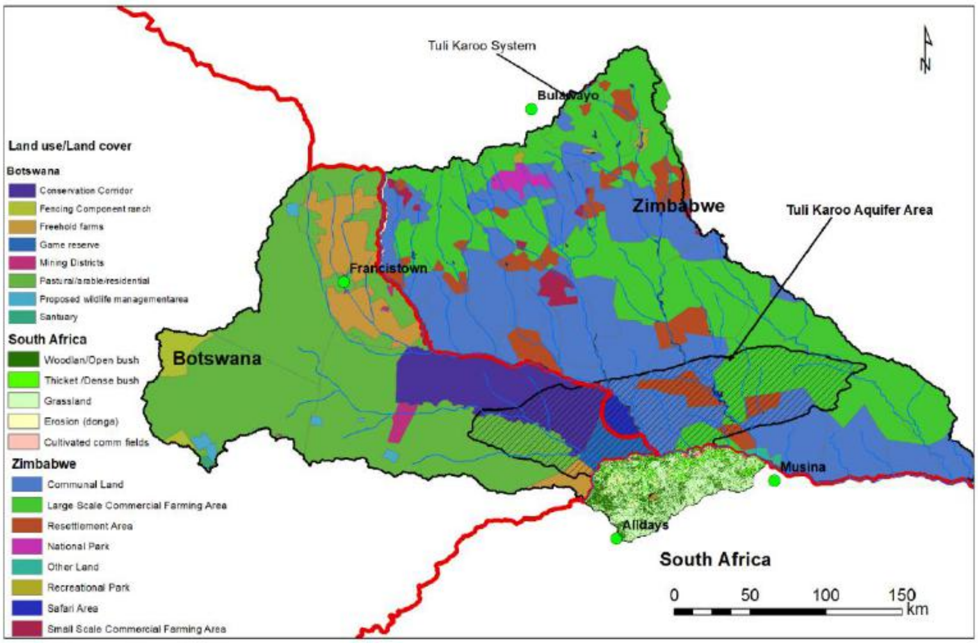


Figure 7.1: Land Use and Land Cover of the Tuli Karoo (Source: Member countries)

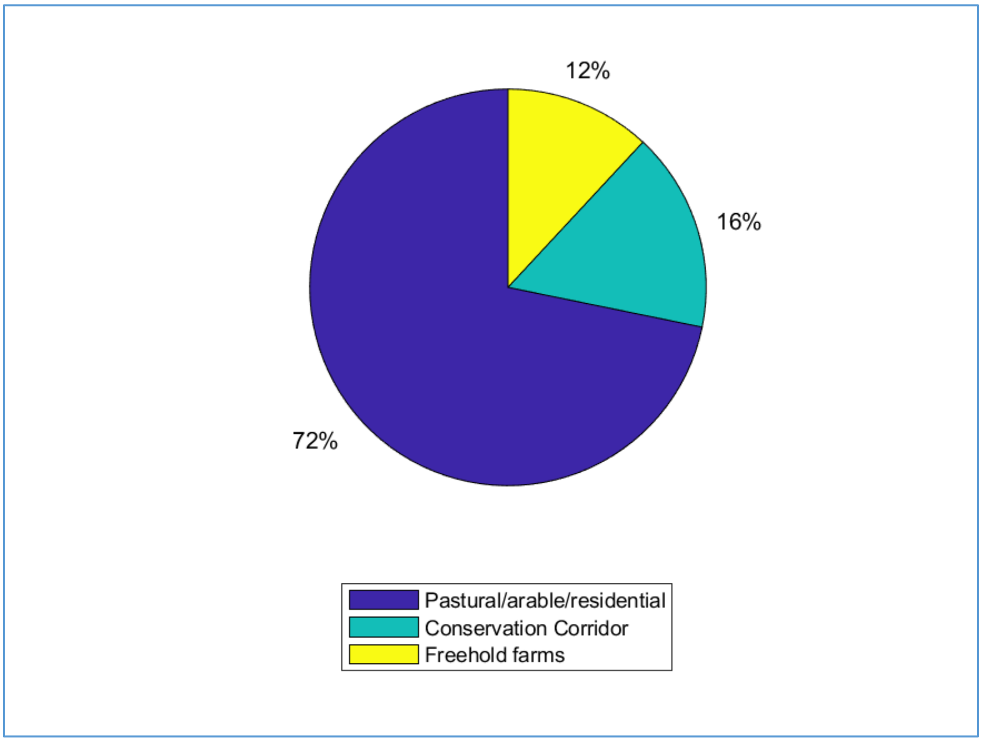


Figure 7.2: Land Use of Tuli Karoo System, Botswana portion Classes (>3% of area)

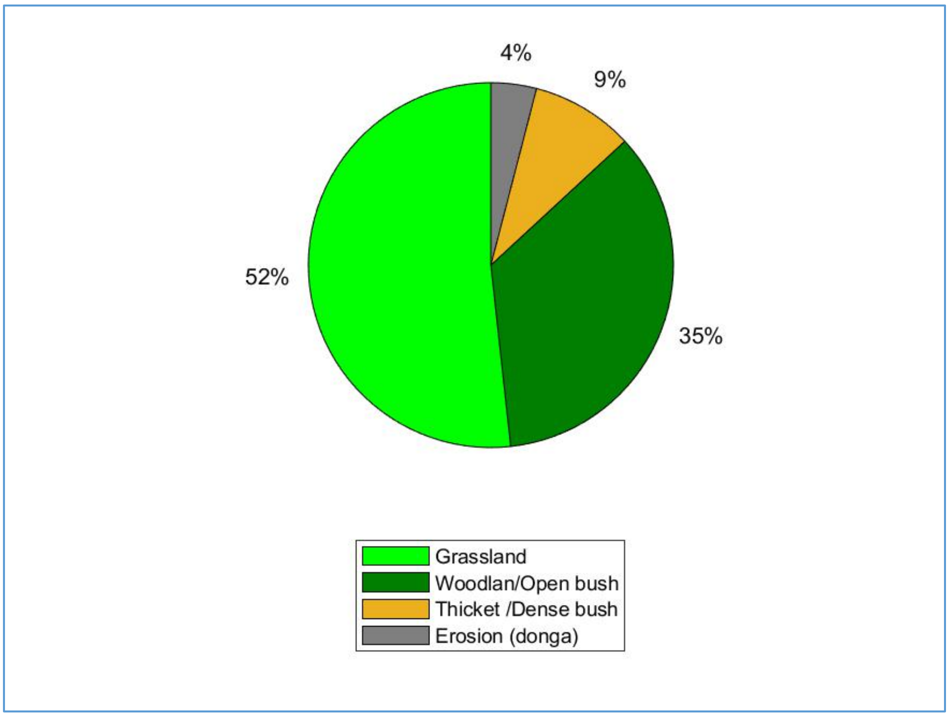


Figure 7.3: Land Cover of Tuli Karoo System, South African portion Classes (>3% of area)

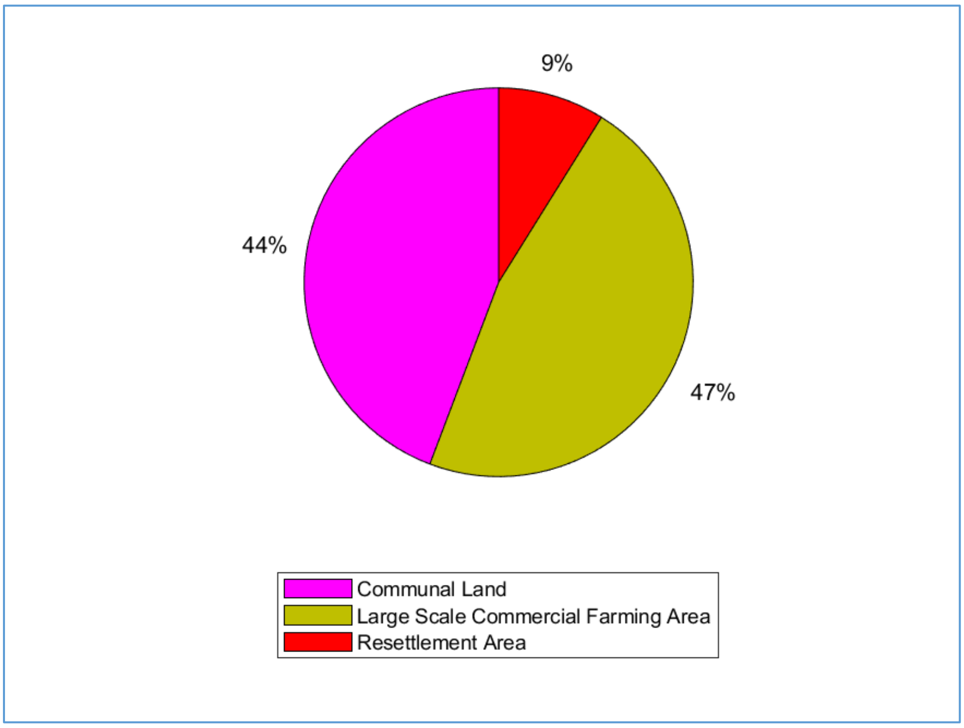


Figure 7.4: Land Use of Tuli Karoo System, Zimbabwean portion Classes (>3% of area)

The Tuli Karoo System is rural. Reflecting its rural nature, land in the Tuli Karoo System is often used for pastoral purposes, farming, and as grassland (Figure 7.1). The Shashe and Mzingwane catchments in Zimbabwe are predominantly used for communal land while the Bubi is mainly used for large scale commercial farming. The upper part of the Sashe and Mzingwane in Zimbabwe are dominantly used for large scale commercial farming. The Motloutse catchment in Botswana is mainly used for pasture, arable land and residential area The dominant land use type in Botswana is pasture, arable and residential areas (Figure 7.2). In South Africa, the dominant land cover is grassland and wood land and bushes (Figure 7.3). In Zimbabwe, the dominant land uses are communal land and large scale commercial farming (Figure 7.4).

7.2 Land Cover: Global Data

Drawing on global data to standardize land cover classes across countries. To generate a common picture of land cover in the Tuli Karoo Aquifer System, land cover map for the study area was extracted from European Space Agency (ESA, 2016) . The land cover map was produced from Sentinel-2A observations from December 2015-Decmeber 2016. The Sentinel based Africa land use and land cover map (20 m resolution) consists of 10 classes.

Tuli Karoo System is heavily covered by shrubs As shown in figure 7.5, approximately 60% of the Tuli Karoo System is covered by shrubs. About 21% of the shrub area is in Shashe, 18% in Motloutse and 13% in Mzingwane catchment. Presence of shrubs coverage may protect the soil from surface runoff. Root systems of vegetation tend to enhance soil porosity and permeability. Vegetation increase infiltration by three mechanisms: by retarding surface water movement, by reducing rain drop compaction, and by increasing organic matter content, bulk density and surface horizon depth (Adams et al., 2003). In Nyazvidzi catchment (Zimbabwe), a decrease in forest and shrubs cover by 36% was evidenced between 1984 and 2013, concomitant with an increase in cultivated land by 13% over the same period (Gumindoga et al., 2018). This is expected as forest areas in many places are converted to cultivated land due to lack of arable land and with the aim of increasing agricultural productivity to feed increasing population. Change in land use land cover can have a wider range of environmental consequences including: soil erosion due to deforestation, agricultural pollutants (e.g. pesticides, nitrate, and phosphate), loss of habitat, etc. Soil erosion can lead to silting of stream, lakes and other waterbodies. According to Mufute (2012) studies about 68% of small reservoirs in the Mzingwane catchment were affected by erosion. To combat soil erosion and increase water availability various soil and water conservation technologies are being tested in Mzingwane catchment (Mupangwa et al., 2006).

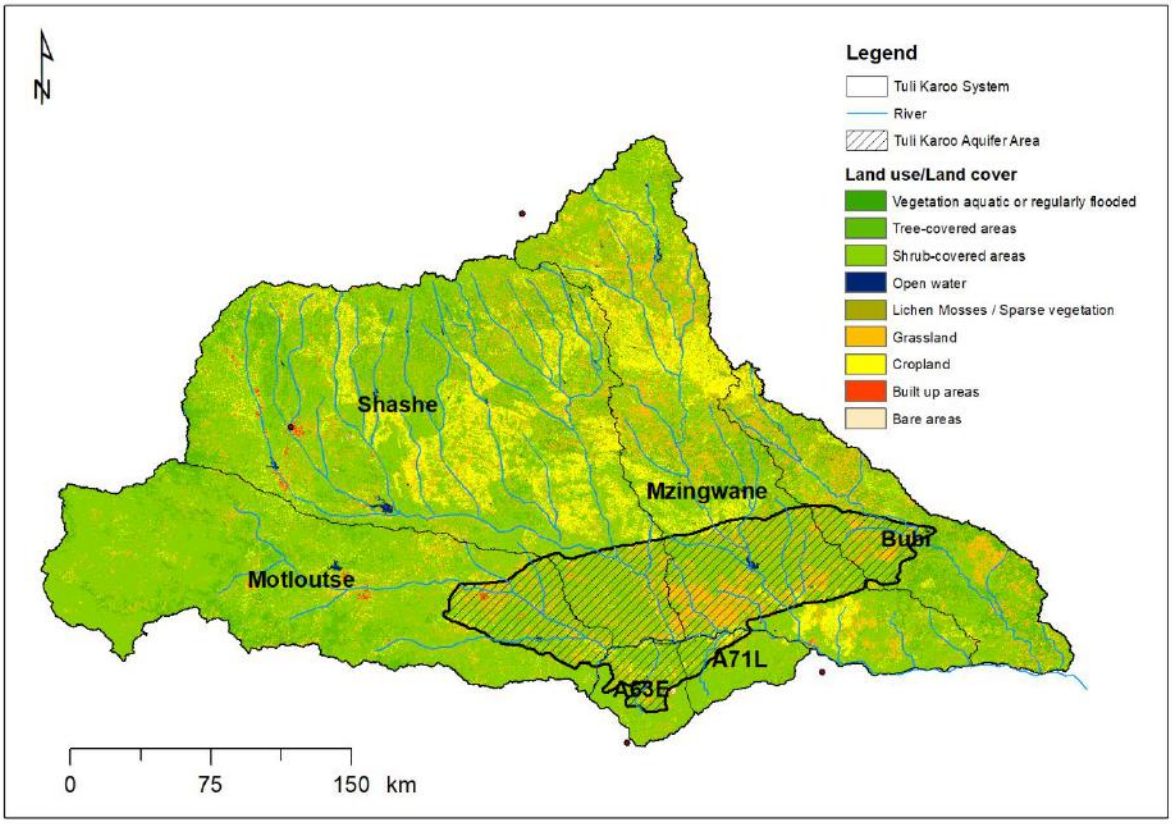


Figure 7.5: Land Cover, Tuli Karoo System (Source: ESA, 2016)

Shrubs and Grasslands predominate in the Tuli Karoo As noted, about 60% of the Tuli Karoo System and 67% of the Tuli Karoo Aquifer Area is covered by shrubs (Figure 7.6). Grass land cover accounts about 16 and 26% of the Tuli Karoo System and Tuli Karoo Aquifer Area, respectively. Figure 7.7 show typical land cover in the Tuli Karoo Aquifer Area. 11% of the areas is cropped in the Tuli Karoo System only 4% in the Tuli Karoo Aquifer Area.

