Water and Cooperation within the Zambezi River Basin (WACOZA)

National University of Science and Technology, Zimbabwe (NUST, ZIM)

Intermediate report on Zambezi River Basin Groundwater Hydrology Characterisation in Zimbabwe

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Contents

LIST OF FIGURES 3
LIST OF TABLES 4
1.0 INTRODUCTION 5
1.1 Background 5
1.2 Selected Study Areas within the Zambezi River basin in Zimbabwe 5
1.3 Structure of the report 6
2.0 MULTI-SCALE GROUNDWATER HYDROLOGY BASELINE DATABASE AT ZRB AND ZIMBABWE SCALE 8
2.1 Surface Hydrology 8
2.2 Geological setting of the Zambezi basin in Zimbabwe 9
2.3 Characterisation of ZRB groundwater hydrology in Zimbabwe 10
2.4 Aquifer properties in the ZRB in Zimbabwe 12
3.0 BASELINE CONDITIONS DATABASE ON GROUNDWATER DEMAND VS. AVAILABILITY AND QUALITY 13
3.1 Introduction 13
3.2 Baseline Conditions of Ground water Availability in ZRB in Zimbabwe 14
3.3 Ground Water Demand in ZRB Zimbabwe 18
3.4 Baseline Conditions of Water quality in ZRB in Zimbabwe 21
4.0 MAJOR BASELINE FINDINGS IN ZRB IN ZIMBABWE 25
4.1 Multi-scale groundwater hydrology baseline database at ZRB and Zimbabwe scale 25
4.2 Baseline conditions database on water demand vs. availability and quality 25
REFERENCES 26

LIST OF FIGURES

Fig 1.1 Hydrological catchment areas in the Zambezi River Basin in Zimbabwe 6
Fig 2.1 The DEM of the Zambezi River Basin in Zimbabwe 8
Fig 2.2 The geology of the Zambezi River Basin in Zimbabwe 9
Fig 2.3 Depth of boreholes in the Zambezi River basin 11
Fig 2.4 Borehole Yields in the Zambezi River Basin in Zimbabwe..12
Fig 3.1 Percentage distribution of water source types in Gwayi Catchment 16
Fig 3.2 Percentage distribution of water source types in Manyame Catchment 16
Fig 3.3 Percentage distribution of water source types in Mazowe Catchment........................17
Fig 3.4 Percentage distribution of water source types in Sanyati Catchment 18
Fig 3.5 Land use patterns in the Zambezi River Basin in Zimbabwe......................................19
Fig 3.6 Percentage land use in the Zambezi River Basin in Zimbabwe 20
Fig 3.7 Borehole distribution on various land use in the ZRB in Zimbabwe 21

LIST OF TABLES

Table 3.1 Groundwater recharge estimation as proportion of precipitation............................ 13
Table 3.2 Selected District study areas.. 15

1.0 INTRODUCTION

1.1 Background

Evidence from National plans for water supply and sanitation indicate that in almost all the riparian countries of the Zambezi River basin, groundwater is the main source of rural water supply. It is also an important source of urban and peri-urban water supply for rural towns and some major cities (SADC-WD/Zambezi River Authority, 2007). Therefore it is imperative that groundwater hydrology and quality investigations are key to the “Water and Cooperation within the Zambezi River Basin (ZRB)” case study project for Southern Africa Centres of Excellence (CoEs) in the framework of AU/NEPAD ACEWATER2 project. The general objective of the case study project was to assess Water-Energy-Food-Ecosystem (WEFE) interdependencies by developing and testing a Spatial Decision Support System on Water Cooperation, across the Zambezi River Basin.

In order to contribute to the development of the Spatial Decision Support System on Water Cooperation, the following specific objectives guided scientific activities related to groundwater hydrology and quality:

1. To provide a multi-scale groundwater hydrology baseline database at ZRB and selected countries level, based on literature review, available data sources and existing country/regional scale studies of major relevance to WEFE nexus;
2. To provide baseline conditions database on groundwater hydrology and water demand vs. availability for few shared regional case studies, by gathering and processing data and by-products and to perform groundwater assessment;
3. To perform vulnerability assessment to contamination of selected aquifers across the ZRB.

1.2 Selected Study Areas within the Zambezi River basin in Zimbabwe

Zambia and Zimbabwe have the biggest area shares inside the basin, therefore, their population in the watershed are also substantial with approximately 7.5 million each. Actual population for Zimbabwe is 7 603 000 which is 25.3% of the total population in the basin (World Bank 2010). The Zambezi River enters Zimbabwe at the Zambezi-Chobe confluence close to Kazungula, where the boundaries of Namibia, Botswana, Zambia and Zimbabwe merge. The Zambezi River forms the border between Zambia and Zimbabwe. The river is divided into 3 segments, the Upper, Middle and Lower Zambezi. The Zimbabwean sub-basins form part of the 853 km long middle Zambezi, which stretches from Victoria Falls to Cahora Bassa Gorge. The sub basins of the Zambezi river basin in Zimbabwe, namely the Gwayi, Sanyati, Manyame and Mazowe sub-basins shown in Fig 1.1, constitute 15.8% of the total basin area, and 54.5%

of the total area of Zimbabwe. The combined surface runoff from the Zimbabwean sub basins is estimated to be 34mm. The sub basins in Zimbabwe form four of the seven hydrological zones in Zimbabwe.

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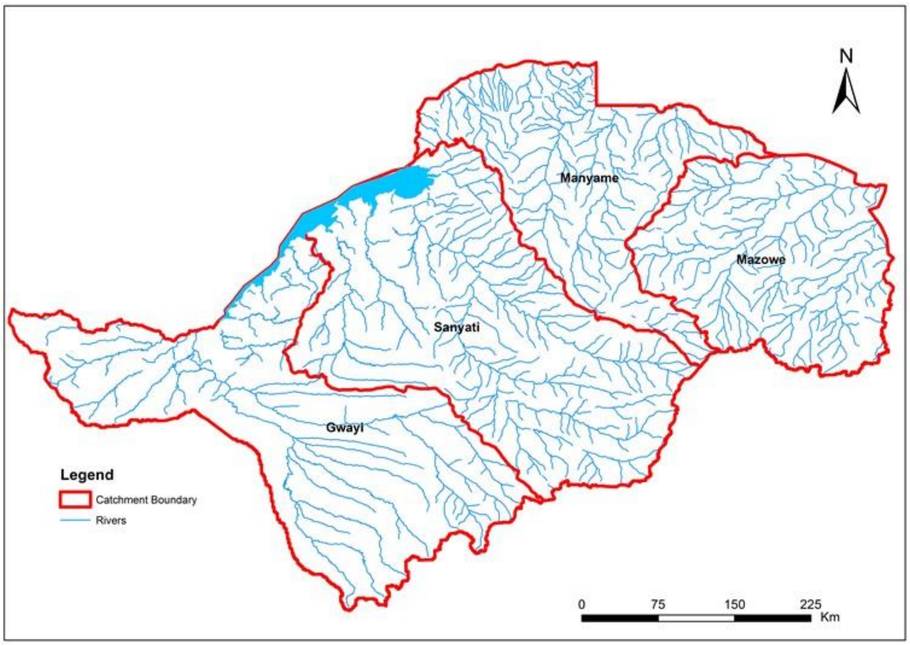

