Groundwater Resource Supply Augmentation: A Case Study of Dzamba and Mabulo Villages in Vhembe District Municipality, Limpopo Province, South Africa

By

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DECLARATION

I, Funzani Duncan Munyai, hereby declare that the dissertation submitted by me to the School of Faculty of Science, Engineering, and Agriculture in the Department of Earth Sciences at the University of Venda, in fulfilment of the degree of Masters of Earth Science in Mining and Environmental Geology, is my independent work. I have not previously submitted it to any other institution of higher education. In addition, I declare that all sources cited have been acknowledged employing a list of references.

I furthermore cede the copyright of this dissertation and its contents in favour of the University of Venda.

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I hereby express my sincere gratitude to all who have motivated and supported me in completing this thesis.

ABSTRACT

The Limpopo Province of South Africa is relatively water-scarce due to climate change, population growth, and economic development. It is well known that every geographical area has some inborn causes of water scarcity related to its origin, structure, geographical location, and setup. The study area is located in Thulamela Local Municipality (TLM) in the Vhembe District, Limpopo province of South Africa, and faces many challenges, including a lack of sustainable water supply. Based on the location of the communities living in the area (being in the most rural areas of Limpopo province), essential service delivery, like water supply, is a severe problem. Dzamba-Mabulo Communities rely on rivers, streams, and springs for water supply. With the effects of drought and climate change, surface water sources often dry up, leaving these communities in a water crisis. The only alternative water source for this area is the groundwater.

Most of the research site is covered by the Soutpansberg Group "hard rock" formations, which essentially have no primary porosity. The weathered and fractured discontinuities, also known as secondary porosities, are where groundwater is primarily found. Most boreholes drilled at the research site are poor yielding because most existing boreholes were not scientifically sited. Due to the complex nature of the underlying hard rock, the available groundwater is in the fractured aquifer systems.

The study aims to explore groundwater and develop wells for these communities to augment the existing water supply for sustainable use. Groundwater supply was developed (siting, drilling, pump testing, and water quality testing) in groundwater potential areas. The transmissivity values obtained using Theis and Cooper-Jacob methods were 2,0 m^2/day and 1,59 m^2/day, respectively. While the Storativity (S) was 0,00003 (Theis method) and 0,4 x 10^{-7} (Cooper-Jacobs). The study recommends submitting future groundwater project reports within the study area to the Department of Water and Sanitation or Local Municipality to update the groundwater databases. The hydrogeological characteristics of the study site will serve as a basis for future groundwater development data collection within the research area, for future reference.

The study found an average yield from the pump test for borehole B1 (newly developed borehole) of 0,37 l/sec over 24 hours of daily pumping. The volume of water allowed to be abstracted per day is 32,10 m^3, which can meet the basic human need of 25 litres per person per day for 1,284 persons. This

is more than 1,6 times the total 18,950 m^3 per day required for the 758 Dzamba and Mabulo Villages population. This amount of water can be abstracted with a dynamic water level of 65 mbgl if pumped for 24 hours or 48,30 mbgl if pumped for 12 hours.

Keywords: Hydrogeology, Groundwater Occurrence, Groundwater Exploration, Groundwater Sustainability, Groundwater Management.

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ACRONYMS

A	Area
AMCOW	African Ministers Council of Water
C	Current Electrode
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
ECA	Economic Commission of Africa
FC	Flow Characteristics
GRAII	Groundwater Resource Assessment Phase II
GRIP	Groundwater Resource Information Project
I	Current
IC	Ion Chromatography
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
IPCC	Intergovernmental Panel on Climate Change
NGI	National Geo-Spatial Information
P	Potential Electrode
SANS	South African National Standards
Sr	Specific Retention
Sy	Specific Yield
T	Transmissivity
TLM	Thulamela Local Municipality
UN-IGRAC	United Nations – International Groundwater Resource Assessment
USAC	United States Army Corps of Engineering
V	Voltage
VES	Vertical Electrical Sounding
WHO	World Health Organisation

CHAPTER 1: INTRODUCTION

1.1 INTRODUCTION AND BACKGROUND

Dzamba-Mabulo communities are situated on the western side of the Dzimauli area in Vhembe District Municipality (VDM), Limpopo Province, South Africa. The research site is located within the now defunct Mutale Local Municipality, which is now under Thulamela Local Municipality in the Vhembe District. Based on the location of these communities (in the most rural areas), essential service delivery, i.e., water, is a severe problem. According to the Department of Water Affairs and Forestry (2011), these communities were meant to be supplied with water from the Mutale Main Regional Water Scheme (RWS). However, these communities source water from available rivers, streams, springs, and groundwater.