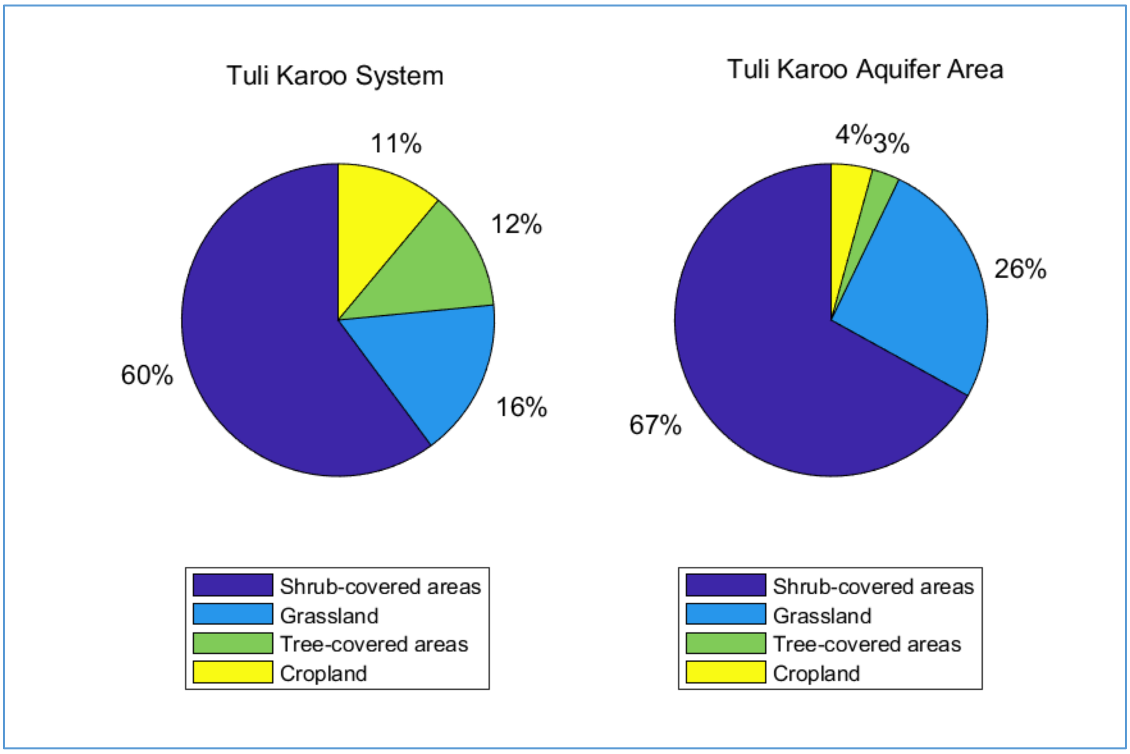


Figure 7.6: Percentage of area covered by different land use and land cover types

Figure 7.7: Mapungubwe National Park, typical land cover of the Tuli Karoo Aquifer Area (Photo Credit: Resego Mokomela)

7.3 Irrigated Area

Drawing on global remote satellite data to estimate irrigated area in the Tuli Karoo. IWMI (2010) irrigated area maps – based on 16-day MODIS 250 m Normalized Difference Vegetation Index (NDVI) composites images (MOD13Q1) – were used to analyse the seasonal vegetation trends, the agricultural areas were categorized into irrigated and rain fed. By analysing the cyclic nature of vegetation change in agricultural systems, agricultural areas with multiple cropping cycles were identified. Agricultural areas were categorized into single, double and continuous crops depending on cropping intensities (IWMI, 2010). IWMI (2010) adopted FAO definition of area under agricultural water management for defining classes for irrigated areas[8]. In this classification area under agricultural water management is divided in to two:

- Area equipped for irrigation
- Area with other forms of agricultural water management including non-equipped cultivated wetlands and inland valley bottoms, water harvesting, soil moisture management and non-equipped flood recession cropping. In IWMI (2010), this category is titled "water managed non-irrigated".

Less than one percent of Tuli Karoo System is irrigated. The total irrigated area including irrigated double crop, irrigated single crop and irrigated-triple crop account about 1% of the study area (Figure 7.8 and Table 7.1). Nonetheless, water Managed- Non Irrigated crop type account about 10.5% of the study area. About 5.4% of the Water Managed-Non irrigated type is in Shashe sub-basin, 2.9% in Mzingwane and 2.9% is in Motloutse. Only 0.6% of the Tuli Karoo Aquifer Area is irrigated and Water managed non-irrigated area accounts about 5.1% of the aquifer area. Irrigated areas are found predominately in Shashe, Mzingwane and Motloutse catchments.

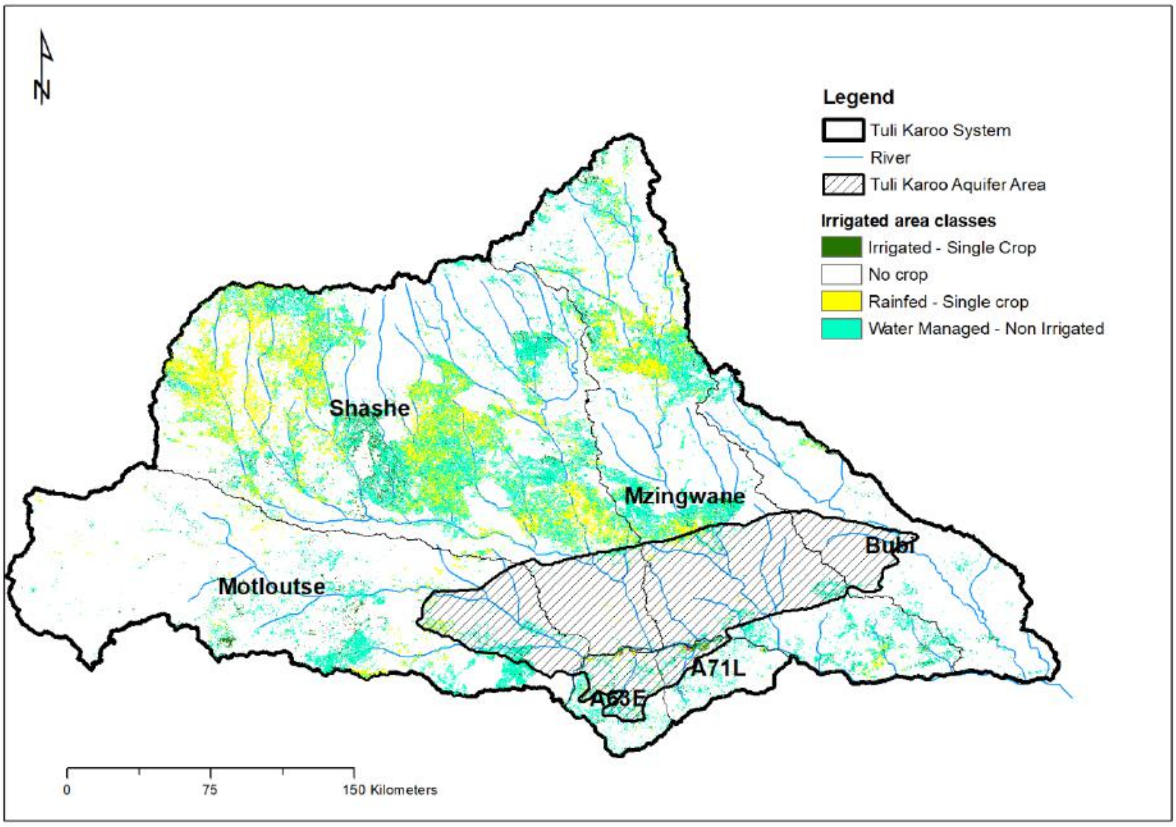


Figure 7.8 Irrigated and Rainfed Agriculture (Source, IWMI, 2010)

[8] http://www.fao.org/nr/water/aquastat/irrigationmap/glossary.pdf

Table 7.1: Proportion of irrigated and rain fed crop areas

	Proportion of Tuli Karoo System (%)	Proportion of Tuli Karoo Aquifer Area (%)
Irrigated-single crop	1	0.6
Rainfed Single Crop	6	1.2
Water Managed- Non Irrigated	10.5	5.1
No crop	82.5	92.8

7.4 Transfrontier Conservation Areas

Importance of Transfrontier Conservation Areas An ecological area of protection that crosses the boundaries of two or more countries, including one or more protected area as well as multiple resource areas are known as Transfrontier conservation areas (TFCAs), international peace parks, transfrontier conservation and development areas, transfrontier parks, transfrontier nature reserves, transboundary parks, or cross-border parks (Tanner et al. (2004). The main benefit associated with TFCA establishment include (Tanner et al., 2004).:1) Ecological-natural resource and environmental protection, biodiversity, creation of larger reserves, Transfrontier conservation areas, as large protected areas, have been shown to dramatically increase biodiversity and ecological health in comparison to smaller protected areas 2) Economic- increased economic potential through eco-tourism and cross border economic interaction, 3) Socio-cultural- preservation and/or restoration of cultural integrity, interaction of cross border indigenous peoples, and 4) Political- promotion peace and improved international relations (Muboko, 2017). TFCAs have also been established to ease tensions between nation-states in border disputes through the creation of a buffer zone.

The TFCA in the Tuli Karoo In the Tuli Karoo Aquifer System, the Greater Mapungubwe TFCA has been proposed (Figure 7.9). The Greater Mapungubwe TFCA consist of the Mapungubwe National Park, the northern Tuli Game Reserve in Botswana and the Tuli Circle in Zimbabwe (Fleminger, 2018). A memorandum of understanding (MOU) between South Africa, Zimbabwe and Botswana was signed in 2006 for establishing joint committee and creation of the Limpopo/Shahse TFCA (Fleminger, 2018). The Greater Mapungubwe Transfrontier Conservation Area: 4,872 km^2 in extent, 2,561 km^2 (53%) in South Africa, 1,350 km^2 (28%) in Botswana, and 960 km^2 (19%) in Zimbabwe (DWS, 2019). The Southern African side of the TFCA falls inside the Vhembe Biosphere Reserve.

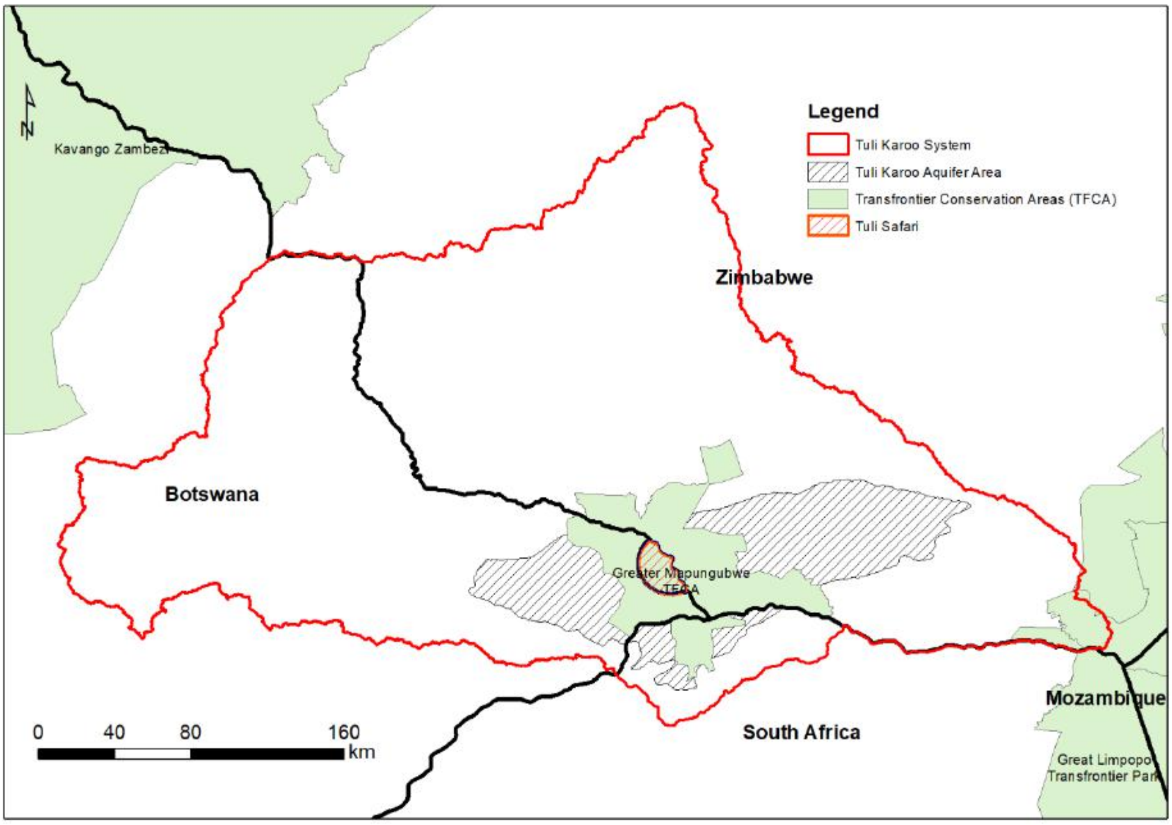


Figure 7.9: Transfrontier Conservation Areas in the Tuli Karoo System (Source: BIOPAMA, 2011)

7.5 Mining Activities

Diverse set of mines in the Tuli Karoo System The Tuli Karoo is also home for various mining activities. According to mining activities map obtained from SADC (Figure 7.10), there are 42 mining activities which are at different stages of development. The South Africa's largest diamond mine known as Venetia is located in the A63E sub-catchment and has an off-channel reservoir located in the A71L sub-catchment (Kahinda et al., 2016).

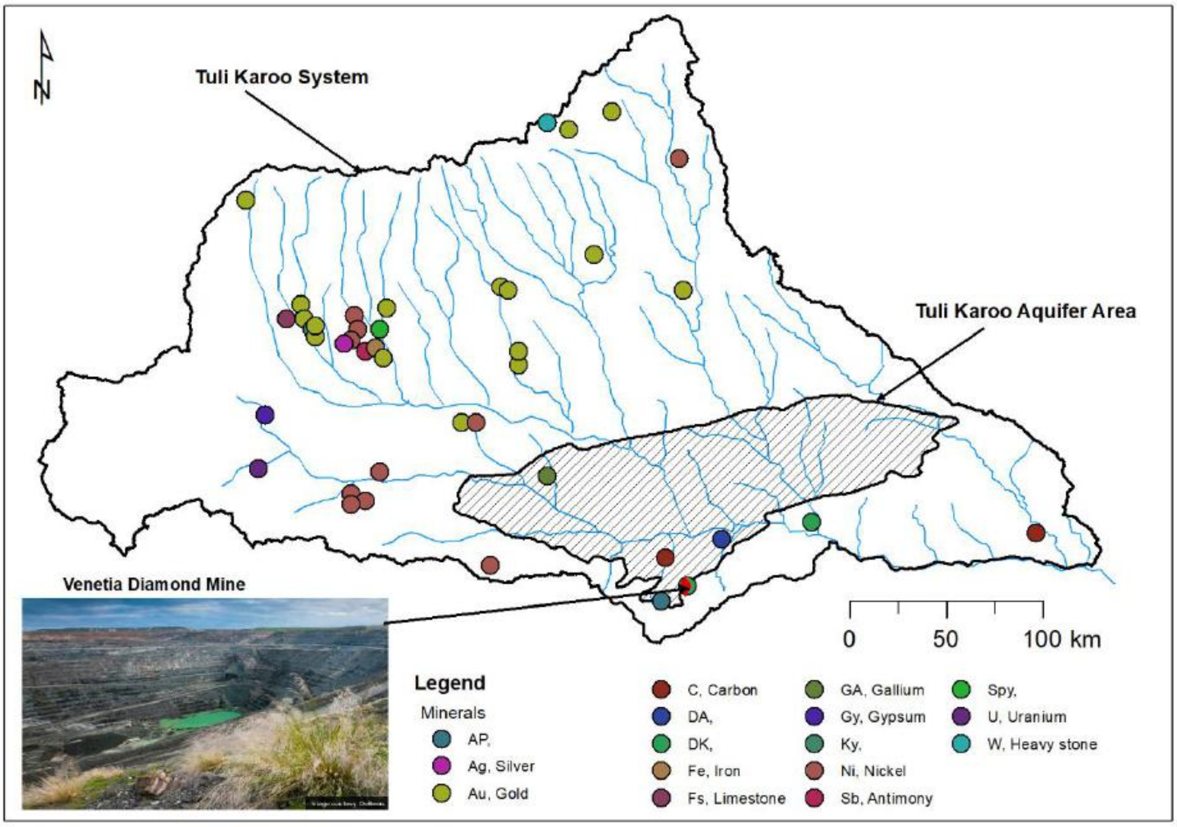


Figure 7.10: Mining Activities (Source: Council for Geosciences, South Africa, 2000)

Adverse impacts of mining Mining activities have various impacts on the environment including pollution of water sources, soil erosion, loss of biodiversity/ ecology, and formation of sink holes (Twerefou, 2009). Mining companies are obliged to meet environmental criteria and to make sure that the mined area to be transformed back to its original form after mine closure. Acid mine drainage is reported to be a major problem on coal and gold mines throughout the world and in South Africa (Bester and Vermeulen, 2010, Ochieng et al., 2010, McCarthy, 2011). According to Ochieng et al. (2010), water draining from coal and base metal mines contains high level of sulphuric acid and heavy metals and contaminate streams and agricultural land when mine water is discharge to stream or used for irrigation purpose. Impact of mining and mineral operation in the water resources in the Limpopo basin including the case study area can be found in Ashton et al. (2001). Table 7.3 summarizes the mining activities and their impact in the Shashe catchment of Botswana and Zimbabwe, respectively.