Fig 1.1 Hydrological catchment areas in the Zambezi River Basin in Zimbabwe

The hydrological catchments drain into four major rivers that drain into the Zambezi River, namely Gwayi River, Manyame River, Mazowe River and Sanyati River. Of the 14140 Mm^3 of surface water that leaves the country, 99.7 % is contributed by the Mazowe River to Mozambique, and 40 million m^3/year through the Nata River to Botswana (Davis and Hirji, 2014). Studies of rainfall records such as by Tumbare (2004) in the basin covering two centuries reveal that droughts were recorded in 60 years out of the 200 years. Studies have also revealed that during drought years the demand for ground water for food production increases demonstrating the interdependencies of Water, Energy, Food and the Ecosystem (WEFE). Droughts are expected to become more frequent and more intense due to climate change (Tumbare, 2004).

1.3 Structure of the report

The context of this intermediate report was to provide a baseline database on the character of ground water hydrology in the Zambezi River Basin in Zimbabwe as presented in specific objectives 1 and 2. For the purposes of this report, baseline data was analysed for the following thematic areas:

- Groundwater hydrology
  In this section an analysis of the state and spatial distribution of aquifers in the ZRB was made based on available data and literature review.
- Groundwater availability and quality
  Groundwater availability was analysed in the form of spatial distribution of boreholes and the respective yields of the boreholes found in the river basin.
- Water demand and water use patterns
  Water demand and water use patterns were analysed according to selected districts in the different catchments.

2.0 MULTI-SCALE GROUNDWATER HYDROLOGY BASELINE AT ZRB AND ZIMBABWE SCALE

2.1 Surface Hydrology

Although the focus of this report is groundwater hydrology, the surface hydrological properties of the basin are introduced briefly since groundwater and surface water systems are linked. The Digital Elevation model (DEM) in Fig 2.1 shows the four major river systems that constitute the Zambezi River Basin in Zimbabwe. The low lying areas act as the recharge zones for the basin since the potential evapotranspiration exceeds the annual precipitation in most parts of the basin (FAO 2016).

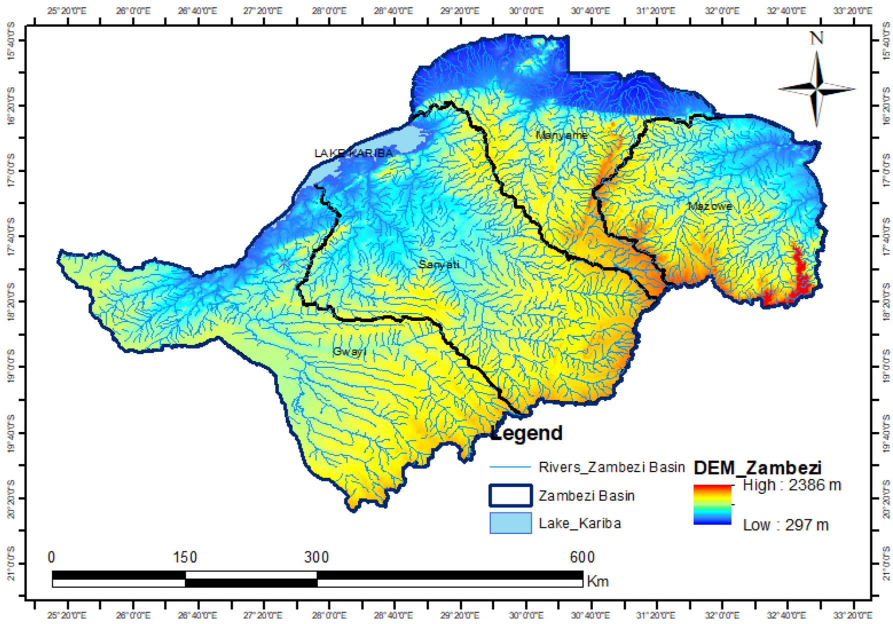

Fig 2.1 The DEM of the Zambezi River Basin in Zimbabwe

The Gwayi catchment covers an area of 87960km^2, with altitude varying from 600m to 1500m above mean sea level. Mean annual rainfall ranges from 400 mm in the western part of the catchment to 700 mm per annum (ZINWA, 2006; FAO 2016). The Mazowe catchment covers an area of 38937km^2. Mean annual rainfall varies in the catchment, ranging from 415 – 800 mm per annum. The upper and middle areas of the catchment receive the higher rainfall.

The Manyame catchment has an estimated area of 40497 km^2. Elevation ranges between 300-1800m above sea level. The mean annual rainfall in this catchment is 750 mm, with the upper Manyame receiving the higher average of 800 mm per annum, while the lower catchment receives 730 – 790 mm / year. Although this catchment receives higher than the national average rainfall, localized areas in the Lower Manyame and Angwa Rukomechi areas receive lower rainfall than the rest.

2.2 Geological setting of the Zambezi basin in Zimbabwe

The geological origins of the Zambezi basin in Zimbabwe are complex as described by Davies (1986) and Key et al., (2015), among others. Overall, Zimbabwe's groundwater resources are limited since about 60% of the country is underlain by crystalline basement rocks, (Mudimbo et al., 2018; Davis and Hirji, 2014). The geology of Zimbabwe comprises, in chronological order, the broad classes of recent unconsolidated sediments (aeolian sands and alluvium), Kalahari basin sedimentary formations, Upper and Lower Karoo formations, igneous intrusives, and basement complex formations, respectively (Mudimbo et al., 2018). These broad classes are depicted in Fig 2.2.