These communities access water from the Thengwe River (a tributary of the Mutale River), other local streams (Balula, Tshilimbani, and Tshitapatapa), and local springs. The nearest artificial reservoirs to these villages are Nwanedi and Nandoni Dams, approximately 22 km and 34 km, respectively, away from these villages (Figure 1-1 and Figure 1-2). Because of drought and other climatic factors, the local streams are drying up, affecting the water supply availability to these communities. Nwanedi and Nandoni bulk water schemes that lie within the neighbourhood do not supply water to the Dzamba and Mabulo communities, and there are no signs that they will be considered anytime soon from these bulk water schemes. The ever-increasing demand from the burgeoning population of the Dzamba-Mabulo villages may exceed the capacity of the current water sources, and the only feasible and reliable water supply source can be groundwater.

According to DWAF (2011), the existing supply of water from both surface and groundwater (existing boreholes) and the Mutale Regional Water Scheme is insufficient for domestic use in these communities. The report indicates that groundwater resources can be exploited to augment the current water supply by equipping existing boreholes or drilling additional boreholes within the study area.

There is a rising belief that groundwater resources will become more strategically important in Africa, particularly for marginalized, vulnerable populations (AMCOW, 2008; ECA et al., 2000). The Nwamitwa case study in South Africa (Du Toit et al., 2012) suggests that it is possible to supply a rural community (Nwamitwa village) with groundwater where the surface water scheme is insufficient for the village's water demand. In the Molemole Local Municipality of the Capricorn District, Limpopo province of South Africa, Matukane (2016) successfully developed underground water to enhance the Matoks bulk-water supply plan. A surplus of more than 10 ml groundwater was developed for the Matoks Villages and was sufficient to meet their future demand until 2030.

Most societies have seen significant groundwater use as the primary supply or augmentation to the existing water system. The most practical and reasonably priced way to enhance the current bulk-water supply in Dzamba and Mabulo settlements is to use the groundwater resource. According to DWAF (2011), the information currently available about "the groundwater resources in the region" is unreliable. A thorough hydrogeological evaluation and borehole hydrocensus are crucial for the region to raise the confidence level of the data and understand groundwater resources.

One of the primary objectives of South Africa's National Water Policy through the Reconstruction and Development (RDP) Program is to provide a clean, safe water supply at a minimum of 25 litres per person per day within 200m of every household (DWS, 2003; Kelbe et al., 2004; Farrar, 2012; Van Schalkwyk, 1995). According to Stats SA (2011), Dzamba village has a total population of 224 people, 64 households and an average of 3,8 people per household. About 98,5 % of the Dzamba community relies on groundwater (Spring and Borehole) as a source of water (Appendix **A**).

Considering the population of the Dzamba community, at 25 litres per person per day (DWS, 2003; Van Schalkwyk, 1995), the community has a water demand of about 5,6 m^3 per day. This, therefore, implies that a borehole yielding 0,5 litres per second a day for 12 hours of pumping can supply adequate water to the Dzamba community.

According to Stats SA (2011), Mabulo village has a total population of 344 people, with 89 households and an average of 3,9 people per household. 97,7 % of the Mabulo community relies on groundwater (Springs and boreholes) as its primary water source (**Appendix A**). Considering the population of the Mabulo community, at 25 litres per person per day (DWS, 2003; Kelbe et al., 2004; Farrar, 2012; Van Schalkwyk, 1995) will have a water demand of about 8,6 m^3 per day. This, therefore, implies that a borehole yielding 0,5 litres per second a day for 12 hours of pumping can supply adequate water to the Mabulo community.