Some of the most common environmental effects of mining are (FAO, 2004):

- destruction of landscapes and ecosystems by open-cast mining;
- waste accumulation and groundwater contamination by leachates;
- lowering of the groundwater level;
- toxic concentrations of elements such as copper, nickel, zinc, chromium and boron;
- environmental health threats through unsafe mining operations, or specific minerals (e.g. asbestos

Table 7.3: Mining operations in the Shashe Catchment (Source Ashton et al., 2001)

Name of Mine	**Country**	**Commodity (ies) mined**	**Status**	**Total produced/t**	**Probable impact**
Matsitama	Botswana	Copper	Operating	Small	Very low

Tati	Botswana	Gold	Operating	Small	Low-Medium (As)
Selkirk	Botswana	Copper, Nickel	Operating	Small	Low
Champion	Zimbabwe	Arsenic	Closed 1924	1022.7	High
Hydra	Zimbabwe	Arsenic	Closed 1946	553.3	High
Vubachikwe	Zimbabwe	Arsenic	Closed 1949	110.1	High
Antelope	Zimbabwe	Gold	Closed	9.2	Medium
Blanket	Zimbabwe	Gold	In operation	27.0	High: Arsenic possible
Freda	Zimbabwe	Gold	In operation	10.5	High: Arsenic possible
Horn	Zimbabwe	Gold	Dump retreatment	5.0	High: Arsenic & bismuth possible
Vubachikwe Black Jack	Zimbabwe	Gold	In operation	25.1	High: Size & Arsenic possible
Noel	Zimbabwe	Nickel	Closed 1963	4651.9	High: Arsenic possible
Hampden Iron	Zimbabwe	Pyrite	Closed 1942	1492.0	High

7.6 Key Messages

The review of land use and land cover of the Tuli Karoo System reveals important considerations for shared water management. Key messages are as follows:

- ***Irrigation is limited in the Tuli Karoo*** Although nearly 12 percent of the Tuli Karoo System is cultivated, less than 1% of the land areas is irrigated. Given the drive for greater food security and resilience, there may be need to expand irrigation in an efficient and sustainable way.
- ***Watershed management may be key to maintaining groundwater infiltration, ecosystem health and extending dam lifespans by reducing siltation*** The shrubs, grasslands and pasture that cover most of the Tuli Karoo system play a valuable role that should not be overlooked. The services derived from such land use help to attenuate surface flow and facilitate groundwater infiltration. The will also help prolong lifespans of dams by reducing sedimentation. All of these processes add value.
- ***There is a need to monitor mining activities*** Mineral resources are lucrative and can help spur growth in the region. Nonetheless, mining can produce large volume of waste and chemical pollutant which are concern for human health and ecosystem (e.g. acid mine drainage). Ongoing monitoring can help manage these externalities.
- ***There is potential for expansion of shared wildlife protection areas for tourism*** The concentration of wildlife conservation reserves in the Tuli Karoo Aquifer Area calls for consideration of integration. Protection of conservation areas and limiting transboundary animal disease is a key for maximizing the benefit gained from a TFCA. Nonetheless, if carefully undertaken, benefits derived from a TFCA may exceed benefits derived from separate, neighbouring conservation areas in each of the three countries.

8. Water Use

The Tuli Karoo Aquifer represents an important natural resource that supports productive activities including irrigated agriculture, urban and rural water supply, industry, mining, livestock and wildlife. Much of the aquifer system falls in areas of high water stress. More informed, integrated management of the resource may expand opportunity for communities living in these dry areas. Key water uses are as follows: Agriculture, domestic (household) use, mining, and the environment. In what follows, focus is devoted to water use in each of these sectors.

8.1 Agriculture: Crops and Livestock

Crops

Calculating water use in Agriculture Crop Areas Building on irrigated land use mapping described in chapter 7, IWMI (2010) irrigated area maps using 16-day MODIS NDVI composites images (MOD13Q1) data of resolution 250m in Asia and Africa were coupled with Global Land Evaporation Amsterdam Model (GLEAM) data (Martens et al., 2017) to estimate crop water use -- Evapotranspiration (ET) – in irrigated and rainfed areas (Table 8.1). To confirm accuracy, the irrigated water use (consumption) calculated from this remote sensing method was compared with the irrigation water consumption volumes reported from several reports in the three countries (Botswana, Central Statistics Office, 2007, 2019; Masamba, 2009; DWS, 2019; Government of Zimbabwe, 2019).

Area used for Irrigation and rainfed agriculture water use As highlighted in chapter 7, total irrigated area in the Aquifer Area is approximately 12,000 ha. The largest area under irrigation is in South Africa (6,900 ha), followed by Zimbabwe (2,900 ha) and then Botswana (2,000 ha). Total rainfed area is just over 84,000 ha. The largest area under rainfed production is in Zimbabwe (31,670 ha), followed by Botswana (28,440 ha) and then South Africa (24,780 ha). Overall, approximately 1 percent of the Tuli Karoo Aquifer Area is under irrigation, under 6 percent of the system is used for rainfed agriculture and about 10.5% is used for water managed - non-irrigated crops. Crops grown include wheat, potatoes, lucerne, butternut, leafy vegetables and citrus fruits.

Water use in irrigation and rainfed agriculture Water consumption under irrigation was 133 million m^3/a (Table 8.1) based on 2017 evapotranspiration data. If one assumed farmers typically apply an additional 25 percent water to cater for water lost beyond the root zone (MoAIWD, 2016), the irrigation water demand becomes 166 million m^3/a. This water demand is comparable to 147 million m^3/a obtained from more recent reports from the three countries (Botswana, Central Statistics Office, 2007, 2019; Masamba, 2009; DWS, 2019; Government of Zimbabwe, 2019). Water efficiency in irrigation in the system should not be underestimated. The South African side is characterised by high tech irrigation systems that include the drip and dragon-line systems (short drip lines mounted on a mobile centre pivot) to use irrigation water efficiently (potential for 20-50 % water savings, reduces evaporation and wind drift), especially in large commercial farms (Dragon-Line Southern Africa (Pty)Ltd, 2018).

Table 8.1. Crop water use under Irrigated and Rainfed areas, Tuli Karoo Aquifer Area in 2010 (Data source: IWMI, 2010; Martens et al., 2017)

Land Use	ET (m)	Area (km^2)	Volume of water use (million m^3/a)
Irrigated - single crop	1.3	81.4	106
Irrigated - double crop	0.8	27.9	23
Irrigated - triple crop	0.4	9.5	4

Sum	2.6	118.8	133
Water managed - non-irrigated - single crop	37.0	675.2	24,980
Water managed- non irrigated - double crop	0.5	6.6	3
Rainfed- single crop	15.7	160.3	2,516
Sum	53.1	842.2	27,500

Irrigation Water Use in Botswana Estimated irrigation water demand for the portion of the Aquifer Area in Botswana is 26 million m^3/a. In Botswana, a total irrigated area of 1,500 ha in the Tuli Karoo Aquifer Area was used to estimate the irrigated water demand based on the 17,320 m^3/ha/a water demand (Botswana, Central Statistics Office, 2007; Masamba, 2009). Generally, reclaimed wastewater offers an excellent source of water for irrigation in Botswana, but only 10 percent of the return flows from wastewater treatment plants are reused, the rest being lost to seepage and evaporation. In the Tuli Karoo Aquifer Area, there is nonetheless no water from wastewater treatment plants that is used in irrigation. Urban areas only considered for wastewater use for irrigation include Gaborone, Lobatse, Selebi-Phikwe, Serowe and Tonota (Department of Agriculture and Agro-industry, 2011). The last three are in the Tuli Karoo System.

There are four types of farming in the irrigation sector (Botswana, Central Statistics Office, 2007) in Botswana:

- Private irrigated farms owned by individuals and ranging in size from 1 to 100 ha (with the smaller farms being more common). These farms mostly grow high-value food crops for the local markets;
- Group schemes developed by government and donor agencies to provide livelihood alternatives to local people. These consist of 10 ha schemes divided into individual plots.
- Institutional schemes owned and operated by government organisations.
- Company-owned schemes owned and operated by companies such as the Botswana Development Corporation, which has 570 ha in the Tuli Karoo Aquifer area in Botswana, Mogobane and Kasane. This includes the Tuli Block, an area located at the confluence of the Shashe and Limpopo rivers.

Irrigation Water Use in South Africa Estimated irrigation water demand for portion of the Aquifer Area in South Africa is 63.3 million m^3/a. The WARMS database (2019) – containing information on registered users in the aquifer area – was used to identify registered volume for irrigation in the aquifer area, which were summed. Notably, this volume may be over or under estimation of irrigation water demand as the process of validation and verification is still to be done by the Department of Water and Sanitation, South Africa. Furthermore, there could be informal water use and irrigation not captured. The types of farmers in the South African portion of the aquifer are smallholder and big commercial farmers (Council for Scientific and Industrial Research-Environmentek, 2003). Smallholder farmers do crop production, while commercial farmers are into crop, livestock and game farming and game reserves (Council for Scientific and Industrial Research-Environmentek, 2003).

Irrigation Water Use in Zimbabwe Estimated irrigation water demand for the aquifer portion in Zimbabwe is 57.3 million m^3/a. The area proportion method was used to estimate the irrigation water demand based on the total irrigation demand for Mzingwane Catchment (63,000 km^2) of 514 million m^3/a, where portion of the aquifer (7,027km^2) lies. In Zimbabwe, sources of irrigation water include sand abstraction systems (water is pumped from rivers through well points sunk into riverbed sand) and dam-fed schemes. Plots vary in size from 0.1 to 0.5 ha/household (Government of Zimbabwe, 2019). Zhovhe Dam supplies both smallholder and commercial farmers with irrigation water, but most farmers far from the Limpopo and its tributaries, rely on groundwater. Most smallholder farmers use inefficient surface irrigation methods (e.g., furrow and border systems – see Figure 8.1), indicating great potential to increase water use efficiency by converting to drip systems and using soil and nutrient monitoring tools (https://via.farm). The farming systems in Zimbabwe include smallholder (communal), old resettlement, small-scale commercial, ARDA estates, A1 and A2 resettlement farming areas.

Figure 8.1: Smallholder border irrigation system downstream of Zhovhe Dam in Zimbabwe (Photo Credit: Manuel Magombeyi)

Non-revenue water

Non-revenue water includes water losses during distribution and any other water that was not accounted for through billing. The water use for livestock, domestic, mining and industrial was first estimated and increased by a percentage of non-revenue water in each of the three countries sharing the Tuli Karoo Aquifer. The average non-revenue water for Francistown (34%), Selebi-Phikwe (17%), Palapye (16%) and Serowe (12%) for 2016/2017 was about 20% (Statistics Botswana, 2017), while for South Africa it was 30% in 2017 (Department of Water Affairs, 2014) for Musina and an average of 48% for local urban areas in Zimbabwe (Non-Revenue Water in Zimbabwe, 2018).

Livestock

Botswana has greatest livestock water demand Estimated livestock water demand for the aquifer area was 1.52 (1.98 including non-revenue water) million m^3/a, with Botswana (1.14 million m^3/a), South Africa (0.014 million m^3/a) and Zimbabwe (0.825 million m^3/a). The water demand for livestock was calculated based on the livestock population and the water demand per livestock (Department of Rural and Agricultural Development, 2018) in the three countries. The type of livestock include cattle, goats, sheep, donkeys and pigs (Figure 8.2). Chicken water demand was also included in the livestock water demand. The population of domestic animals was only available for Botswana.

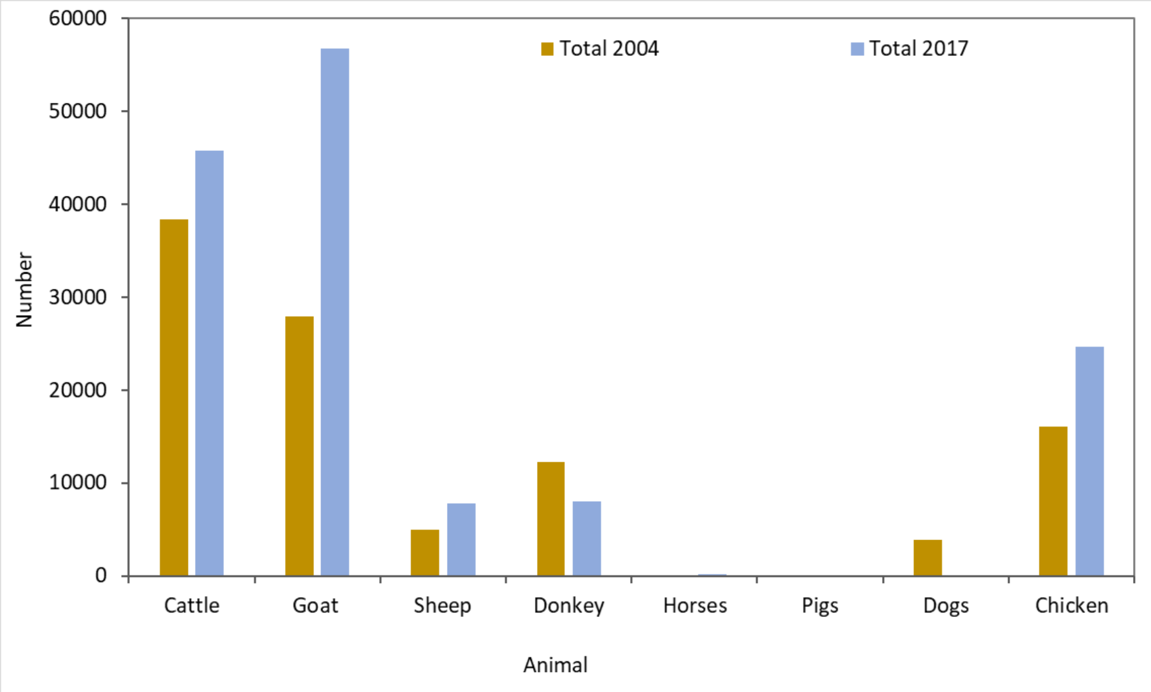


Figure 8.2: Population of animals in Botswana portion of the aquifer (Data source: Statistics Botswana, 2019)

8.2 Domestic Water Supply and Sanitation

Water Supply

Botswana Domestic Water Use The estimated water demand in the Botswana portion of the aquifer area including non-revenue water, 90 percent of which is for domestic use, is 2.11 million m^3 per year, with 1.61 million m^3 per year (76%) supplied from groundwater (Water Utilities Corporation, 2019). Currently (2019), some of the Bobonong water supply boreholes are being pumped 24 hours, while others are on stand-by as the water demand is now being partly supplied from the Thune Dam. The 24-hour pumping schedule is actually preferred in modern pump design, as it limits surging (which in turn limits problems of iron bio-fouling) and the potential for over pumping, as a more conservative pumping yield is set. Water supply problems have been reported, for example at Gobojango village (Water Surveys Botswana (Pty) Ltd, 2009). Further, the water demand for Mabolwe will increase should the establishment of a new immigration post and associated housing be developed.

Safeguarding the Resource In Bobonong, estimated good quality water supply volumes of 6,000 to 10,000m^3/day are potentially available for at least 20 years (up to 2030) from the start of pumping (2010) so long as the pumping rates for each borehole do not exceed a safe yield of 500 m^3/day (Water Surveys Botswana (Pty) Ltd, 2009). However, the number of boreholes drilled in the aquifer in relation to yields is also important in determining sustainable rate of abstraction. It is therefore necessary to protect this critical resource. Best practice of groundwater protection zoning of nominal 100 m and 1,000 m radius contamination protection zones are applied around individual production wells in Botswana (Water Surveys Botswana (Pty) Ltd, 2009), although in other countries these values vary from 10-50 m, with higher values required for springs (e.g., 30 m) than boreholes (e.g., 10 m) (WHO, 2006). However, borehole interference protection zones needs consideration as well. This is standard practice in the UK and the zones represent rudimentary distances to allow for biodegradable decay times for microbiological pathogens (50 days) and more resistant contaminants (hydrocarbons, etc.)

representing a 1 year travel time (approximately). Not all countries enforce the protection, despite a recognition of their desirability (WHO, 2006).

South Africa Domestic Water Use The estimated domestic water demand in the South African portion of the Aquifer Area is 0.42 (0.55 including non-revenue water) million m^3/a based on 60 litres/capita/day (Republic of South Africa, 2001). The basic water services are defined in South Africa as 25 litres/capita/day (Republic of South Africa, 2001), but for planning purposes DWS –South Africa recommends 60 litres/capita/day (range 60-100 litres/capita/day) for planning purposes for low-income housing and rural villages. There are various levels of supply in South Africa: survival - typically 5 litres/capita/day at a distance of 1000 m (varies from district to district; rudimentary - 25 litres/capita/day at 200 m; household – 60 litres/capita/day at household and urban - 450 – 650 litres/household per day. The WARMs database (DWS, 2019), which is a list of registered and licensed uses including stream-flow reduction activities, industry, domestic and de-watering was used to extract domestic water volume of 0.004 million m^3/a. This volume was not used in this report as it omitted other domestic water service providers. This recommended figure together with population figures in the aquifer area (19,300 people) were used to estimate domestic water demand. The WARMS database was used to identify the registered domestic water uses. Most people in the South African portion of the Aquifer Area have access to potable water supply through taps or on-site boreholes. The water supply sources range from bulk to on-site rudimentary supplies (Table 8.2) based on the data from the Limpopo Province.