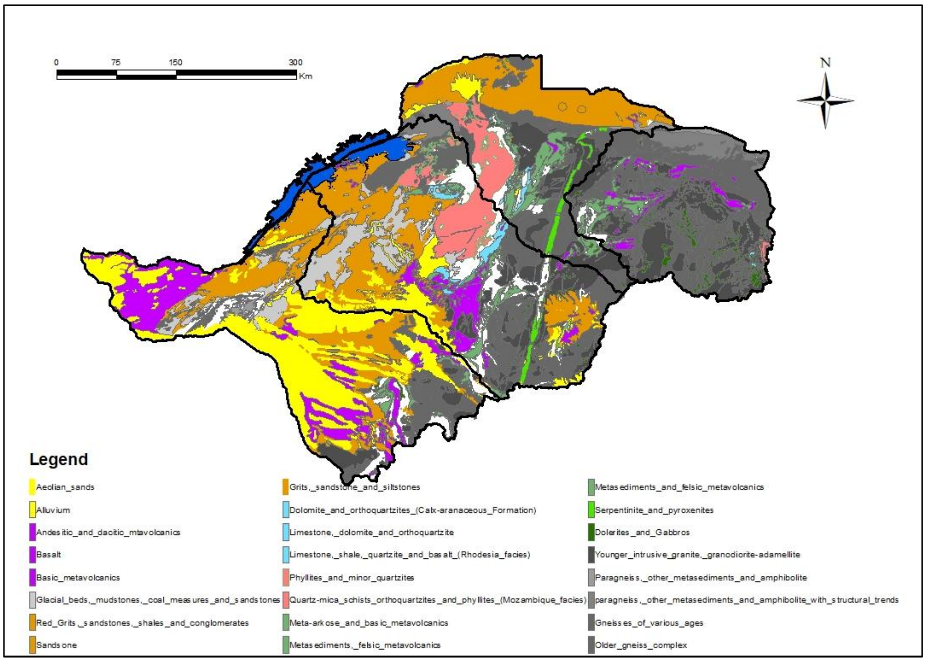

Fig 2.2 The geology of the Zambezi River Basin in Zimbabwe

The recent sediments generally do not exceed 25m depth except in the Sabi Valley and the Zambezi valley where they reach depths of 40m or more. The sandstones, siltstones, grits and Kalahari sand, mainly covering Western Zimbabwe, constitute the Kalahari basin. A substantial thickness of alternating sandstones, siltstones and mudstone of the Lower Karoo is overlain by the Upper Karoo Batoka basalts and metavolcanics.

The 550km long great dyke is an intrusive feature that hosts economically important deposits of mainly chromite and platinum. The various metasediments that include quartzite, shales and phyllites overlie the basement complex that covers at least 60% of the country (Mudimbo et al., 2018). Basement rocks include mainly gneisses intruded by granites of various ages. Within the basement complex, weathering plays an important role in groundwater occurrence. Weathering thicknesses less than 30m tend to occur on the younger granites and gneisses, while greater thicknesses occur within the greenstone belts and the older African erosional surface.

2.3 Characterisation of ZRB groundwater hydrology in Zimbabwe

Previous studies tend to characterize aquifer units primarily according to rock type, with additional characterisation according to annual rainfall, topography, land use and land cover. Local aquifers occur within basement rocks in areas with high fracture density, or a substantial thickness of weathered regolith. Within the Zambezi basin, there are local aquifer systems with varying groundwater potential.

In the Gwayi catchment, the forest sandstone aquifer is part of the transboundary Karoo Aquifers, shared by Botswana, Namibia, South Africa, Zambia and Zimbabwe. This catchment consists mainly of Kalahari sands and the Karoo sedimentary formations. Within the Karoo sequence, different lithologies account for differences in the groundwater potential within the catchment. The Upper Karoo sequence comprises the Batoka basalt, the forest sandstone, and the escarpment grit, whereas the mudstone, and the upper and lower Wankie sandstone constitute the lower Karoo. The aquifers in this catchment have good primary porosity and excellent groundwater potential (Pavelic et al, 2012; Davis and Hirji, 2014). Although the groundwater potential is high, it may be uneconomic to abstract the groundwater due to water table depths in excess of 100m in the sandstone formations as depicted in Fig 2.3.

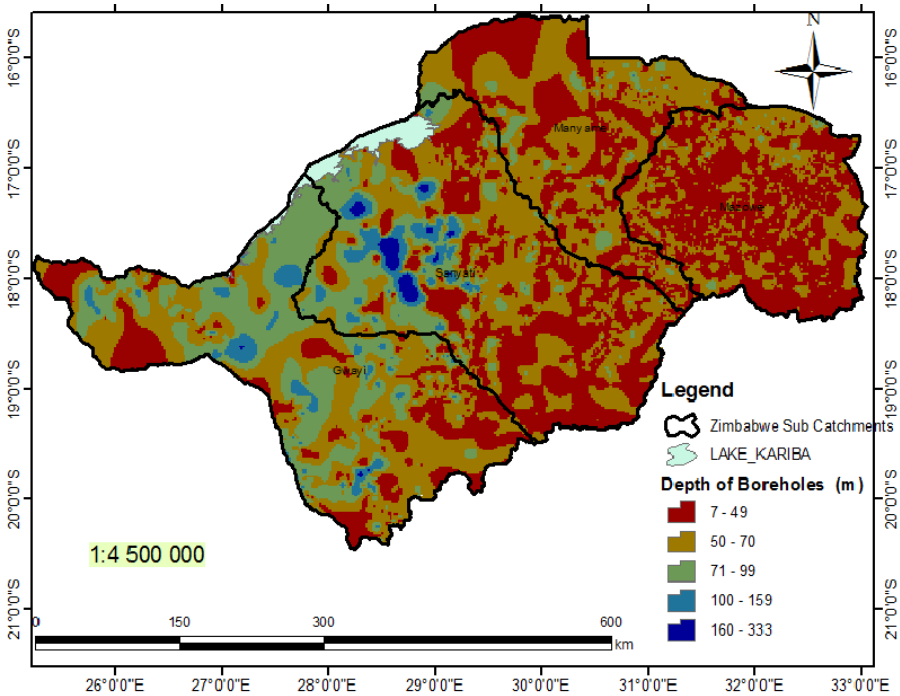

Fig 2.3 Depth of boreholes in the Zambezi River basin

Manyame catchment is dominated by granite and metamorphic rocks, with Karoo sediments accounting for just 20% of the geological formations. Aquifers in this region are mainly as a result of extensive weathering of the basement rocks. However in this catchment, weathered argillites do not make good groundwater reservoirs due to the high proportion of fines in the weathered regolith.

The geology in Mazowe catchment is entirely crystalline metamorphic rock province. The major rock types are gneiss and young intrusive granite on post African and Pliocene surface. As such, aquifers in this area are all due to secondary porosity due to weathering and fracture porosity. The groundwater potential is marginally higher in the watershed areas where the regolith is deeper, than in the downstream areas with limited regolith. Groundwater development potential is generally low, with water table depth being less than 10 metres. Borehole depths in this catchment rarely exceed 70m (Fig 2.3) and are mainly controlled by the depth of weathered regolith. Borehole yields are of the order of 10 – 50 m^3 day^{-1} (Interconsult, 1985).