In this study, geophysical techniques were applied to delineate the suitable areas for borehole drilling. One site was identified for drilling and drilled, and an existing borehole was rehabilitated. Pump testing was conducted on the drilled borehole. Pumping tests are normally conducted to estimate aquifer hydraulic characteristics. Hydraulic parameters provide information on the hydraulic behaviour of the borehole, the reservoir and its boundaries, necessary parameters for efficient aquifer and well field management (Khadri & Moharir, 2016). These parameters assist in quantitatively predicting the hydraulic response of the aquifer to recharge and pumping (Senior & Goode, 1999). Curve matching of theoretical type curves to observed drawdown data is used to determine the best model that fits the pump test data for the calculation of hydraulic characteristics (Kruseman & De Ridder, 2000). To avert the challenges encountered in choosing an appropriate conceptual model (type curve), diagnostic plots (semi-log and log-log plots and derivatives) were used to interpret pumping test data. The study inferred groundwater storage potential, the ability of the aquifer to transmit water, and identified potential problems associated with groundwater over abstraction in the area (fractured basement crystalline aquifers), based on aquifer hydraulic characteristics. The water quality was also investigated to ascertain its suitability for domestic use. The acquired data was analysed to demonstrate that groundwater can successfully augment the existing water supply for Dzamba and Mabulo communities.

1.2 DESCRIPTION OF THE STUDY AREA

1.2.1 Study Area

The north-eastern section of South Africa is where the research area is situated. It is found inside the bounds of Vhembe District in the Province of Limpopo's Thulamela Local Municipality (TLM). The region is located about 30 kilometres from the northern part of Thohoyandou. The investigation site encompasses 10 square kilometres and is the remainder of the Soutpansberg mountain range. Its centre coordinates are 22.813418 latitude and 30.328742 longitude (**Figure 1-1** and **Figure 1-2**). Within the A92A catchment of the Mutale River Catchment are the borders of the research area.