Table 8.2 Main source of water for people in South African portion of the Aquifer Area, 2017 (Data Source: Statistics South Africa, 2019)

Water source	Number of persons
Piped (Tap) water in dwelling	2,578
Piped (Tap) water on site or in yard	6,513
Borehole on site	2,087
Neighbour's tap	1,257
Public tap	4,086
Water-carrier/Tanker	314
Water vendor	968
Borehole off site/communal	717
Flowing water/Stream/River	151
Well	138
Spring	151
Other	339
Total	**19,300**

Zimbabwe Domestic Water Use The estimated domestic water demand, coupled with water demand for industry and mines[9], in the Zimbabwe portion of the aquifer is 2.23 (3.302 including non-revenue water) million m^3/a. Water demand estimated from population of 62,100 people with an average water demand of 60 litres/capita/day (Republic of South Africa, 2001) was 1.36 million/a. Boreholes and deep wells are the most commonly used means to secure water for these three sectors (Figure 8.3). There is one artesian well in this part of the aquifer area (not shown in Figure 8.3). Of the various water supply points for these three sectors, 55.9 percent are fully functional, 14.2 percent partially

[9] In Zimbabwe, it was not possible to disaggregate domestic water demand and water demand for industry and mines.

functional, 16.9 percent non-functional, 6.9 percent had collapsed or are abandoned and 6.1 percent were not specified (RWIMS, 2018). About 133 new rural water supply points in the form of boreholes, shallow wells, deep wells and springs are planned for 2020-2025 in the aquifer area in Zimbabwe (RWIMS, 2018). Construction of such new water supply points should go some way to reducing the 36 percent and 8 percent of the rural and urban population in the Zimbabwe portion of Aquifer Area, respectively, who lack access to water supply.

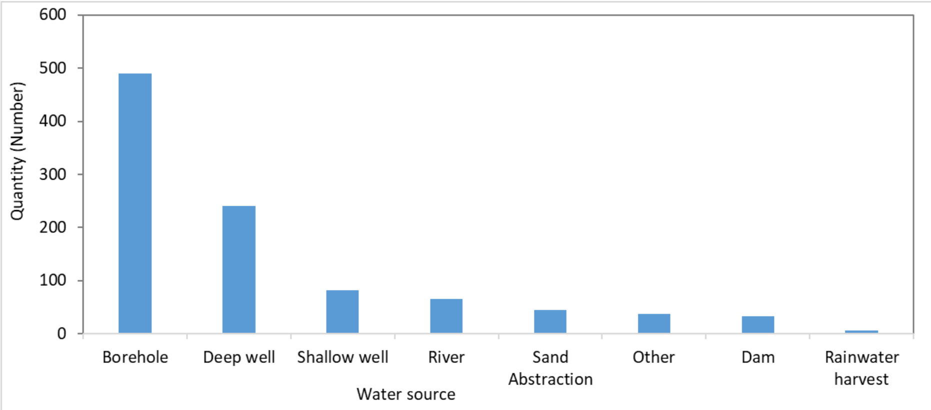


Figure 8.3: Number and type of water supply sources in the Aquifer Area in Zimbabwe (Source: RWIMS, 2017)

Holistic perspective on domestic water use in the Aquifer Area Providing safe drinking water is a priority for governments from the three countries sharing the Tuli-Karoo aquifer. As signatories to the Sustainable Development Goals (SDGs), the countries are committed to ensuring their population have access to improved water source. Improved water source referred to piped water indoors, outdoors, neighbour's tap, communal tap, bowser or tanker and borehole. The domestic water use was adjusted to reflect the current (2019) population in the aquifer area. Overall, 65 percent of the population in the Aquifer Area had access to safe water sources, while 35 percent have access to unprotected water sources (Figure 8.4). The greatest proportion of population that accessed unprotected water sources is in Zimbabwe portion of the aquifer area, followed by Botswana. The largest proportion of population used wells at 33 percent (suggesting shallow groundwater levels) followed by those who used piped water outdoors (21 percent) and borehole (14 percent). Only 8 percent have piped water indoors. Dam/pool and rainwater tanks cover 0.13 percent and 0.02 percent of the sources in the aquifer area, respectively (not shown in Figure 8.4). There is need to protect wells (both shallow and deep) and also provide onsite water disinfection to improve safe water access to about 33 percent of the population in the aquifer.

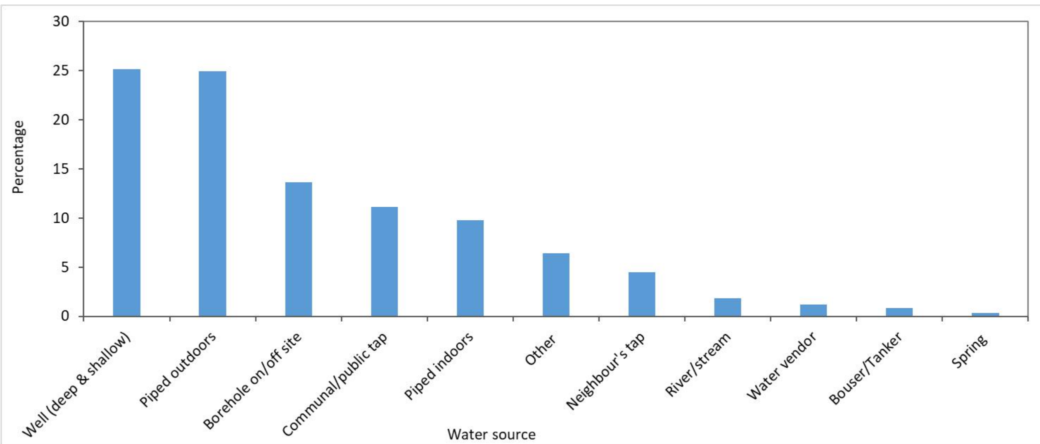


Figure 8.4: Type of water source in the Aquifer Area (Data source: Statistics South Africa, 2019; RWIMS, 2018; Botswana Central Statistics, 2015)

Sanitation

Sanitation in South Africa The highest proportion (67 percent) of households use pit latrines (with or without ventilation pipe), with 3.7 percent requiring sanitation in the South African portion of Aquifer Area (Table 8.3). Data on sanitation coverage for South Africa was obtained from the household survey of 2017 (Statistics South Africa, 2019) for the Limpopo Province with an area of 125,754 km^2. The sanitation coverage for the South African portion of the aquifer area (3,757 km^2) was determined by area proportion method. At the time of writing, no data was available on wastewater generated in the Botswana portion of the Aquifer Area.

Table 8.3 Sanitation facility used by people in the Aquifer Area (Data source: Statistics South Africa, 2019)

Sanitation facility	Number of people
Flush toilet connected to a public sewerage system	3,978
Flush toilet connected to a septic tank	1,133
Pour flush toilet connected to a septic tank	63
Chemical toilet	189
Pit latrine/toilet with ventilation pipe	6,282
Pit latrine/toilet without ventilation pipe	6,710
Ecological sanitation systems	88
Open defecation (e.g., no facility, field, bush)	718
Other	138
Total	**19,300**

Sanitation in Zimbabwe The level of safe sanitation coverage in the Zimbabwe portion of the Aquifer Area currently stands at just 20 percent (RWIMS, 2018), but this is envisioned to 90 percent in 2040 (Government of Zimbabwe, 2019). Clearly, there is need to improve maintenance, rehabilitation and expansion of the water supply and sanitation infrastructure in small towns and growth points and urban areas which is affected by lack of funding and poor management. The collapse of the water supply was linked to the outbreak of cholera in 2008/2009 (Government of Zimbabwe, 2019). The estimated wastewater generated in Zimbabwe portion of the Aquifer Area is 0.8 million m^3/a for the year 2018 (Government of Zimbabwe, 2019). This quantity of wastewater is projected to steadily increase in small towns and growth points in the aquifer area (Figure 8.5). The rural sanitation needs consists of expansion of safe on-site disposal sanitation facilities that include the Blair VIP type and other on-site sanitation facilities.

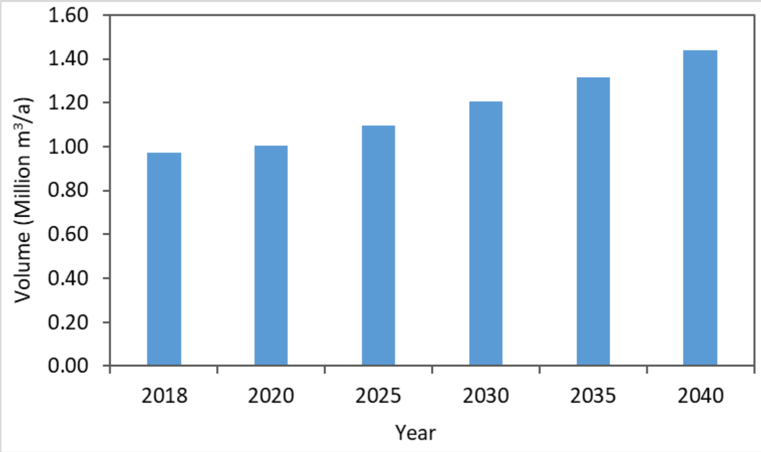


Figure 8.5. Wastewater generated from small towns and growth points in the Zimbabwe portion of the Aquifer Area (Data source: Government of Zimbabwe, 2019)

Holistic perspective on sanitation access in the Aquifer Area Access to sanitation facilities was measured at household level by assessing whether households has access to flush toilet either in-house, communal or shared with a neighbour or had access to a sanitary pit latrine or other toilet (Figure 8.6). Overall, 52.3 percent of the population in the aquifer area had access to improved sanitation facilities, while 47.3 percent had no sanitation facilities (Figure 8.6). The greatest proportion of population without sanitation is in Zimbabwe portion of the aquifer, followed by Botswana. The largest proportion of population used own pit latrines at 24.2 percent (because of relatively low construction cost) followed by those who use Ventilated Improved Pit latrines (VIP) (16.2 percent) and own flush toilets (10.4 percent). The use of unlined pit latrines was still prevalent in most villages in the aquifer area, despite the unpleasant smell, breeding of flies and spread of diseases. Moreover, pit latrines can cause groundwater pollution in the long-term depending on the depth to groundwater level at different areas. Hence, there is need to line future pit latrines to reduce the risk of groundwater pollution in the aquifer.

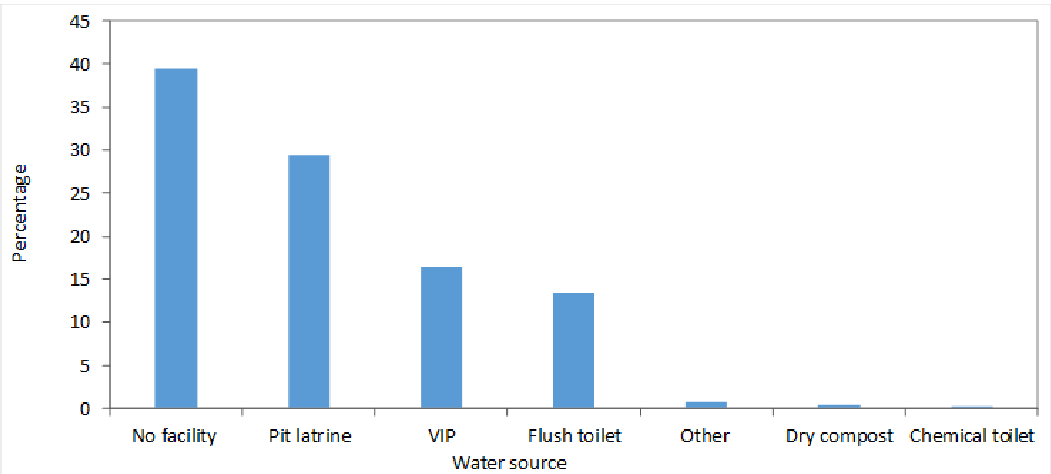


Figure 8.6. Proportion of types of sanitation facilities in the Aquifer Area (Data source: Statistics South Africa, 2019; RWIMS, 2018; Botswana Central Statistics, 2015).

8.3 Mining and Industry

Mining Water Demand The estimated water demand for mining and industry in the Tuli Karoo Aquifer Area was 11.74 (14.64 including non-revenue water) million m^3/a, based on reported water demand (Botswana Central Statistics, 2015; Statistics South Africa, 2019; Government of Zimbabwe, 2019). The aquifer area hosts three mines, namely; Venetia Diamond Mine and Vele Coal Mine (both in South Africa), and Tuli Coal Mine in Zimbabwe which could affect both quality (nitrate) and quantity of groundwater. Although Venetia Diamond Mine is outside the aquifer area, it uses groundwater from the aquifer, initially from Greefswald and Schroda farms with a plan to later abstract from Schroda only.

Coping with environmental externalities of mining Environmental impact assessments for open cast mines do not consider the possible impacts beyond the respective political borders (Gomo and Vermeulen, 2017) because there are no co-governance and co-management agreements in place between sharing countries. Therefore, there is a possibility of cross-border negative impacts on groundwater resources. This necessitates the understanding of groundwater-surface water interaction in the area considering that this is an interlinked system between the sharing countries. Since the mines could be tapping both shallow and deep alluvial aquifers, hydraulic connectivity between the two aquifers must be understood.

8.4 Environment and Ecosystems (including fisheries)

Groundwater Dependent Ecosystems (GDEs) Groundwater plays an environmental role both directly by sustaining ecosystems and indirectly through its interactions with surface water resources (Le Maitre et al., 1999; Winter et al., 1999). Ecosystems can be dependent on groundwater quantity or quality, or both; also in time and space. The ecosystems for which functioning would be seriously affected if the availability of groundwater was changed are referred to as Groundwater Dependent Ecosystems (GDEs).

GDEs in the Tuli Karoo The predominant GDEs in the Tuli-Karoo TBA are riparian vegetation along the Limpopo and Shashe River banks. Other GDEs include terrestrial woodlands (e.g., acacia, mopane savanna trees) and grasslands of savanna biome (Low and Rebelo, 1996; Wessels et al., 1999) vegetation type, and wetlands (e.g. Kalope/Maloutswa in Mapungubwe National Park) including water pans. In the Northern Tuli Game Reserve, Botswana, it was observed that the major mopane leaf lush occurs independently of rainfall (Styles et al., 2001) which could indicate that they have access to aquifer water to some extent. By inference, some plants in the Tuli-Karoo are presumed to tap on groundwater for survival due to their estimated root depths. A root depth analysis is needed to ascertain this presumption, specifically for the Tuli Karoo Aquifer Area. It is important to ascertain the impact of groundwater utilization on groundwater dependent ecosystems in the area.

Species critical to ecosystems health The area comprises various tree and animal species, some of which were identified (Council for Scientific and Industrial Research-Environmentek, 2003), including:

- *Tree species*: Ficus sycamorus, Combretum imberbe, Terminalia prunoides, Croton megalobotris, Acacia xanthophloea (fever tree), Faidherbia albida (anaboom), Xanthocercis Zambeziaca (nyala tree, meeting tree), and Sclerocarya birrea. The forest also has many creeper and liana species.
- *Animal species:* bush buck, duiker, klip springer, giraffe, bush pig/ wart hog, baboons, vervet monkeys, dassies, hornbills, sun birds, impala, Martial eagle. There also are elephants, leopards, kudu and lions. Baobabs, mopane and palms are characteristic of the floodplain and hills away from the gallery forest.

Riparian Ecosystems Riparian GDEs are near stream ecosystems depending on groundwater discharge as baseflow during dry seasons (Figure 8.7a). In many cases the flows also are critical for meeting human needs both directly and by sustaining human enterprises. In many areas in the Tuli Karoo, non-perennial riparian zones are supported by alluvial aquifers and the perennial systems receive a substantial proportion of local groundwater fed baseflow e. g. Riparian fringe woodlands. In many situations riparian plants are tapping groundwater rather than surface flows and therefore groundwater extraction could have severe impacts on the nature of such differentiated systems (Colvin et al., 2003).

Terrestrial Ecosystems: Fauna Animal species found in the Tuli Karoo include bush buck, duiker, klip springer, giraffe, bush pig/ wart hog, baboons, vervet monkeys, dassies, hornbills, sun birds, impala, martial eagle. There also are elephants, leopards, kudu and lions. Reduction of vegetation in the basin is partly attributed to these animals feeding on, basking under and scratching the trees. Moreover, they can trample on new vegetation stifling their growth and propagation.

Terrestrial Ecosystems: Vegetation Woody shrubs and trees, especially evergreen trees, often have tap roots that can reach 5 - 10m depth and not infrequently more than 20 m, and their presence in areas with a rainfall of less than 500 mm may indicate groundwater use and dependence (Figure 8.7b). Tree species in the Tuli Karoo include Baobabs, mopane and palms which are characteristic of the floodplain and hills away from the riparian gallery forest. Others are Ficus sycamorus, Combretum imberbe, Terminalia prunoides, Croton megalobotris, Acacia xanthophloea (fever tree), Faidherbia albida (anaboom), Xanthocercis Zambeziaca (nyala tree), and Sclerocarya birrea.