Geological formations in Sanyati catchment include crystalline and metamorphic rocks (70%) with low groundwater potential, and Karoo sediments (30%) with good groundwater potential. The Lomagundi Dolomite aquifer occurs at the centre this catchment and has very high borehole yields of 500 – 2000 m^3/day. Average borehole depths in the dolomite are 50 – 80 metres (Pavelic et al., 2012). The long-term abstraction of groundwater for commercial irrigation from the Lomagundi aquifer has reportedly resulted in a lowering of the water table and diminished borehole yields.

2.4 Aquifer properties in the ZRB in Zimbabwe

Aquifer hydraulic properties data in the ZRB in Zimbabwe are scarce and as Bonsor and MacDonald (2010) recommend, yield data may be used as proxy for transmissivity and storativity. Their review revealed that in crystalline basement aquifers, most borehole yield values lie between 0.1 l/s and 5 l/s, and in basement regolith, yield values showed the least variation. As Fig 2.4 shows, borehole yields in the basin range from below 70, 000 litres/day in the basement aquifers (Manyame and Mazowe Catchments) to over 2,000,000 litres/day in the Lomagundi Aquifer.

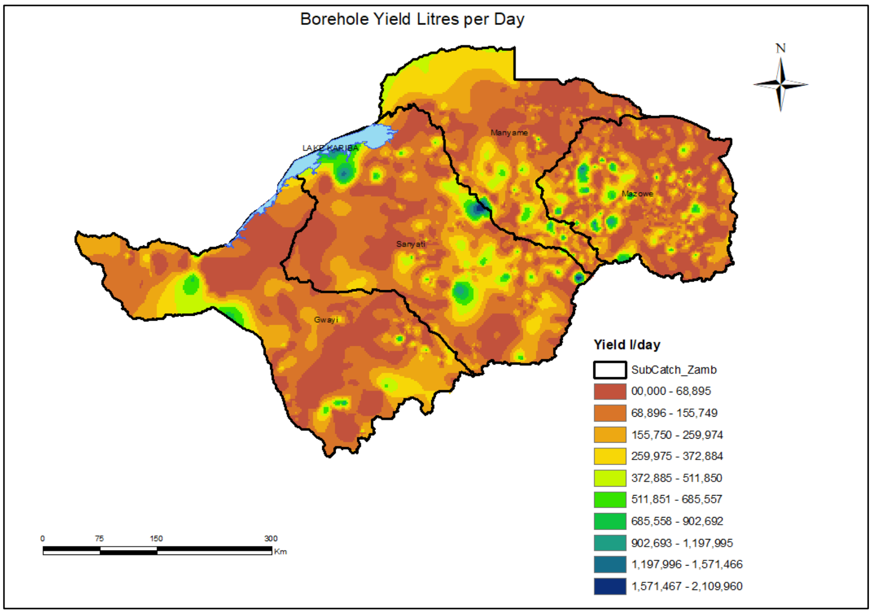

Fig 2.4 Borehole Yields in the Zambezi River Basin in Zimbabwe

High yields are also obtained in the Gwayi catchment within the sands and sandstone. Bonsor and MacDonald (2010) found that, unlike in basement regolith, yield values in meta-sedimentary rocks show a wide variability.

3.0 BASELINE CONDITIONS ON GROUNDWATER DEMAND VS. AVAILABILITY AND QUALITY

3.1 Introduction

Good estimates of the recharge rate in the aquifer units are required to estimate the water that can be safely extracted from ground water sources in the ZRB. In data scarce areas, various techniques have been used to estimate recharge to aquifers. One of the methods that may be applied is to estimate the recharge as a proportion of the precipitation. Table 3.1 may be used as an initial estimate of recharge where there are no studies available as in the case of the ZRB in Zimbabwe. Bonsor and MacDonald (2010) found a strong linear relationship between rainfall and recharge (R^2 = 0.73) in basement aquifers and in regions with rainfall higher than 500 mm/year, but a nonlinear relationship in sedimentary aquifers. Due to the high potential evapotranspiration of up to 2000 mm in the low lying areas (FAO 2016), groundwater recharge occurs mainly during high intensity rainfall events (De Vries and Simmers, 2002). As such, total annual rainfall may not be a good predictor of annual recharge for parts of the Zambezi basin (Wang et al., 2010).

Table 3.1 Groundwater recharge estimation as proportion of precipitation

Precipitation (mm/yr)	<400	500	600	700	800	900	>1000
% Precipitation	2	2	4	5	7	10	15
Recharge (mm)	8	10	24	35	56	90	150

Recharge estimation studies within the sub basins are few, and the according to the SADC GMI database, the recharge rate for the country is 20-100 mm per annum. Sibanda et al., (2009) estimated recharge of the Nyamandlovu aquifer to be 15-20 mm per year based on the chloride mass balance method, water-table fluctuation method, Darcian flownet computations and groundwater modeling. This value is equivalent to just 2.7 – 3.6 % of the annual precipitation of the area. This value of computed recharge is in good agreement with the guideline provided in Table 3.1. Therefore, in the absence of recharge studies for this area, recharge values were estimated as a fraction of the annual average precipitation.

Gwayi catchment has an estimated recharge of 1600Gl per annum; Manyame catchment has an estimated recharge of 1900Gl per annum; Mazowe catchment has an estimated recharge of 1920Gl per annum and Sanyati catchment has the highest recharge per annum, estimated at 2750 Gl per annum. The total groundwater recharge per annum in the four catchments is 8170 Gl. Applying a factor of safety of 0.6, the water that can be safely extracted from the combined catchments is 4900 million m^3/year. FAO (2016) estimates the country's renewable groundwater resource to be 6 000 million m^3/year. Thus, the contribution of the Zambezi River basin to the groundwater reserves of Zimbabwe is quite substantial at 82% of the total renewable groundwater.

Safe yield may be defined as the accomplishment and maintenance of a long-term balance between the amount of ground water withdrawn annually and the annual amount of recharge (Sophocleous and Sawin, 1997). Safe yield may also be defined as the maximum abstraction of an aquifer that does not exceed the recharge from precipitation and surface water infiltration. However, this definition of safe yield ignores the fact that over long periods under equilibrium conditions, natural recharge is balanced by discharge from the aquifer into streams, springs and by evapotranspiration (Sophocleous, 2000). Consequently, if abstraction equals recharge, eventually streams, marshes and springs may dry up. According to Sophocleous (2000), groundwater losses can be accounted for by making the safe yield slightly less than the average annual recharge. Maxwell et al., (2012) suggest that provision be made for losses and natural ecosystem maintenance requirements by estimating safe yield to be less than annual recharge by a factor of safety of 0.6.