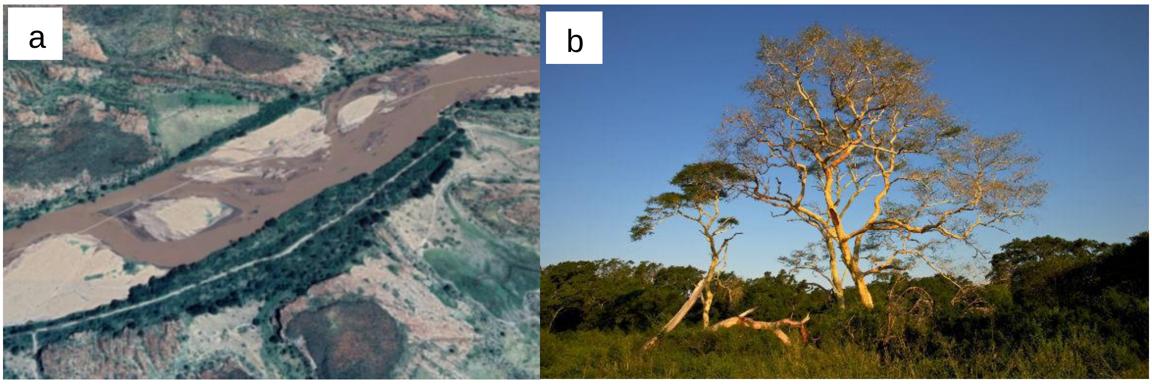


Figure 8.7: Riparian vegetation, Limpopo River (a) and Fever Tree, Terrestrial Ecosystem (b)

Wetlands, Pans and Springs Wetlands typically possess a known or likely component of groundwater discharge in their hydrological cycle; including some endorheic pans. Springs are included because there is essentially a continuum from a spring which has a definite discharge point to wetlands which depend on diffuse discharge over wide areas. Maloutswa pans are known to be used by animals for drinking purposes, whilst communities also make use of them. Climate variability has led to the shrinking and drying up of most wetlands in Zimbabwe (Ndiweni et al., 2014), and ecological approaches to protect and restore wetland functions have been proposed. Mapungubwe National Park in South Africa initiated a groundwater programme in order to conserve and protect GDEs such as the gallery forest and Kalopi/Maloutswa Wetland.

Fisheries The aquifer area has few fish species due to the harsh environment that include wide variations in temperature, prolonged dry periods, and highly variable river levels. However, there are greater fish populations in the more permanent tributaries of the Limpopo River and in many dams built within the aquifer area (FAO, 2004). No data on fish quantities was obtained from the three countries.

Game Reserves and Parks The estimated game reserve water demand is 0.1 million m^3/a, based on elephant population only. Hence, there is data game on the population of other wildlife animals. The proposed Limpopo/Shashe Transfrontier Conservation Area (TFCA) is expected to cover 4,872 km^2, of which 53 percent will be in South Africa, 28 percent in Botswana and 19 percent in Zimbabwe. The area has a rich biodiversity, with several important Iron Age sites. Viable populations of lion, leopard, and cheetah are still prevalent and a population of 1,400 elephant exist within the region. The resident elephant population is estimated at 600 within the Northern Tuli Game Reserve, making it the largest population on private land in Africa. The water demand for these elephants is 0.1 million m^3/a. The area also habitat to 19 mammals and 26 plant species, as well as over 350 bird species having been recorded to - including the Black Eagle.

Importance of wildlife Tuli is sometimes called the *Land of Giants*, for it populations of elephant, lion, leopard, cheetah, giraffe and eland. The array of animals include the wildebeest and zebra, troops of monkey and baboon, as well as populations of steenbok, the timid duiker, grysbok, impala, common waterbuck, bushbuck, and warthog. Also present are aardvark, aardwolf, bat-eared fox, African wild cat, spotted hyena and black-backed jackal. The permanent pools in the Limpopo river harbor crocodiles and all the waterways are home to a variety of indigenous fish. Wild dogs and raon antelope, and tsessebe have been reintroduced on the South African side of the river and the Tuli area has a great diversity of bird life. However, data on the population of the wildlife was not available, except for elephants and hence, water demand could not be estimated for all the wildlife in the aquifer area.

Defining Environmental Flows Environmental flows refer to the quality, quantity, and timing of water flows required to maintain the components, functions, processes, and resilience of aquatic ecosystems that provide goods and services to people (Hirji and Davis, 2009). The groundwater Reserve study conducted by the Department of Water Affairs (DWA, 2011) raised a concern that surface water is very limited whilst there is large groundwater use, thus cautioning against the possible groundwater over-exploitation at local scale. Environmental flows are central to supporting groundwater depended ecosystems (GDEs), sustainable development and poverty alleviation, though allocating water for environmental uses remains a challenge in the basin.

Surface and Groundwater Environmental flows in the South African portion of the Tuli Karoo The estimated surface water and groundwater environmental flows in the South African part of the Tuli Karoo Aquifer Area are 4.99 million m^3/a (DWA, 2011). The environmental reserve is required to satisfy Resource Quality Objectives (RQOs), which is the water quality and quantity target required at minimal to be satisfied for a healthy environment. The groundwater environmental reserve is 4.57 million m^3/a (Table 8.4), while the surface component is 0.237 million m^3/a. This gives a total reserve of 4.81 million m3/a for both surface water and groundwater components, which is still close to 4.99 million m^3/a estimated in the aquifer area. Due to the high rainfall variability and low recharge, new allocation of groundwater abstraction should take into consideration the existing groundwater allocations for the environment and the sustainability of the groundwater resource. Further, potential of contamination of water from mining effluent and acid mine drainage from Venetia mine and decant from the old mine at Musina in South Africa and other mines in Botswana and Zimbabwe should be recognized, to ensure satisfaction of environmental needs.

Table 8.4. Groundwater Environmental Reserve in the Tuli Karoo Aquifer Area (Data source: DWA, 2011).

Sub-Catchment	Site	Area (km^2)	Reserve million m^3/a
A-71	Tuli Karoo Aquifer (Upper Sand)	1,770	3.17
A63-2	Tuli-Karoo Aquifer (Mogalakwena)	1,990	1.40
Tuli Karoo Aquifer Area		3760	4.57

Environmental flows (reserve) in Zimbabwe The estimated environmental flows in the Zimbabwe portion of the Tuli Karoo Aquifer Area are 4.4 million m3/a in 2018. This reserve was calculated based on area proportion method of the Class C environmental flows allocated to Mzingwane Catchment to allow for minimal modification of rivers due to community development. There is no mention of the groundwater reserve in literature made available from Zimbabwe. The country makes use of internationally determined standard of EFRs pegged at approximately 10 percent pending more specific and locally determined Environmental Flow Requirements (EFRs) informed by assessment of environmental flows within local rivers in Zimbabwe in the seven catchment areas (Government of Zimbabwe, 2019). Environmental Flow Requirements (EFRs) in Zimbabwe were determined using a hydrologic method, a Revised Desktop Reserve Model (RDRM) which allowed for rapid assessment.

Environmental flows are yet to receive focus in Botswana. Information on environmental flows in Botswana was not available. There may be perceptions that the environment is a relative luxury given the extreme water stress and intense demand for water for basic needs.

8.5 Summary

Water Abstraction, Tuli Karoo Aquifer Area Irrigation is the largest water user 81.9 percent of water is used in irrigation in the Tuli Karoo Aquifer Area, followed by mining (8.2 percent), environmental flows (5.1 percent) and water supply service including domestic use (3.3 percent), livestock (1.1 percent) and industry (0.4 percent) as shown in Figure 8.8. Irrigation schemes often do not have enough water to fully satisfy demand (FAO, 2004). Unabstracted water, e.g. green water in rainfed agriculture, should also be recognized. Rainfed agriculture consumes 27,497 million m^3/a of green water, way above the blue water of 173.56 million m3/a consumed in the aquifer area.

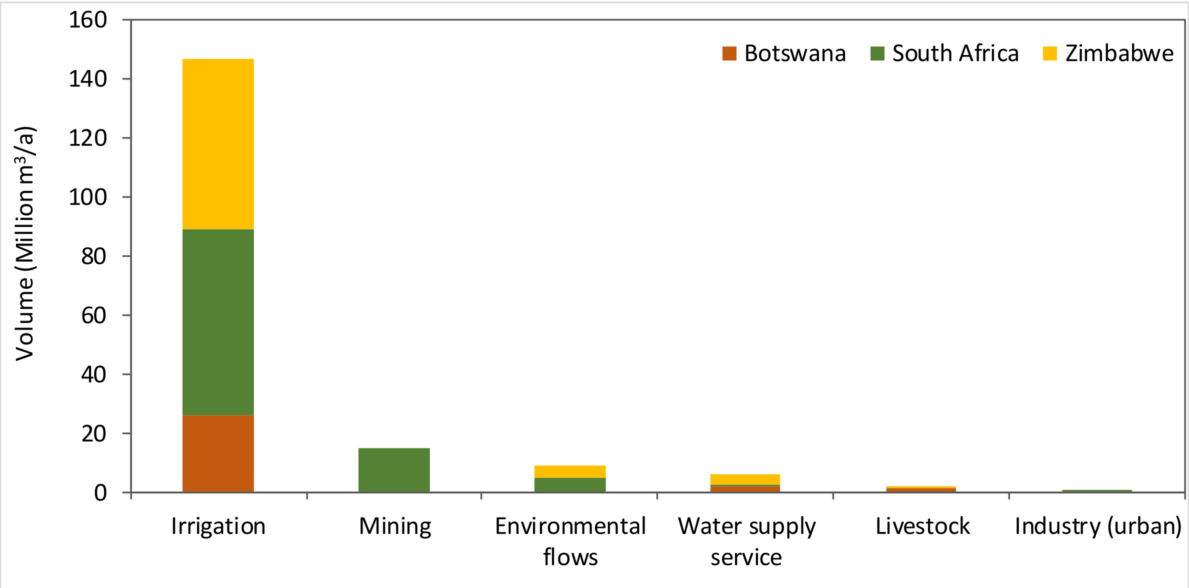


Figure 8.8: Summary of water Use in the Tuli Karoo Aquifer Area

Water Use is greatest in South Africa The total water demand or use in the Tuli Karoo Aquifer Area is estimated at 179.09 million m3/a (Table 8.5). The proportion of water use in Botswana, South Africa and Zimbabwe was 16 percent, 47 and 37 percent, respectively. South Africa uses the highest volume of water in irrigation and mining. This places pressure on both the quantity and quality of the resource. Further, given South Africa's downstream nature, it may leave its water use somewhat vulnerable to upstream modification. Botswana uses the highest volume of water for livestock watering compared to the other countries. A summary of estimated water use in each country is shown in Table 8.5. In general, groundwater is used extensively in the aquifer, mainly for irrigation and rural supplies as much of the rural population is located far from surface water resources (FAO, 2004).

Table 8.5. Water Use, Tuli-Karoo Aquifer Area

Water use	Botswana	South Africa	Zimbabwe	Total	Percent
Irrigation (million m^3/a)	26.0	63.3	57.3	146.7	81.9
Mining (million m^3/a)	-	14.6	-	14.6	8.2
Environmental flows (million m^3/a)	-	**4.8	4.4	9.2	5.1
Water supply service (million m^3/a)	*2.1	0.5	***3.3	6.0	3.3
Livestock (million m^3/a)	1.1	0.01	0.8	2.0	1.1
Industry (million m^3/a)	-	0.6	****	0.6	0.4
Total (million m^3/a)	**29.3**	**84.0**	**65.9**	**179.1**	**100**

* The water demand includes 10 percent non-domestic water use (mining and industry); ** the value includes surface water environmental flows (0.237 million m^3/a) and groundwater reserve of 4.57 million m^3/a; ***Water supply for Zimbabwe includes domestic, industry and mine water demand; ****Figure is included in the water supply service volume; (-) figure not provided. The water uses for domestic, mining, industry and livestock include non-revenue component of 20%, 30% and 48% for Botswana, South Africa and Zimbabwe, respectively.

8.6 Key Messages

The review of water use in the Tuli Karoo Aquifer Area reveals important considerations for shared water management. Key messages are as follows:

- ***Irrigation efficiency improvements should be explored*** Irrigation is the greatest user of water in the Aquifer Area and most irrigation water use is in South Africa. Introduction of sprinkler, dragon line and drip irrigation technologies for smallholder farmers in three countries could increase irrigation water use efficiency noticeably and substantially reduce the irrigation water demand. Similarly, use of technologies such as Wetting Front Detectors (WFDs) and Chameleons[10] can allow farmer to use less water and appropriately manage nutrients. These sort of interventions should be explored to enhance food security and resilience in this water stressed context.
- ***Water and Sanitation should be expanded*** More than 1/3 of the population lacks access to safe water supply and nearly half to sanitation. The realities undermine efforts to develop, and pose health risks to the populations that should be avoided. Expansion of water supply could is therefore necessary for improved health, and expansion of appropriate sanitation could enhance protection of the groundwater from contamination.
- ***Approaches to environmental flows should be harmonized*** While each of the three countries possess key environmental resources and groundwater dependent ecosystems, the way that they treat e-flows and the environmental reserve is not always aligned. Failure to align approaches in a shared water body can lead to poorly timed or insufficient water provision to the environment. It may therefore be beneficial to undertake discussion focused on harmonization of approaches.

[10] https://via.farm

- ***There is need for estimation of source-specific volumes of water use, how it varies and where are the spatio-temporal mismatches/gaps exists*** To fully understand water use in the system, it would be ideal to clarify the degree to which surface vs. groundwater is tapped for various purposes and any spatial mismatches of supply and demand identified. Such an understanding would help focus management efforts.

9. Institutions and Governance

Like most developing countries, those in the Tuli Karoo System have aspirations for economic growth in a way that accounts for concerns of resource depletion and pollution. Policy and legal frameworks, and the organizations mandated to enforce them, are key to facilitating effective management to realise these aspirations. This chapter examines these instruments and arrangements that apply across, in and within the three countries sharing the system also focusing on regional, national and local institutions.

9.1 Regional and Transboundary Frameworks

Regional Frameworks

SADC Botswana, South Africa and Zimbabwe are all members of the Southern African Development Community (SADC), a regional economic community that aims to advance socio-economic cooperation and integration as well as political and security cooperation. Economic development remains at the centre of the SADC regional strategy and vision (SADC, 2005). The 2016-2020 Regional Strategic Action Plan on Integrated Water Resources Development and Management (SADC, 2015) identifies areas of focus within the region, including transboundary aquifer management. SADC encourages member states to characterize and enhance knowledge of transboundary aquifers through TDAs and SAPs, as well as increasing cooperation among member states for managing transboundary ecosystems.

Regional Conventions and Policies An extensive set of regional policy exists to frame and guide cooperation on shared waters (Table 9.1). The *SADC Revised Protocol on Shared Watercourses* (SADC, 2000) lays the foundation for transboundary cooperation and calls for policy harmonisation on managing shared ground and surface watercourses. The Regional Water Strategy for 2006, implements the Regional Water Policy of 2005 by providing strategies for achieving regional integration in water management, including specific areas related to information sharing, infrastructure development, water demand management and establishment of joint institutions. Regional Strategic Action Plans for specific periods, the latest being for 2016-2020 (RSAP IV), which seek to further socio economic growth in the region with special attention to the water-energy-food nexus to achieve security in these three socio economic pillars (SADC, 2016), are drawn out of the Regional Indicative Strategic Action Plans (RISDP).

Table 9.1 Relevant SADC Water Policies and Strategies (Source: Adapted from SADC, 2015)

Policy/Strategy	Summary
The SADC Revised Protocol on Shared Watercourses (2000)	The overall objective of the SADC Revised Protocol on Shared Watercourses is to foster closer cooperation for judicious, sustainable and coordinated management, protection and utilisation of the 15 SADC shared watercourses, and to advance the SADC agenda of regional integration, poverty alleviation and economic development.
The SADC Regional Water Policy (2005)	The SADC Regional Water Policy provides a framework for sustainable, integrated and coordinated development, utilisation, protection and control of national and transboundary water resources in the SADC Region, for the promotion of socioeconomic development and regional integration and the improvement in the quality of life of all people in the region

Policy/Strategy	Summary
The SADC Regional Water Strategy (2006)	The Regional Water Strategy provides a framework for the implementation of the Regional Water Policy. The Strategy coves implementation modalities, roles and timelines.
The SADC Regional Awareness and Communication Strategy for the Water Sector (2009)	The SADC regional awareness and communication strategy aims to improve awareness and understanding on water issues and initiatives in the SADC region, contributing to poverty eradication and regional integration.
The SADC Guidelines for Strengthening River Basin Organisations (2010)	The SADC Guidelines for Strengthening River Basin Organisations cover four areas: establishment and development, environmental management, funding and financing and stakeholder participation.
Climate Change Adaptation in SADC: a Strategy for the Water Sector (2011)	The SADC climate change adaptation strategy aims to improve climate resilience in SADC.
SADC Regional Indicative Strategic Development Plan (2015-2020)	The five year plan was drawn to realise the economic productivity potential of the SADC region.
The SADC Regional Strategic Action Plans: I, II, III, IV	The main objective of the RSAP I (1999 to 2004) was to create an enabling environment for joint management of regional water resources. The RSAPII (2005-2010) emphasizes infrastructure development. The RSAP III (2011-2015) places focus on strengthening the enabling environment for water resources governance, management and development through the application of integrated water resources management. RSAP IV (2016-2020) seeks to further socio economic growth in the region with special attention to the water-energy-food nexus to achieve security in its pillars.