An analysis of the groundwater -surface water connectivity show that many of the rivers in the different sub-basins are non-perennial with very little base flow contribution to the overall surface runoff. Estimates of base flow indices were made by ZINWA, (2006) using the smoothed minima techniques as demonstrated by Bullock et al., (1997) and Mazvimavi et al., (2004). Within the ZRB in Zimbabwe, base flow indices range from 0.05 to 0.40. The highest base flow indices, which indicate the highest groundwater contribution to surface water, were recorded in the alluvial deposits of the Gwayi catchment and the upper regions of both the Manyame and Mazowe catchments.

3.2 Baseline Conditions of Ground water Availability in ZRB in Zimbabwe

Groundwater availability was analysed in the form of spatial distribution of boreholes and the respective yields of the boreholes found in the river basin. The ground water sources in the selected districts are boreholes, deep wells, shallow wells, artesian wells and springs. These sources are communally, institutionally or individually owned. The availability of these ground water sources vary from one catchment to another.

For the purposes of analyzing baseline conditions of water demand versus availability in ZRB in Zimbabwe thirteen (13) districts which had available data were purposively selected to represent the different hydrological catchments in the ZRB as shown in Table 3.2.

Table 3.2 Selected District study areas

Zambezi Sub catchment	**Selected Districts**
Gwayi	• Binga • Hwange • Nkayi • Lupane
Manyame	• Kariba • Hurungwe • Makonde
Mazowe	• Mudzi • Mutoko • Uzumba Maramba Pfungwe
Sanyati	• Gokwe North • Gokwe South • Zvimba

In Gwayi catchment, four districts namely Binga, Hwange, Nkayi and Lupane were studied which are predominantly rural. Communities in these districts utilise groundwater from boreholes, artesian wells, deep wells, shallow wells and springs as shown in Fig 3.1. Boreholes constitute the highest percentage of ground water sources with an average of 53% for the four districts while the source with the lowest percentage is artesian wells with an average of 1%.

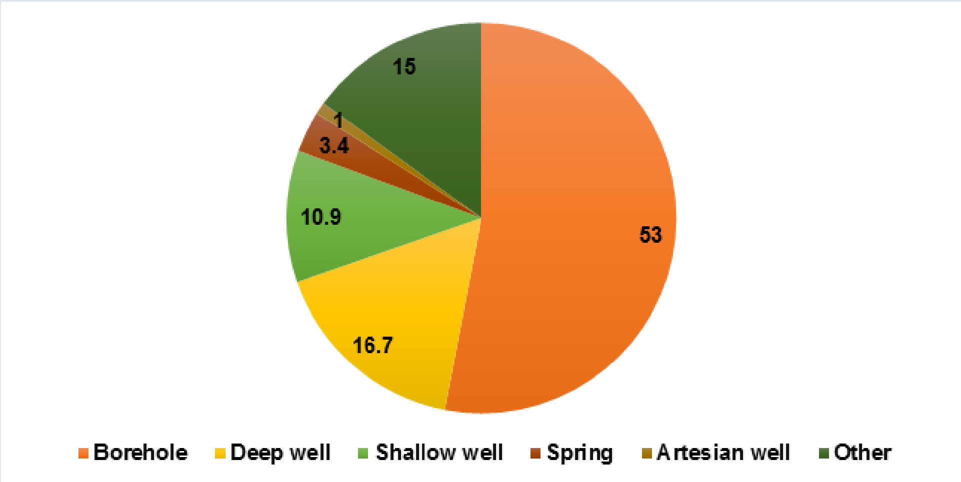

Fig 3.1 Percentage distribution of water source types in Gwayi Catchment

In Manyame catchment ground water is tapped from boreholes, springs, deep wells, shallow wells and springs (RWIMS, 2018). Similar to other catchments boreholes are a dominant source of ground water in the catchment as they constitute 56.6% of the ground water sources (Fig 3.2). However Manyame catchment has the highest proportion of springs (6.3%) as compared to the other catchments in the basin.

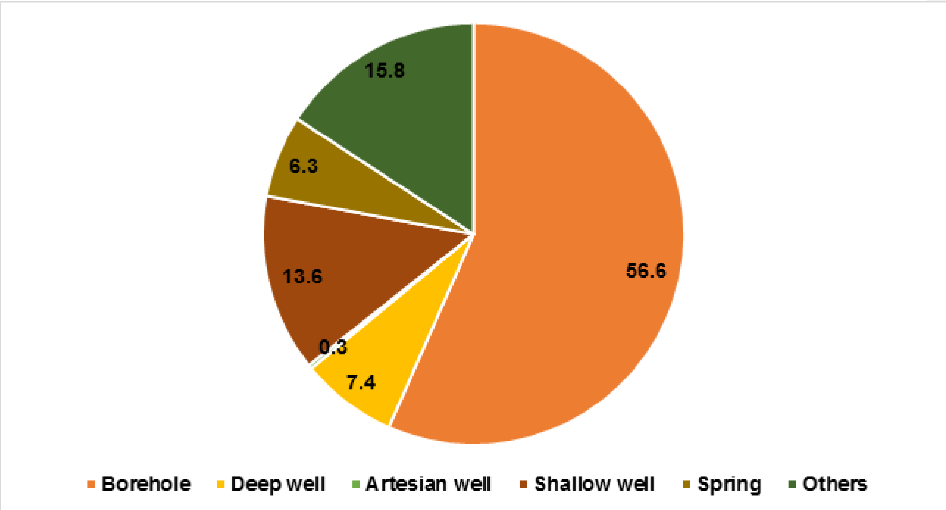

Fig 3.2 Percentage distribution of water source types in Manyame Catchment

In Mazowe catchment, the major source of groundwater was the boreholes (52.9%) with Mudzi district having the highest percentage of boreholes (62.6%) while Uzumba Maramba Pfungwe had 50.1% and Mutoko had 45.9%. The second major source of ground water in the four selected districts was deep wells followed by shallow wells (Figure 3.3).