Transboundary Water Institutions

Limpopo Watercourse Commission (LIMCOM). At the basin level, all three countries fall within the Limpopo Watercourse Commission (LIMCOM). Established through the 2003 *Agreement on the establishment of the* Limpopo Watercourse *Commission* (LIMCOM, 2003), the objectives of LIMCOM are as follows:

- Advise countries and provide recommendations on the uses of the Waters of the Limpopo river
- Manage aspects related to the efficient and effective collection, processing and dissemination of data and information with regard to the Limpopo;
- Develop water infrastructure and the major investment in infrastructure programmes such as dams
- Promote regional co-operation and strengthening relationship amongst the four countries
- Act as an instrument to facilitate the sharing of benefits amongst the four countries
- Institutionalize cooperation in the integrated management of shared watercourses
- Promote stakeholder participation in decision-making.

LIMCOM's Practical Journey: In practice, the evolution of LIMCOM has been slow. Until recently, the River Basin Organization (RBO) consisted of only one staff: the executive secretary. There are nonetheless regular meetings at a political-level, as well as three task teams: i) a technical task team, ii) a flood task team, and iii) a legal task team. The RBO has gained some momentum since 2017, with the confirmation of a non-interim executive secretary and progress toward staff appointments. Overall, LIMCOM wields positive influence on water relations among basin-countries. The degree of such influence is nonetheless largely "soft" in nature.

Limpopo Groundwater Committee (LGC) In March 2019, the LGC was put into place. Facilitated by the Southern African Development Community-Groundwater Management Institute (SADC GMI), the LGC aims to promote understanding of groundwater management and availability in the basin. The specific areas covered by the committee are as follows:[11]

- Transboundary Cooperation that will facilitate the integration and harmonization of groundwater provisions between the national and basin level commitments;
- Support the need to update Protocols/Agreements with reference to solutions to address shared groundwater challenges, sharing of data and benefits from the cooperation;
- Promotion of Transboundary Aquifer Management in the riparian Member States and in collaboration with relevant government authorities;
- Jointly finding solutions to shared groundwater challenges through Transboundary Diagnostic Analysis (TDA) and Strategic Action Plans (SAP).
- Research on groundwater challenges in LIMCOM Transboundary Aquifers which will involve studies/pilots, information exchange on findings, training and implementation of solutions to emergent and priority groundwater management challenges;
- Collaborate on establishment and operationalization of institutional arrangements for shared Transboundary Aquifer management;
- Joint planning and implementation of activities such as workshops, research projects, etc including solicitation of funding where necessary; and
- Information and Communication Technologies for knowledge sharing platform to build an integrated data management system.

The formation of the LGC is timely, and provides and important bridge between cooperation on small ground-surface systems in the basin and the broader basin-wide LIMCOM. The aims of the Tuli Karoo work were presented at the inaugural LGC meeting, and agreement was reached to regular report progress on the Tuli Karoo through this newly formed committee.

9.2 National Constitutions and Country Visions

Constitutional rights of citizens. The supreme law of the three countries is the National Constitution. In South Africa, the Constitution of 1996 has received much acclaim for its progressive nature in granting basic human rights, such as access to free basic water. The tone of the constitution is a reflection of the repressive history of the apartheid era which aims to right the wrongs of the past (Government of South Africa, 1996). In Zimbabwe, the National Constitution only took effect through a referendum in 2013. The Zimbabwe constitution guarantees fundamental human rights as well as freedoms including rights to ''safe, clean and potable water'' (Government of Zimbabwe, 2013). In Botswana, the Constitution came into effect in 1966 and was revised in 2006. Under the Botswana constitution Bill of Rights, rights to water or health are not explicitly stated, the Government of

[11] https://sadc-gmi.org/2019/03/25/limpopo-river-basin-course-commission-limcom-and-sadc-groundwater-management-institute-launch-the-limcom-groundwater-committee/

Botswana is therefore not legally compelled to protect such rights as they are not legally enforceable (Government of Botswana, 2006; Mogomotsi et al., 2018).

Country Visions. All three countries in the Tuli Karoo System emphasise consideration for socio-economic growth. Guided by their Constitutions, there is an overarching drive to improve economic growth and reduce poverty, though the precise paths and timeframes toward this broader aim varies somewhat across the three countries. Botswana's 2036 vision is for 'economic prosperity for all' and to grow from an upper-middle-income economy to a high-income economy by 2036 (Government of Botswana, 2016) Zimbabwe, for example, aims to become a middle income economy by 2030 and looks to strengthen science and technology uptake to improve livelihoods and the economy (Government of Zimbabwe, 2018). In its National Development Plan, South Africa aims to 'eliminate poverty and reduce inequality by 2030' (NPC, 2016). Also articulated in this national development plan is the commitment to move toward a low carbon economy and ensuring environmental sustainability.

9.3 National Water Laws and Policies

Botswana

Botswana is currently in the midst of institutional reform with respect to water resources management. Reorganization of ministries has been ongoing since 2016. Following the approval of the functional structure, the current stage is focused on refining the operational structure[12]. With increasing economic expansion, Botswana began experiencing a rise in the demand for available water resources, leading to the National Water Policy Review (NWPR) in 2006. The review cited concerns with water supply sustainability, highlighting challenges such as high costs of supply expansion, and thus suggesting a move towards water demand management (WDM) (Setlogile and Harvey, 2015). Further, the review recommended a shift in policy towards IWRM (Mogomotsi et al, 2018).

Water Act (1968) The 1968 Water Act is the anchoring law of Botswana water policy. Calls for revision have been made but no changes have been to the Act to date (Mogomotsi et al., 2018). To make up for the deficiencies of the Act, several policy reviews and plans have been drafted as shown in the sections below. One of the major shortcomings highlighted in this Act was the lack of integrated management of water resources, which has been addressed in subsequent policies such at 2012 National water Policy which emphasise the integrated management of water.

National Water Policy (2012). The National Water Policy (NWP) emanated, at least partially, in response to the NWPR of 2006. The NWP embraces principles of integrated water resource management (IWRM) and encourages the conjunctive use of 'all categories / qualities of water' (MoMEWR, 2012). Abstraction of groundwater also receives attention with concerns around salinity and cost of exploitation of the resource. Challenges regarding water resource management are indicated around the limited nature of surface water as well as its transboundary context (MoMEWR, 2012). In addition, the policy highlights challenges around the organization of water management and proposed that water supply and sanitation responsibilities be reorganised under the Water Utilities Cooperation (MoMEWR, 2012). However, this may not have taken place, as currently the sanitation function falls under the Department of Water and Sanitation (DWS).

Integrated Water Resources Management & Water Efficiency Plan (IWRM&WE) **(2013)** Noting the need to optimise water use across various sectors and a growing population, a plan was drafted to address water use efficiency through managing the increasing demand on water resources. This plan would translate findings in the NWPR into actionable items for improving water supply and tightening the regulatory framework for specific water users (Mogomotsi et al., 2018). A primary motivation for

[12] Personal Communication with Director, DWS-BW

the plan the increasing urbanisation and drought frequency, worsened by the impact of climate change in the already water-scarce country (DWA-BW, 2013).

South Africa

Similar to Botswana, South Africa has been faced with a number of policy and institutional reforms since its independence in 1994. The main thrust of the post-colonial water law was ensuring equitable distribution and access to water for the indigent and historically disadvantaged individuals.

National Water Act (Act 36 of 1998). Water resources in South Africa are governed under the National Water Act, Act 36 of 1998 (Government of South Africa, 1998) which repealed the Water Act of 1956. The Act prescribes the use of Water Use Licenses as a tool to ensure equitable allocation of resources. It also lays down measures to deal with failure to comply with license conditions. A process for verification and validation of existing lawful uses carried over from the 1956 Water Act, was initiated in a bid to rationalize current water usage. In the previous Water Act of 1956, water rights were linked to land ownership (riparian rights) giving access only to a minority few, mostly white landowners (Kapangaziwiri et al., 2018). The new Water Act of 1998 institutes the formation of Catchment Management Agencies (CMAs), Water User Associations (WUAs) and articulates their role in water management.

Water Services Act (Act 108 of 1997) This Act was formulated to address water supply and provide access to basic water supply to all South Africans, including sanitation services. Also included in the Act is guidance towards setting of standards and tariffs for water supply. Institutions established through this Act include Water Boards and Water Service Authorities. Industrial effluent discharge into municipal infrastructure is regulated through this Act while wastewater discharge into natural systems is governed under the National Water Act of 1998.

National Water Resource Strategy II (2013) The vision for the National Water Resources Strategy II (NWRSII) is summarised as “Water for an equitable and sustainable future” (DWASA, 2013). Drafted under the then Department of Water Affairs (DWA), the main objectives of the strategy are to direct how water can be managed to (i) improve socio-economic standards and reduce inequalities (ii) create employment opportunities and (iii)sustainably meet competing demands for the resource while ensuring its protection and conservation. One of the messages emerging from the NWRSII (2013) was the need for conjunctive use of ground and surface water to augment water supply and reduce cost of water imports in water-scarce catchments. It was noted that dam construction in some areas resulted in the reduction of groundwater utilization, with particular reference being made to the Inyaka Dam. The message was therefore to promote conjunctive use of both surface and groundwater to reduce water supply risk in the area (DWA-SA, 2013).

National Water and Sanitation Master Plan (2018) At the core of the National Water and Sanitation Master Plan (NWSMP) are six thematic areas (i) regulation of water and sanitation (ii) improving raw water quality (iii) protecting and restoring ecological infrastructure (iv) reducing demand and increasing supply (v) redistribution for transformation and (vi) managing effective water services and sanitation (DWS, 2018). This would be achievable within an enabling environment consisting of clear legislation, technical and financial capacity, data and information, and research and development (DWS, 2018). One of the calls to action of the plan was the need to harmonize water and sanitation-related legislation to make it less complex and effective for service delivery. Among the policy proposals suggested in the NWSMP are (i) enforcement of the polluter pays principle (ii) use-it-or-lose- it principle (iii) equity in water allocation (iv) free basic water and sanitation for poor households only (v) establishment of CMAs (vi) creating a link between spatial planning and the water and sanitation master plan (DWS, 2018).

Water Policy Review (2013) In 2013, a process of reviewing water policies in South Africa commenced with the aim of reviewing the (i) 1994 White Paper on Water Supply and Sanitation (ii) 1997 White Paper on a National Water Policy for South Africa (iii) 2001 White Paper on Basic Household Sanitation and the (iv) 2003 Strategic Framework for Water Services. This review tabled areas of concern related to institutional arrangements, governance and equitable allocation (DWASAb, 2013). Of the institutional arrangements and governance concern areas, most important are:

- Delayed establishment of catchment management agencies
- Slow transformation of the infrastructure centred Irrigation Boards into Water User Associations
- The then-DWA not exercising its role in developing norms and standards for Water Service Authorities for water supply and sanitation

Zimbabwe

This section outlines key pillars of post-colonial water resources management in Zimbabwe. Notably, the first piece of legislation governing water resources came into effect 18 years after the country gained independence from British rule in 1980.

National Water Act of 1998. The National Water Act of 1998 sets the legal foundation for managing water resources in Zimbabwe (Government of Zimbabwe, 1998). This Act of 1998 repealed the Water Act of 1976 which was mainly tailored for commercial farmers and had a number of shortcomings such as (i) once a water right was issued, it had no expiry and could not be reviewed unless the holder volunteered to do so (ii) once resources in any area were all allocated there was no room for further allocation, in spite of the nature of the application (iii) inadequate address of groundwater abstraction beyond the registration of a borehole (Makurira and Mugumo, 2005). The new Water Act of 1998, therefore, set out to provide a more participatory approach to water management through the formation of catchment councils and sub catchment councils. Under this Act, all surface and groundwater became state-owned (Chikozho and Latham, 2005).

ZINWA Act of 1998 The Zimbabwe National Water Authority (ZINWA) Act of 1998 was enacted by parliament parallel to the National Water Act of 1998, to establish the implementing arm of the ZINWA Act which is the Zimbabwe National Water Authority. Through this Act, roles of ZINWA, Catchment Councils and Sub Catchment Councils were further articulated and put in place to further the goals of IWRM as set out in the legal framework. Political and economic pressures have adversely impacted the progress of IWRM implementation in Zimbabwe, a country whose economy is greatly dependant on the water-intensive agricultural sector. Further, as widely publicized, deterioration in irrigation infrastructure and inability of institutions to implement their mandate have been noted among the many challenges that impeded IWRM success in Zimbabwe (Manzungu and Derman, 2016;).

National Water Policy (NWP) 2012. The NWP (2012) aims to restore and re-establish the water sector in Zimbabwe, which had faced neglect due to socio-political and economic challenges (MoWRDM, 2012) to. The water policy identified major challenges in water resources development and management, among them being (i) underutilisation of water as seen in 2010 when 70% of total available water was not used for productive purposes (ii) reduction in demand for water for irrigation, impacting on revenues. (iii) shortcomings in data and information collection, negatively impacting effective decision making regarding water resources. The policy reemphasises the need for embracing IOWRM principles as was envisaged for the sector through the National Water Act of 1998 (MoWRDM, 2012).

Environmental Management Agency (EMA) Act (Chapter 20:27), 2002. This Act provides oversight on environmental management and protection including water. Wastewater discharge and pollution regulations are also articulated in this Act. The NWP of 2012 highlights the disjointed nature of legislation governing water resources and its limitations. It notes that The EMA Act is limited in correction and prevention of pollution as punitive measures are not necessarily linked to change in performance of remedial action (NWP, 2012).

9.4 Water Resource Management Organisations (Statutory Institutions)

Botswana

There are more than 10 organizations that play a key role in Botswana's statutory water governance framework. The main ones are described below and depicted in Figure 9.1.

Ministry of Land Management, Water and Sanitation Services (MoLMWSS). After a restructuring exercise in 2016, the MoLMWSS was created. Previously water was managed under the Ministry of Mineral, Energy and Water Resources (MoMEWR). Under the new ministry, key areas of oversight include policy development for water and land management including transboundary water resources management and negotiations. The ministry works through nine departments which include the Department of Water and Sanitation, Department of Lands and the Land Tribunal. The Water Utilities Cooperation (WUC) is a parastatal under the ministry's watch (MoLMWSS, 2019).

Department of Water Sanitation (DWS). Until recently, the DWS was known as the Department of Water Affairs (DWA), responsible for the management, planning and development of water resources. The DWA took on the sanitation function to become the DWS, despite the proposal in the National Water Policy of 2012 to consolidate the sanitation function under the Water Utilities Cooperation (WUC) (MoMEWR, 2012). The DWS is mainly focused on the management of water resources while the WUC focus of developing water supply services.

Water Utilities Cooperation (WUC). WUC's main responsibility in water supply services. It manages and monitors water resources from a supply-provision point of view. WUC was established under the Water Utilities Corporation Act. Concerns of overlap have been raised with DWS and the allocation of roles under the Water Sector Reform Programme (WSRP). The WSRP outcomes were implemented from 2009, and WUC took over its rationalised functions in 2013. DWS thus become responsible for water resources management and planning, forfeiting its water supply functions. WUC would then be responsible for water supply, reticulation and wastewater (WUC, 2019)

Water Apportionment Board (WAB) Under the Water Act of 1968, the WAB has the authority to grant water right related to (i) diversion, storage, abstraction and use of raw water including rights to discharge effluent for a period determined by the Board. Rights are subject to amendment as deemed necessary by the board (Water Act, 1968). WUC is also subject to licensing by WAB. Water tariffs are adjudicated according to volume of water abstracted. In the new institutional restructuring, the WAB would be replaced by the Water Resources Council (WRC) (Setlogile and Harvey, 2015).

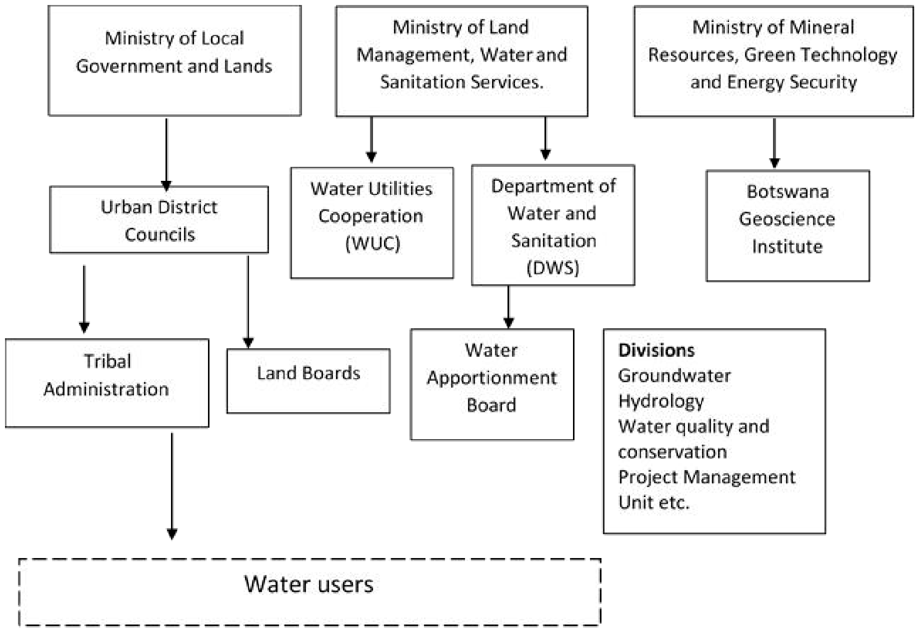


Figure 9.1: Botswana Water Resource Management Organisations

South Africa

Minister of Human Settlement, Water and Sanitation. At the time of writing, the Minister of Human Settlement, Water and Sanitation had recently been appointed under the new administration, post May 2019 presidential elections. This post is a merger of the Departments of Human Settlement and Water and Sanitation. This move may have been informed by the National Water and Sanitation Master Plan which highlighted the need to link spatial planning with water and sanitation.

Department of Water and Sanitation (DWS). The DWS is mandated with ensuring management and equitable distribution of water resources. Its overall mandate is to be the custodian of South Africa's water resources, managing them towards social and economic prosperity. Through a number of instruments including water use licenses (WUL), the department aims to keep tabs on water allocation in the country. Initiatives such as Blue Drop and Breen are directed at improved water supply and wastewater treatment plant performance. Guided by the National Water of 1994, the DWS has gone through a number of institutional reforms from being the Department of Water Affairs and Forestry (DWAF) to Department of Water Affairs (DWA) and currently the Department of Water and Sanitation (DWS, 2018).

Catchment Management Agencies (CMA). Instituted through the Water Act of 1998, Catchment Management Agencies were to be framed along hydrological boundaries. According to the Act, 9 CMAs should currently be functional. However, due to political and economic influences only two CMAs have been established to date. The function of CMAs is to decentralise decision making in catchments and to provide a participatory platform on which stakeholders within a catchment can address local catchment issues in an integrated manner.

Water User Association and Irrigation Boards. Before independence, Irrigation boards (IBs) were formed among white commercial farmers for allocation of water. Under the new Water Act, an inclusive Water User Association was envisaged which would cut across racial and political divides. There has been slow adoption of WUAs, with a number of them still functioning as IBs which are tied to water infrastructure (DWASA, 2013b).

Water Boards (WB) and Water Service Authorities (WSA). Created through Chapter 6 of the Water Services Act of 1997, WBs provide water bulk water to more than one Water Service Authority (WAS). They are state owned and are directly regulated by the Minister, in this case the Minister of Human Settlement. Water and Sanitation. Currently, 15 WBs are in operations whose function extend to include dam operations in addition to operation of bulk water infrastructure. WSAs on the other hand are those municipalities who are tasked with the water supply function in their municipalities (DWS, 2019). The relationship of these organisations is illustrated in Figure 9.2.

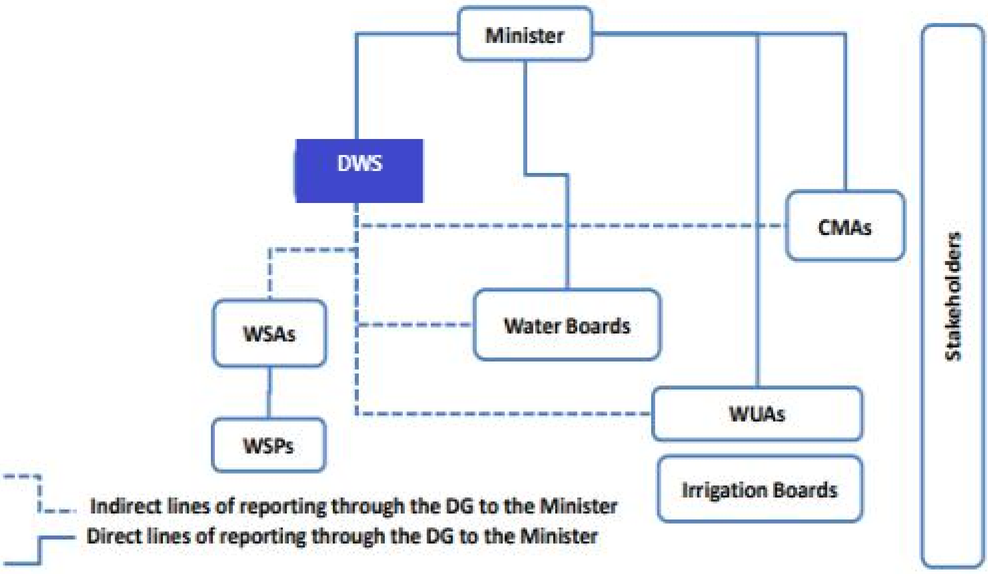


Figure 9.2: Water related Organisations, South Africa (*Source*: DWASA, 2013b)

Zimbabwe

Overarching Ministries The Ministry of Land Water, Agriculture, Climate and Rural Resettlement (MoLAWCRR). The MoLAWCRR is the main ministry governing water resources with ZINWA and the water supply and sanitation function reporting to it. The ministry is a recent amalgamation, following the election of a new government in 2018. It brings together three main functions of agriculture, water and rural resettlement. The Ministry of Environment, Tourism and Hospitality Industry takes on the function of environmental management through its implementing arm, Environmental Management Agency (EMA).

Zimbabwe National Water Authority (ZINWA). Formed in 2000, the parastatal's mission is to supply water to both rural and urban communities, sustainably through strategic water infrastructure investments. ZINWA currently operates over 50 water supply stations across the country (ZINWA, 2019). In 2004, ZINWA transferred its pollution control function to the newly formed Environmental Management Agency (EMA), letting go of its apparently conflicting water protection function. Currently the parastatal reports to the MoLAWCRR through the ZINWA board of directors (figure 9.23). its infrastructure development function is set to strengthen, with a pipeline of proposed reservoir construction projects including the Thuli Manyange Dam.[13] The Thuli Manyange dam is set to be built on the Thuli River, South of Gwanda and will have a projected capacity of 33 million cubic metres. Tuli Moswa water supply and irrigation project is also planned for the near future as project bid document for these two projects has already been advertised for tender.

[13] Personal Communication, ZINWA.

Environmental Management Agency (EMA). Instituted by the EMA Act of 2002, EMA is a parastatal with the mission to 'promote sustainable management of natural resources and the protection of the environment with stakeholder participation' (EMA, 2015). Part of its functions includes licensing for wastewater discharge and coordinating ambient water quality monitoring for the country's rivers and aquifers. Its functions are broadly split into (i) environmental management and planning services catering for environmental education and publicity programs and environmental protection and (ii) Environmental protection services which look into impact assessments, ecosystem protection, solid waste management, hazardous substances, wastewater and effluent licensing and compliance monitoring as well as air quality-related licensing and services.

National Action Committee (NAC) and the National Coordinating Unit (NCU). The current National Action Committee was mandated in 2010 and is made up Permanent Sectaries from various ministries. The purpose of this inter-ministerial committee is to have oversight over the Water Sanitation and Hygiene (WASH) sector. Through policy guidelines, the NAC provides monitoring, supervisory and resource mobilization services for the WASH sector. The National Coordinating Unit is the secretariat of the NAC implementing the WASH-related mandate of the NAC (Figure 9.3). An information management system (Rural Water, sanitation and hygiene Information Management System) maintains a database of WASH statistics on water access and sanitation facilities. The original function of the NAC was mostly limited to rural WASH but now includes urban WASH and water resource management functions (NAC, 2019).

Catchment and sub-catchment Councils. Catchment councils provide planning and oversight for respective catchments, including assessing and approval of water use permit applications and directing the function of the lower-tier sub-catchment councils (Mtisi, 2011). Sub-catchment Councils form the lowest level of statutory water management institutional structures. The Mzingwane Catchment, within which lies the Tuli Karoo transboundary Aquifer Area, consists of 4 sub-catchment councils (i) Upper Mzingwane sub catchment council, (ii) Lower Mzingwane sub-catchment council, (ii) Mwenezi sub-catchment council (iii) Shashe sub-catchment council. In sub-catchment council meetings, a number of issues are discussed which include (i) water resource planning (ii) water allocation (iii) catchment protection (iv) administrative issues[14]. Council members include MoLAWCRR, ZINWA, community members, water users and municipality representatives. Further, sub-catchment councils play a regulatory and supervisory function for permits issued in their jurisdiction, colleting required fees from water users and reporting to the catchment council (Mtisi, 2011).

[14] Minutes of the Mwenezi sub-catchment council meeting, March 2019.

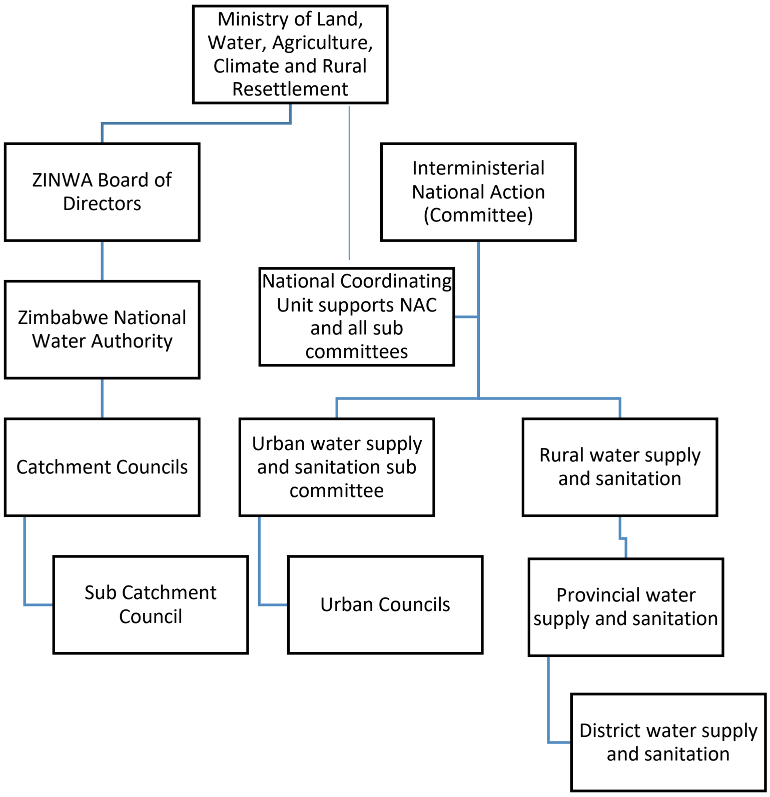


Figure 9.3: Water management Organisations, Zimbabwe

9.5 Customary Water Institutions

Indigenous institutions are a reality in water management. While there are merits and demerits of both customary and statutory institutions, the pervasiveness of customary institutions calls for focus on them here.

Common Colonial Legacy The legacy of colonialism is a shared attribute among all three countries sharing the Tuli Karoo System. Botswana and Zimbabwe were under British rule until their independence in 1966 and 1980, respectively. South Africa's early colonial history was dominated by the Dutch and British rule and later the Afrikaners apartheid regime (1948-1994). Due to colonial influence, customary institutions became largely overshadowed by statutory institutions inherited from western systems. To a large degree customary norms which were mostly unrecorded and flexible were often difficult for colonisers to comprehend (Gondo and Kolawole, 2019) and hence the need to 'standardise them' through a statutory framework. The post-colonial period has seen the perpetuation of western style legal frameworks which have largely disregarded customary systems.

Legal Pluralism and Hybrid Laws Studies on the importance of customary law in natural resource and water management has pointed to the importance of, and existence of legal pluralism and hybrid law, terms which represent an application and acknowledgement of different governance systems that can coexist in a society (von Benda-Beckmann et al.,1997; van Koppen et al., 2007; Gondo and Kolawole, 2019; van Koppen and Schreiner, 2019). In the Tuli Karoo System, acknowledging the existence of customary institutions may strengthen water resources management in the shared systems not withstanding their limitations such as conflict with constitutional rights.

Tuli Karoo System: Customary Water Institutions The rural nature of the Tuli Karoo System suggests that there could still be strong prevalence of customary institutions with respect to water allocation, ownership and use. The tribunal system (*Kgotla* in Botswana and *Dare* in Zimbabwe) present an accessible platform for local communities to discuss issues and receive adjudication. The Village Development Committee (VDC) in Botswana, is a committee made up of village representatives at local level who are elected by the Kgotla. VDCs in Botswana are a forum for solving community problems and setting the developmental agenda for the village, however they have no statutory authority to allocate water (Ngwenya, 2007). Similarly, Village Development Committees (VIDCOs) can be found in Zimbabwe under the rural district and traditional leadership line functions. Their functions, much as in Botswana, are related to developmental concerns in village communities.

Customary Water Management in Zimbabwe In the Manyame and Mazowe catchments of Zimbabwe, where there are predominantly Shona people, there is evidence that customary structures are still quite dominant and relevant in the communal areas (Chikozho and Latham, 2005). Statutory structures failed to recognise existing to customary and traditional demarcations of water management in that traditional and cultural territorial groupings were ignored by catchment delineations, thus making them irrelevant for local water management. Customary institutions were found to be well understood and respected by village communities because they could relate better to them compared to statutory institutions. For example, a participatory approach not only includes consulting village members but also the ancestral spirits who must first be appeased before developments such as dam construction can take place. In order to streamline statutory efforts, communications with ZINWA officials point to the integrating of customary structures into the legislative structure with traditional leadership afforded a seat at catchment council meetings and engaged in the water management processes in their localities.

9.6 Comparison of Water Management Institutions

Laws and Policies

National Water Laws and Policies: Similar elements across the three countries. While water-related legal and policy frameworks contain some differences, at least three fundamental elements are common to the three countries:

- ***Integrated approaches that balance competing demands*** In Botswana considerable attention has been paid to ensuring water supply security, managing the rising water demand from an increasing urban population. These challenges are worsened by the nature of water resources in Botswana which are largely transboundary and in short supply (MoMEWR, 2012). South Africa has focused on both water access - through providing free basic water - and equitable water allocation. The water allocation aspect being propelled by the need to redistribute water to the majority who were previously excluded. In Zimbabwe, focus has been placed centrally on balancing water supply and ensuring agricultural water availability.
- ***Participation*** Water laws and policies in the Tuli Karoo System show the appreciation for an integrated and participatory management of water resources, particularly in Zimbabwe and South Africa through their National Water Acts. The Botswana Water Act of 1968 mainly focuses on rights to water, but it is supported by policies that emphasise IWRM such as the National Water Policy (MoMEWR, 2012) and the IWRM&WE (DWA-BW, 2013).
- ***Conjunctive Water Management*** The management of ground and surface water conjunctively, comes across in the Botswana and Zimbabwe Water Policies as well as the South African National Water Resources Strategy II. The three countries realise the need for a holistic water management approach that takes into account both water resources and ensures their optimal use.

Organizations

Comparing organizations in the three countries Previous sections highlighted key organizations in water management across the three countries. Comparison of their national mandates suggests good degree of alignment. Botswana and Zimbabwe have a similar ministerial structure with oversight on land and water management. The recent reshuffle in South Africa added the human settlement function to water and sanitation, possibly to better streamline sanitation provision in housing developments and less to do with land management. There is a separate Department of Rural Development and Land Reform in South Africa.

In all three countries, Organisations apply across scales. Institutions in all the countries have local-level governance structures at provincial and district levels (Table 9.2). Communities are largely involved at the participatory level, a platform available in all three countries. In Botswana however, this lower level structure represented by the Village Development Committee (VDC) is not explicitly tailored for water management related issues and is a platform for any other development-related agenda in the community. In South Africa and Zimbabwe there are close similarities between water user associations and the sub-catchment council which comprise of different stakeholder in a community as related to water use and allocation. Both are designed along catchment (basin) lines. Village Development Committees (VIDCO) in Zimbabwe are gazetted under the Traditional Leaders Act of 1998 and Rural District Councils Act of 2012. VIDCOs preside over villages matters largely related to developmental issues, similar to Botswana.

Table 9.2: Comparison of water-related Organisations in the Tuli Karoo System

Governance level	**Botswana**	**South Africa**	**Zimbabwe**	**Comments**
Ministries	Ministry of land management, water and sanitation	Minister for human settlements, water and sanitation	Ministry of land, agriculture, water, climate and rural resettlement Ministry of environment, tourism and hospitality industry	A degree of combined land and water management institutions in all three countries.
Departmental institutions	-Department of Water and Sanitation -Water Utilities Cooperation -Water apportionment board	Department of Water and Sanitation Water Boards Water service Authorities	Zimbabwe National Water Authority Environmental Management Agency Rural water supply and sanitation committee	A separation of water resources management and water supply services
Local (Provincial District) Offices	Yes	Yes	Yes	Departments are largely devolved to provincial and district levels.
Participatory institutions	Village development committee (VDC)	Water user association	Sub catchment council, VIDCO	In Botswana, the VDC not only focuses on water related issues, as in the two countries but also considers other developmental issues in a locality

9.7 Key Messages

The review of water institutions in the Tuli Karoo reveals important considerations for shared water management. Key messages are as follows:

- ***There is commitment to transboundary water cooperation***. Through commitment to the SADC *Water Policy Framework*, the *revised Protocol on Shared Watercourses* (2000), and ratification of the Agreement on the Establishment of *the Limpopo Watercourse Commission* (2003), countries have manifested strong commitment to cooperation.
- ***Institutional alignment is favourable to closer coordination across borders*** Reasonable alignment in water management institutions exists across the three countries, with each placing key focus on integration, participation and conjunctive approaches. Further, statutory institutions show similarities across ministerial and departmental lines of water management and those responsible for water supply. At a local level, WUAs, sub-catchment councils and village development committees cover similar issues.
- ***Principles of IWRM are an integrating force*** While IWRM is no panacea, it provides a general legal and institutional framework for facilitating progress and cooperation on relevant key issues and can be used in the Tuli Karoo.
- ***Scale of cooperation requires careful navigation.*** While the Tuli Karoo may be far removed from the offices of national water authorities in the three countries, cross-border water interactions are not normally in the mandates of organisations closer to the ground like CMA and WUAs. Dynamics over resources sharing no doubt need to navigated carefully, but continued engagement with more local actors would seem to make sense as they are likely to be most knowledgeable on demands and dynamics of resources use.