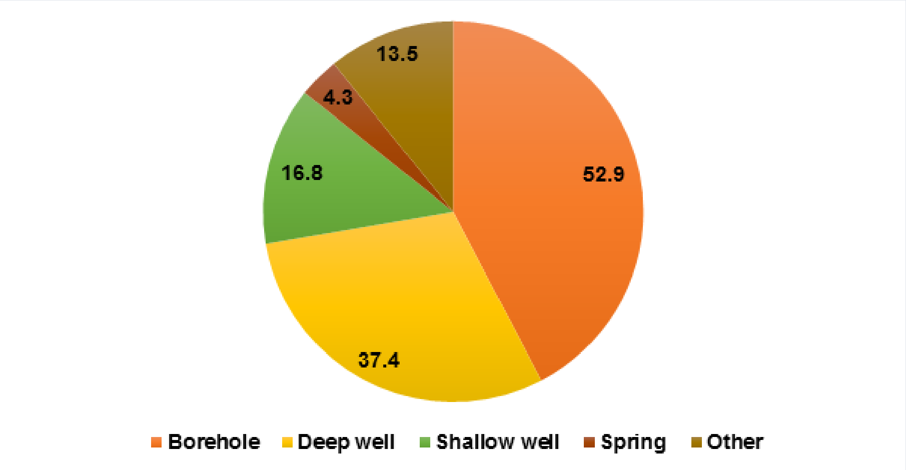

Fig 3.3 Percentage distribution of water source types in Mazowe Catchment

Although ground water is also tapped from springs in the catchment, springs are not a common source of ground water as it only constitutes 4.3% of the water sources. The other sources of water that constitute 13.5% are surface water sources such as dams, sand abstraction sites and rivers.

In Sanyati catchment, groundwater is used for irrigation of commercial farming areas. Gokwe North, Gokwe South and Zvimba were the districts that had available data on water availability in Sanyati Catchment hence their inclusion in the study. The catchment's dominant ground water source is boreholes which constitute 42.9% of the total water sources (Fig 3.4).

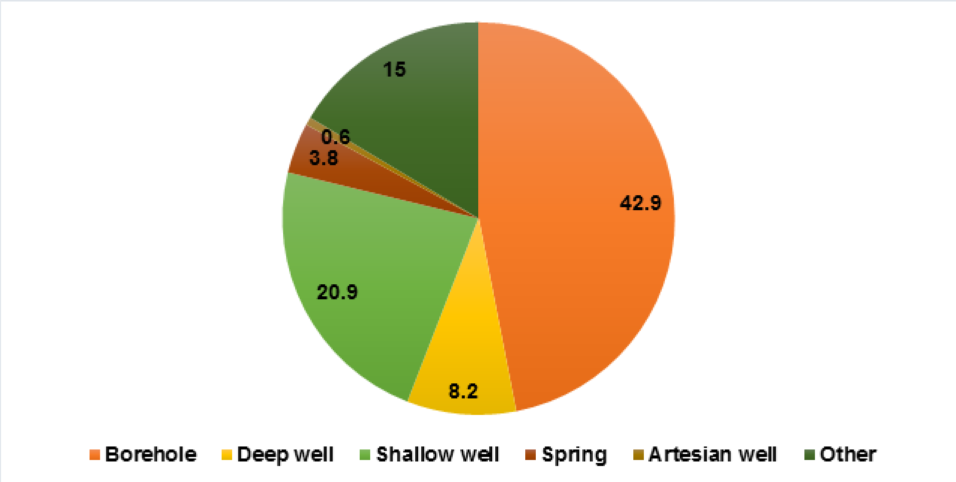

Fig 3.4 Percentage distribution of water source types in Sanyati Catchment

However Sanyati catchment has the least percentage of boreholes out of the four studied catchments. In the catchment artesian wells are the least common ground water source with only 0.6%. Unlike other catchments Sanyati has the highest percentage of shallow wells (20.9%).

3.3 Ground Water Demand in ZRB Zimbabwe

Within the context of this study, water demand was analysed in relation to the different land uses in the basin. WEFE interdependencies are informed by land use patterns of an area. The spatial distribution of the different land use patterns in the river basin in Zimbabwe is shown in Fig 3.5. These land uses are urban land, communal land, small scale commercial farming area, large scale commercial farming area and recreational and national parks.

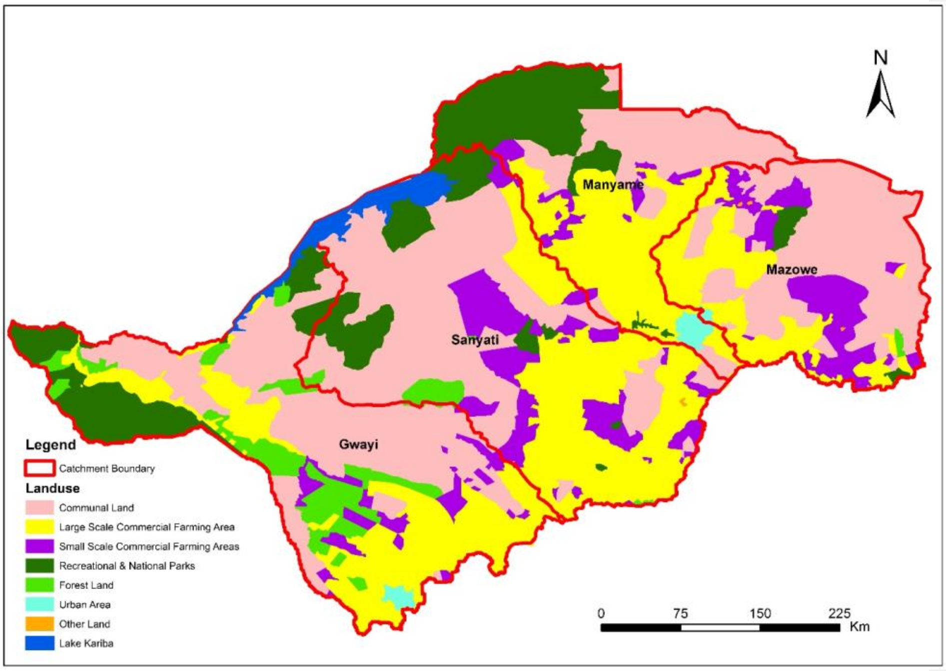

Fig 3.5 Land use patterns in the Zambezi River Basin in Zimbabwe

As shown in Fig 3.6 Communal lands are dominant in all catchments. Large scale commercial farms are more pronounced in the Sanyati and Manyame catchments, whereas small scale commercial farms feature more in Sanyati and Mazowe catchments. Recreational and National Parks are dotted across the river basin with the largest parks being found in Gwayi catchment, Sanyati catchment and Manyame catchment. The country's largest national parks are found in the ZRB for example, Zambezi National Park; Victoria Falls National Park; Hwange National Park; Chizarira National Park; Matusadona National Park; Lake Kariba Recreational Park and Mana Pools National Park. Mining activities are also found in the basin that is in Gwayi catchment, Sanyati, Manyame and Mazowe catchments along the Great Dyke.

Based on these land uses multiple water demands in the basin can broadly be classified as domestic, industrial, mining, agricultural and recreational water demands. However during this study it was not possible to obtain data to enable the quantification of ground water demanded by each sector in the basin. Proportional demand was determined in terms of percentage land use as shown in Fig 3.6. The land in the river basin is predominantly used for agriculture in the form of communal lands (41%), small scale commercial farming (10%) and large scale commercial farming areas (30%).

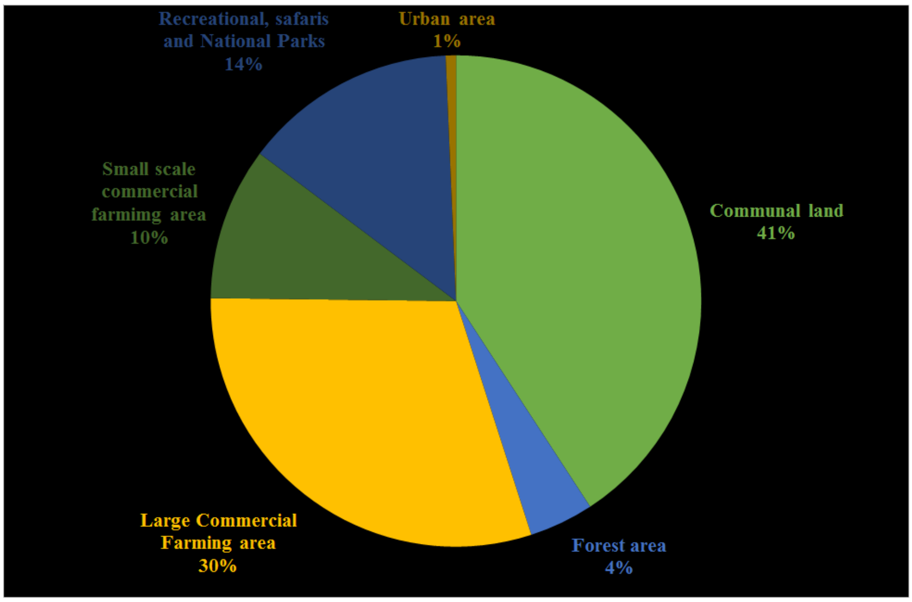

Fig 3.6 Percentage land use in the Zambezi River Basin in Zimbabwe

A substantial amount of land is reserved for safaris and National and recreational parks (14%). Forest areas occupy 4% of the river basin whilst urban areas only make up 1% of the river basin in Zimbabwe. For a basin wide analysis it can be said the major demand for ground water is domestic use by the communal farmers given that communal land makes up 41% of the ZRB in Zimbabwe.

An analysis of the availability as surrogated by number of borehole against demand as surrogated by landuse in the ZRB is illustrated in Fig 3.7 where borehole points were overlaid on landuse in the ZRB. From Fig 3.7 it is clear that the highest density of borehole points are found in the communal lands and small scale commercial farms. Zimbabwe is among the countries of the SADC region that are classified as being "highly dependent" on groundwater for domestic, irrigation and industrial use (Farr et al., 2005). Although both rural and urban areas use groundwater sources, their use is more dominant in rural areas. It is assumed that for urban centers, 90% of the water use comes from surface water, and the rest from groundwater sources while in rural areas, 15% has been estimated to come from surface water and 85% from groundwater resources (Euroconsult Mott Macdonald, 2007). However in urban centers such as Harare (Manyame catchment),the use of groundwater has been increasing over the past few years due to unreliable water supply by the city council. Furthermore the mushrooming of illegal urban settlers and the establishment of houses in areas not connected to municipal water supply systems have also contributed to increased use of groundwater by urban dwellers.

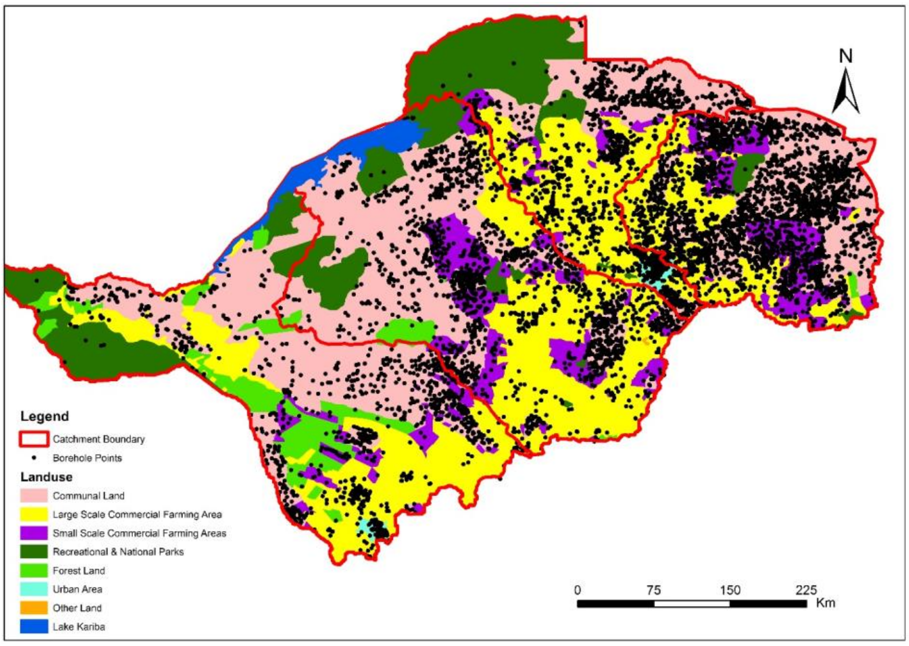

Fig 3.7 Borehole distribution on various land use in the ZRB in Zimbabwe

The National Parks also rely on groundwater for the animals and primary use for the tourists who visit the parks.

A catchment by catchment analysis reveals that Manyame, Mazowe and Sanyati catchments have the largest densities of borehole points as compared to Gwayi. This presents a scenario of possible overexploitation of groundwater in these catchments and underutilization of the ground water resource in Gwayi catchment.

3.4 Baseline Conditions of Water quality in ZRB in Zimbabwe

Generally data on ground water quality is pertinent as it determines the suitability of the available ground water for intended uses. Since ground water in the ZRB in Zimbabwe is the major source of domestic water in rural areas and growth points, water quality data is fundamental in safeguarding human health. This is also of importance as urban areas in the basin have in the recent years increased their demand of ground water. Regarding ground water sources in urban areas, water quality is of interest due to various urban activities that render the water source vulnerable to pollution. Despite the importance of ground water quality data, in the ZRB in Zimbabwe such information is limited. Literature has shown that data on water quality is mainly on surface water sources.