10. Key Issues

The Tuli Karoo: A Complex System of shared waters In the context of shared groundwater systems in SADC that have received project focus to-date (Ramotswa, Stampriet, Shire), the Tuli Karoo appears on the complex end of the spectrum. It is shared by three countries. It is in a highly arid context. Some six surface water catchments intersect with the aquifer, and these catchments have been the focus of substantial water resources development in recent years. The aquifer itself has an alluvial layer that is heavily tapped in South Africa and a sandstone layer that receives substantial use in Botswana. Building on these biophysical realities, the Tuli Karoo System is a geography of food insecurity, climate vulnerability, poverty, unemployment and migration. The bottom line is that there is a pressing need to understand and manage the dynamics of this complex water system in order to most effectively ameliorate socioeconomic conditions.

Potential for more benefits to be tapped Despite the challenged context in which the Tuli Karoo System finds itself, there remains substantial potential for more benefits to be tapped. If carefully undertaken, for example, there may be potential for water use in productive activities such as agriculture—particularly if efficiency gains are achieved. Further, the proportion of water stored is currently high in the three countries yet management of this storage infrastructure appears unilateral. Scope for generation of additional benefit may lie in closer collaboration in the management of such national infrastructure. Yet an additional, and perhaps the most promising, way to enhance benefits derived from this shared system may lie in better understanding and harnessing groundwater. Major knowledge gaps unfortunately remain on availability, use and water level trends in the Tuli Karoo Aquifer. Nonetheless, if groundwater dynamics are better understood, the resource can constitute a powerful vehicle for resilience, food security and rural development—particularly if managed conjunctively with surface waters.

Pervasive and Potential Risks need to be proactively managed Achieving progress toward realizing additional benefits from the Tuli Karoo rests on a premise of effective management of at least four pervasive or potential risks in this shared water system. A first risk relates to climatic realities. In particular, rainfall variability poses a clear risk though to a lesser extent long-term reductions in mean rainfall may also be a concern. A suite of approaches, including subsurface dams and other forms of managed aquifer recharge, can be better evaluated to understand the degree to which they can enhance resilience. A second risk relates to water quality, specifically due to mines and poor sanitation. Measures exist for remediation that can be more actively pursued. A third risk relates to the environment and ecosystem services. Impacts of recent water resources development, and un-harmonized e-flow policies across countries, have not been thoroughly assessed. Needless to say, there is danger that short shrift consideration in this area can have disastrous impacts on other sectors on which greater value is presently placed. A final risk area relates to transboundary relations. Though cross-border impacts were not entirely clear from analyses in this TDA, what is clear is that continued exploitation of this shared system can easily lead to such impacts. It may be important to pre-empt misunderstandings that often accompany such impacts before they materialize. Ongoing joint monitoring, data exchange and knowledge generation on the shared system are key ways to minimize misunderstanding.

Key Issues Ultimately, consideration of preceding chapters of this report led to preliminary identification of five key issues, which can serve as a basis of discussion. Provision of feedback on this TDA may serve as an important conduit for comment on the suitability of these five issues as well as their relative order of importance. These five issues are as follows:

1. There is a need for improved, joint monitoring and greater understanding of the system While the volume of knowledge gaps on the Tuli Karoo can be overwhelming, addressing approximately three key areas can lay a foundation for informed decision-making and management. A first area is understanding river flow and groundwater recharge, presumably through an expanded and coordinated monitoring network. A second area is determining surface vs. groundwater use, perhaps through refinement to data collection methods in countries. A third area is understanding how surface and groundwater interact; focused investigations could be undertaken toward this end through use of chemical tracers.

2. Potential for irrigation expansion can be explored if efficiency gains are acheived Irrigation is simultaneously a means to enhancing food security, promoting rural development and mitigating effects of erratic rains. In the Tuli Karoo, there is likely scope to enhance the efficiency of existing schemes—particularly smallholder schemes and particularly in lower tech contexts outside of South Africa. Realization of such gains would likely free up water to enable potential for irrigation expansion to be considered.

3. Suitable resilience interventions should be identified, assessed and implemented The risks of climate variability and change in the Tuli Karoo are clear, and not unlike other regions in Africa. Interventions that strengthen resilience and are suited to conditions in the Tuli Karoo, can help to insulate communities from these climatic realities. It is critical to clarify suitability of approaches such as subsurface dams – already implemented in some portions of the aquifer area – and to identify new approaches such as pro-active alternation in the use of different water sources in a way that best ensures availability. Other managed aquifer recharge interventions can also be tested. Approaches determined to be successful should be more widely rolled out.

4. Ways to achieve greater satisfaction of environmental flows and ensure GDE health through cross-border policy harmonization should be considered A healthy ecosystem is key to continued viability of this shared system, and water is key to a healthy ecosystem. While other demands on water may constrain full satisfaction of environmental flow requirements, it is critical that provision of water to satisfy ecosystem needs – both conventional environmental surface flows and water for GDEs – be taken seriously. One way countries may be able to make progress toward this end is greater coordination on environmental flows. By aligning management approaches, it may be possible to more meaningful contributions to the ecosystem health in the context of reduced water contributions do not fully achieve optimal levels.

5. Impacts of mining and inadequate sanitation on water quality should be understood and addressed Pollution from mining and sanitation limitations have been prominently noted in earlier chapters of this TDA, in particular chapter 3 and 8. The pervasive risks associated with such pollution need to be remediated. Challenges with mines may be more manageable in some ways, as the source of their impacts may be more easily identified. Nonetheless, through community engagement and long-term change in practice including lining of pit latrines, risks associated with sanitation (e.g., nitrate contamination) may also be alleviated.

The role for Transboundary Water Cooperation A key cross-cutting element to at least three of the key issues identified (i.e., numbers 1, 3 and 4) is the role for transboundary cooperation. Collaboration on monitoring and data synthesis can lead to holistic understanding of the system that strengthens management. Cooperation in the management of infrastructure (e.g., for surface and groundwater use), across borders, can enhance resilience. Similarly, coordination on environmental-water issues is likely to enhance benefits that are derived from separate attempts to allocate water for the ecological needs. Ultimately, this points to the need for greater cooperation on the Tuli Karoo System presumably within, but not limited to, the framework of the Limpopo Watercourse Commission.

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Annex 1

Data Requirement	Source of Data		
	Botswana	**South Africa**	**Zimbabwe**
	Demography and Socioeconomics		
Demography and socio economics Population Gender composition Age structure Education and literacy Human health Poverty status Employment Livelihoods	StatsBW Ministry of Finance Ministry of Nationality, Immigration and Gender Affairs Ministry of Health	StatsSA Ministry of Finance	Central Statistics Office Provincial Administration Offices
	Institutions and		
Key national water and water related institutions and functions	Ministry of Land Management, Water and Sanitation Services	Department of Water and Sanitation Water boards	Ministry of Environment and Tourism
Transboundary Agreements	Ministry of Agriculture and Food security	Catchment management agencies	Environmental Management Agency
	Department of Water and Sanitation-GW division	Water User Associations	ZINWA
Land tenure and customary institutions		Catchment Management forums	Department of Geological Survey
Gender equity and land access and use	Management Office Ministry of Environment and Natural Resources (Department of Meteorological services) Water apportionment Board Botswana		
	Land boards		
	Department of Town	Transboundary	Transboundary
	and Regional Planning Department of Gender and	LIMCOM	LIMCOM
	Transboundary		

	LIMCOM		
Climate Data			
	Botswana	**South Africa**	**Zimbabwe**
Rainfall and temperature time series (daily)	Department of Meteorological Services (DMS)	South African Weather Service; DWS	Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement (MoLAWCRR)
Evaporation time series (monthly)	Botswana Water Accounting Reports - The Department of Water And Sanitation	South African Weather Service; DWS	
Other metrological parameters such as Relative humidity, radiation and wind speed	Department of Meteorological Services (DMS) Statistics Botswana	South African Weather Services; DWS	Meteorological Services Department
Stream flow data	The Centre for Applied Research Botswana	DWS	ZINWA- Hydrology Section
Past flood and drought occurrence	The Centre for Applied Research Botswana Statistics Botswana Natural Disasters Digest	DWS; South African Weather Service; LIMCOM reports	Meteorological Services Department; Ministry of LAWCRR
Geographic location of climate and stream flow gauging stations	Department of Meteorological Services (DMS) Department of Water and	DWS; South African Weather Service; LIMCOM reports	Meteorological Services; ZINWA Hydrology Section
Climate projection and scenarios	Department of Meteorological Services (DMS)	South African Weather Service; DWS	Ministry of LAWCRR – Climate Change Management Department
Hydrogeology and Surface Water Data			

Geological maps (1:250,000 scale)	Botswana Geoscience Institute	Council for Geoscience; DWS	LAWCRR; ZINWA
Soil maps	Food and Agriculture Organisation of the United Nations Ministry of Agriculture	Council for Geoscience; DWS; Department of Agriculture;	LAWCRR; ZINWA

Data Requirement	Source of Data		
	Botswana	South Africa	Zimbabwe
		Department of Environment (DEA)	
Hydrogeological maps	SADC Groundwater Management Institute Department of Water and Sanitation	Council for Geoscience; DWS; Consultants	LAWCRR; ZINWA
Policies (or Reports) on managed aquifer recharge	Ministry of Minerals, Energy and Water	DWS	LAWCRR; ZINWA
Water Quality Sampling Data	Department of Water and Sanitation	Council for Geoscience; DWS	LAWCRR; ZINWA
Basin Maps (GIS format if possible)	Botswana Geoscience Institute	Council for Geoscience	LAWCRR; ZINWA
Borehole database and associated data (e.g. geological profiles)	Department of Water and Sanitation	DWS; Municipality in Musina	ZINWA
Groundwater use and abstraction data	Department of Water and Sanitation	Stats-SA; DWS, Municipality in Musina	ZINWA (Hydrology and Groundwater Sections)
Surface Water use and abstraction data	Department of Water and Sanitation	Stats-SA; DWS, Municipality in Musina	ZINWA (Hydrology section)
River flow data (gauging station)	Department of Water and Sanitation	DWS	ZINWA (Mzingwane Catchment)
Spatial or point rainfall data	Department of Meteorological Services (DMS) Ministry of Environment and Natural Resources	South African Weather Services; DWS, Municipality in Musina	ZINWA (Mzingwane Catchment)
Discharge data	Department of Water and Sanitation Botswana Geoscience Institute	DWS	ZINWA (Mzingwane Catchment)
Aquatic weeds prevalence reports and data	Department of Water and Sanitation	DWS, Municipality in Musina	ZINWA (Mzingwane Catchment)

Groundwater quality (geochemistry)	Department of Water and Sanitation Botswana Geoscience Institute	DWS, Municipality in Musina	ZINWA (Hydrology and Groundwater Sections)
Surface water quality (geochemistry)	Department of Water and Sanitation Botswana Geoscience Institute	DWS, Municipality in Musina	ZINWA (Hydrology and Groundwater Sections)

Data Requirement	Source of Data		
	Botswana	**South Africa**	**Zimbabwe**
Groundwater isotope data	Department of Water and Sanitation Botswana	DWS	ZINWA (Hydrology and Groundwater Sections)
Surface water isotope data	Department of Water and Sanitation Botswana Geoscience Institute	DWS	ZINWA (Hydrology and Groundwater Sections)
Flooding reports (historical)	Department of Meteorological Services Department of Water and Sanitation	Department of Environmental Affairs; DWS; Department of Social Development; Department of Human Settlements	Meteorological Services; ZINWA (Mzingwane Catchment)
Flooding locality data (maps)	Global Flood Map Department of Water and Sanitation	Municipal Disaster Management Department; DWS; Department of Environmental Affairs	Meteorological Services; ZINWA (Mzingwane Catchment)
Strategic Investment/masterplans	Ministry of Minerals Resources, Green Technology and Energy Security	Municipal Integrated Development Plans (IDP) and Spatial Plans; Department of	Ministry of LAWCRR; ZINWA
Lineaments Map (GIS format)	Botswana Geoscience Institute Department of Surveys and Mapping	DWS, Municipal in Musina; Council for Geoscience	Department of the Surveyor General
Groundwater infiltration/recharge rate data	Department of Water and Sanitation Botswana Geoscience Institute	DWS, Municipality in Musina; Council for Geoscience	ZINWA (Hydrology and Groundwater Sections)
	Mapping for Sustainable	Open access SRTM	Open access SRTM

Digital elevation model data, DEM (varying resolutions if possible)	Development-RCMRD The Environmental Information Service Earth Explorer USGS (web portals) Department of Surveys and Mapping	90m or 30m	90m or 30m

Data Requirement	Source of Data		
	Botswana	**South Africa**	**Zimbabwe**
Borehole completion certificates	Department of Water and Sanitation	DWS; Council for Geoscience; Municipality in Musina	Ministry of LAWCRR; ZINWA (Hydrology and Groundwater Sections)
Consultancy Reports on Tuli Karoo Aquifer	Botswana Geoscience Institute	DWS; Council for Geoscience; Department of Agriculture Forestry and Fisheries; Municipality	Ministry of LAWCRR; ZINWA (Hydrology and Groundwater Sections)
Pumping test reports Tuli Karoo Aquifer	Botswana Geoscience institute Department of Water and Sanitation	DWS; Council for Geoscience; Municipality	Ministry of LAWCRR; ZINWA (Hydrology and Groundwater Sections)
Sectoral Water Uses Data			
Crop and Livestock	Ministry of Land Management, Water and Sanitation Services Department of Water and Sanitation Statistics Botswana Ministry of Agriculture Botswana University of Agriculture and Natural Resources	Stats-SA; Department of Agriculture Forestry and Fisheries; Farmer unions or organizations; Musina Local Municipality	ZINWA, Provincial departments, District offices, Catchment council Ministry of LAWCRR
Hydropower	Ministry of Minerals Resources, Green Technology and Energy	Department of Energy	Ministry of Energy and Power
Domestic water supply and sanitation	Department of Water and Sanitation	Stats-SA; Department of Social	Ministry of LAWCRR

	Water Utilities Cooperation	Development; DWS; Municipality; Water services providers	
Navigation	Department of Surveys and Mapping	Department of Marine Resources	Ministry of Transport and Infrastructure Development
Mining	Debswana Ministry of Minerals Resources, Green Technology and Energy Security Water Utilities Corporation	Department of Mineral Resources - DMR; Department Environmental Affairs; DWS	Ministry of Mines and Mining Development

Data Requirement	**Source of Data**		
	Botswana	**South Africa**	**Zimbabwe**
Industry	Ministry of Minerals Resources, Green Technology and Energy Security	Stats-SA; Department of Mineral Resources - DMR; Department of Environmental Affairs	Ministry of Industry and Commerce
	Water Utilities Cooperation	Municipality	
Environment and Ecosystems	Ministry of Environment, Natural Resources, Conservation and Tourism	Department Environmental And Sanitation; DWS; Kruger National Park	Ministry of Environment and Tourism
Games and Parks	Ministry of Environment, Natural Resources, Conservation and Tourism	Department of Environmental Affairs DWS; SANParks	Ministry of Environment and Tourism
Land use and land cover change map(GIS format)	Department of Surveys and Mapping Land Boards	Department Environmental And Sanitation; DWS	Ministry of Environment and Tourism
Landfill waste sites(if any)	Ministry of Environment, Natural Resources, Conservation and Tourism	Department Environmental And Sanitation; DWS	Ministry of Environment and Tourism

	Ministry of Land Management, Water and Sanitation Services		
	Department of Water and Sanitation		

Annex 2

Tuli Karoo - Data Collection field trip 27-31 May 2019

Gaborone- Francistown-Bulawayo-Harare-Beitbridge

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Tuli Karoo - Data Collection field trip 27-31 May 2019

Gaborone- Francistown-Bulawayo-Harare-Beitbridge

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Wednesday 27th March 2019.

Tuli Karoo Conjunctive Water Management

Mhlahlandlela Government building

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Annex 3

Consultations

water & sanitation

Department:
Water and Sanitation
REPUBLIC OF SOUTH AFRICA

ATTENDANCE REGISTER

Conjunctive Transboundary Water Management In the Tuli-Karoo

Date: 19 August 2019, Time: 10:00 – 12:30

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