The natural ground water quality in the ZRB in Zimbabwe like the rest of the country is generally considered to be of good quality. The natural localized areas with poor groundwater quality are associated with poor groundwater circulation in confined aquifers, poor recharge in arid areas and hyper-saline paleo-groundwater (Ministry of Environment Water and Climate, 2014). In the ZRB, Gokwe North and Hwange districts have geogenic groundwater fluoride. According to the Ministry of Environment Water and Climate (2014) salinity in the ZRB in Zimbabwe is presumably associated with deep groundwater in the escarpment fault zone and in the deep Kalahari in north west Zimbabwe, likely related to the evaporate sequences in the Kalahari beds.

Apart from the natural causes of ground water pollution in the ZRB in Zimbabwe, numerous anthropogenic causes also exist. In major cities such as Harare and Bulawayo, ground water utilization is high in areas not connected to municipal water supply systems. Previously non-connection of households and establishments to municipal water supply was mainly found in informal settlements. However, this is now also a characteristic of many new planned settlements. In these areas bacteriological contamination of ground water sources is a challenge due to high usage of on-site sanitation systems such as pit latrines. The use of other onsite sanitation systems such as septic tanks has also contributed to groundwater pollution especially where the stand sizes are small and where the sanitation systems are wrongly sited in relation to groundwater sources. A study by Sinandima (2013) showed that ground water quality in Epthworth- Harare was attributed to poor sanitation practices and indiscriminate dumping of solid waste. The study results on microbial water quality indicated that the water was generally unfit for drinking according to the WHO guidelines.

In urban areas groundwater quality is also under threat from wastewater pipes bursts. In Bulawayo, total coliforms and faecal coliforms which pose a threat to human health were found in 27% and 8% respectively of the sampling sites drawn from the Matsheumhlope basement aquifer (Mangore and Taigbenu 2004). Recently the cholera cases in Harare in September 2018 were also blamed on wastewater pipes bursts which contaminated ground water sources exposing people to water borne diseases. In the upper part of Manyame catchment, field evidence has revealed that bacteriological contamination of ground water sources in rural areas (Chihota Communal Lands) is from pit latrines (Dzwairo et. al. 2006). This could be the case with other rural settings in the basin.

Indiscriminate solid waste disposal in urban cities in the ZRB in Zimbabwe is also another source of groundwater pollution. Even where dumpsites are designated, most of them are poorly constructed and poorly managed without impermeable linings and leachate collection as well as treatment facilities (Ministry of Environment Water and Climate, 2014). Sinandima (2013) noted that the use of dumpsites in Epworth was a threat to ground water quality in the area. In the Upper Manyame Catchment, Misi et al (2018) concluded that samples of ground water which were characterized by metallic compounds suggested pollution from mineral dissolution into aquifers from sources such as dumpsites. This was evidenced by samples which were collected from boreholes close to Golden Quarry Dumpsite. The impact of dumpsite leachate on groundwater quality was also noted by Love et al (2006).

In the ZRB in Zimbabwe, patchy sources of information available show that industrial activities have a negative impact on ground water quality. Industries generate effluent and other toxic waste and in many cases such waste is not properly treated. Chemical industries, such as Chemplex and ZimPhos in Harare, leather tanneries in Harare and Bulawayo, and industries that use large volumes of water and discharge bulk effluent back into the drains, such as the dairy industry, all contribute to groundwater quality degradation (Ministry of Environment, Water and Climate, 2014).

With a focus on the mining industry, most mines have open shafts, waste rock dumps and tailings dams with exposed sulphide minerals, making them susceptible to Acid Mine Drainage (AMD). AMD is the formation and movement of highly acidic water rich in heavy metals, caused by the weathering of pyrite (Gray 1997). Whenever pyrite is exposed to air and water (leading to oxidation and hydrolysis), it produces sulphuric acid which in turn dissolves heavy metals in the rock, hence it is characterized by high concentrations of dissolved heavy metals, sulfates and low pH (Gray 1997). When these are in solution they are mobilized to enter the surface and groundwater sources thereby threatening water quality. In the ZRB, Gwayi catchment in particular Hwange district has its ground water sources vulnerable to AMD. In a study done by Mucheriwa (2016), water in Deka River in Hwange was found to be an environmental hazard as it was above the Environmental Management Agency standards and using US EPA standards it was concluded that Deka River is severely impacted by AMD. Although the study focused on surface water, in the absence of ground water quality data, the quality of the surface water source can be used as a proxy of the ground water quality considering the phenomenon in question.

In Mazowe and Sanyati catchments groundwater is also under threat from mining activities although the ground water quality data is not available. For example the high prevalence of artisanal gold miners in the Sanyati catchment has potential negative impacts on ground water quality coupled by high usage of mercury and cyanide as well as poor environmental management practices. In the Mazowe catchment the existence of the Trojan Nickel Mine, Shamva Gold Mine, Mazowe Gold Mine among others should not be underestimated as potential sources of ground water pollution. In these areas studies done by Ravengai et al (2005) and Lupankwa (2006) showed the impact of the mining activities on surface water sources in rivers such as Yellow Jacket and Mazowe and Pote. In the Upper Sanyati catchment, water samples from boreholes located in areas where mining, mineral processing and agricultural activities recorded high values above WHO standards of toxic metals (Madebwe et al 2015).

4.0 MAJOR BASELINE FINDINGS IN ZRB IN ZIMBABWE

4.1 Multi-scale groundwater hydrology baseline database at ZRB and Zimbabwe scale

- The geology of the Zambezi River basin in Zimbabwe is very well documented.
- However there is not enough data on aquifer properties such as their extent.
- There is some limited data on the depth of boreholes and their yields. This is helpful for analysis of WEFE interdependences in the river basin.
- The productivity of the ground water sources in the basin depend very much on the geology in the area and hence vary across the different catchments of the river basin as the geology varies.

4.2 Baseline conditions database on water demand vs. availability and quality

- The ZRB in Zimbabwe is generally rich in ground water resources.
- There is a high demand of groundwater in the ZRB in Zimbabwe as the communities in the basin are predominantly rural.
- There has also been a marked groundwater demand increase in urban areas as municipalities fail to supply adequate water to the growing urban population.
- There is potential overexploitation of the groundwater resources in some parts of ZRB in Zimbabwe.
- Generally there is not enough data on groundwater quality in ZRB in Zimbabwe to inform suitability for human consumption and promote food production in the basin.
- There has been cases of contamination of ground water by wastewater in the major urban centre of Harare resulting in an outbreak of cholera. More work will be done to assess the vulnerability of the groundwater resources to contamination as per the third objective of the project.
- Access to the groundwater resources is through boreholes and mechanical pumps are used in most cases except on commercial farms, National Parks and private urban homes where energy sources such as solar energy, fossil fuels (diesel, petrol) and electricity are used.
- The type of energy used to pump the ground water as well as its availability have a direct bearing on the amount of food produced from irrigated agriculture in the small sale and large scale commercial farming areas in the ZRB.

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