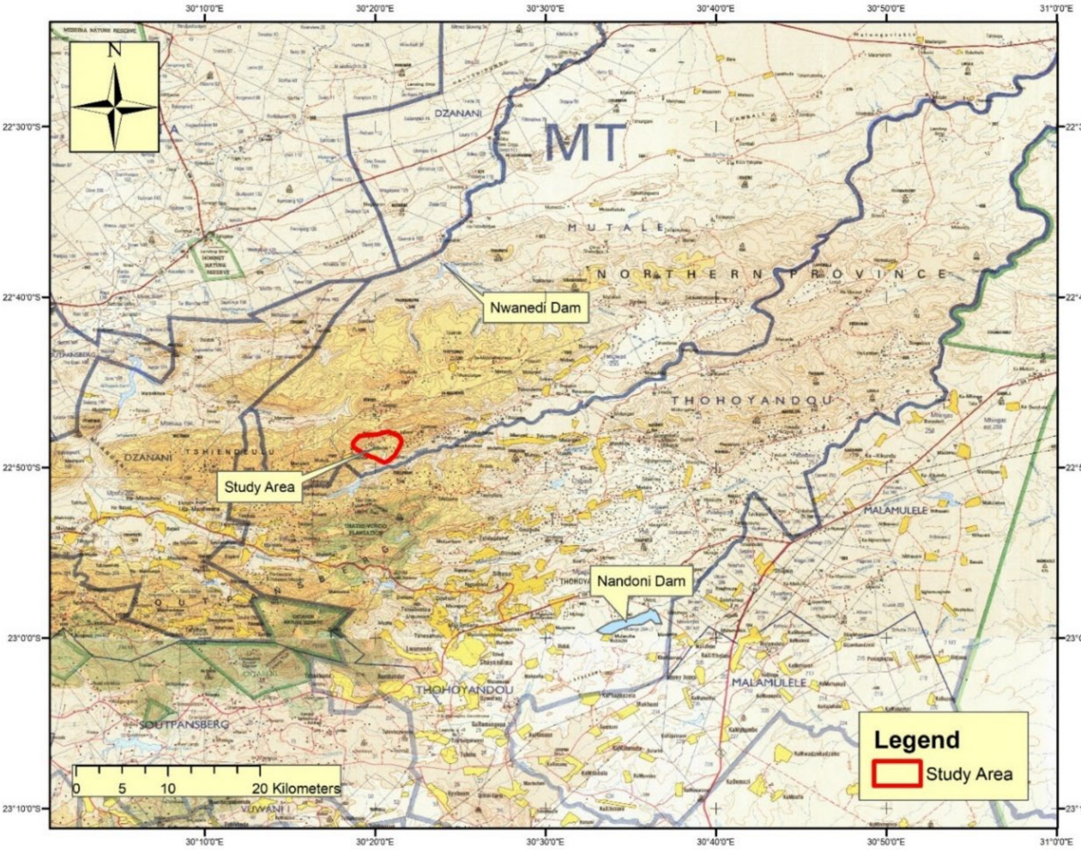


Figure 1-1: Locality map of the research site with reference to Nandoni-Nwanedi dams.

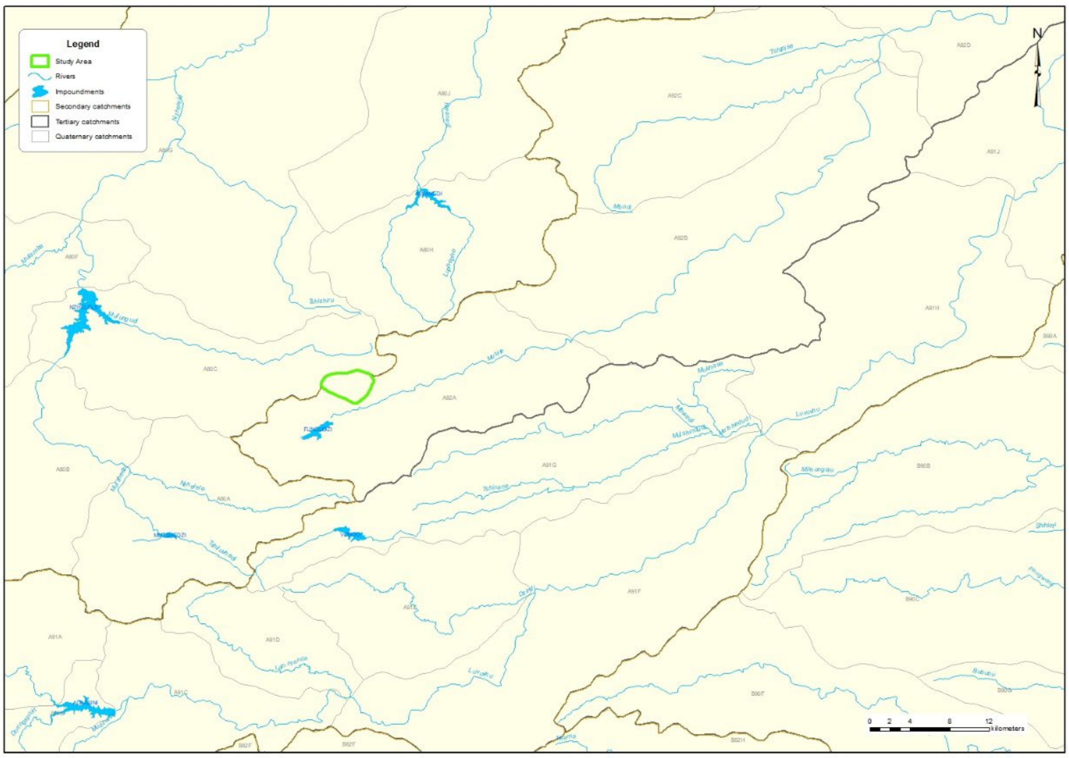


Figure 1-2: Locality map of the research site showing Quaternary Catchments.

1.2.2 Climate

The research site is in a drought-prone tropical climate zone that receives summer rains from October to March of the subsequent year (GRAII, 1990). The range of annual rainfall is 300 to 1100 millimetres. The rainfall data's specifics are displayed in **Figure 1-3**. Rainfall in the low-lying region around the Nzhelele Dam is roughly 500 millimetres annually (Midgley et al., 1994). Between November and March of the subsequent year, afternoon thunderstorms cause most precipitation at the research site. Over 80 percent of the precipitation falls in the summer.

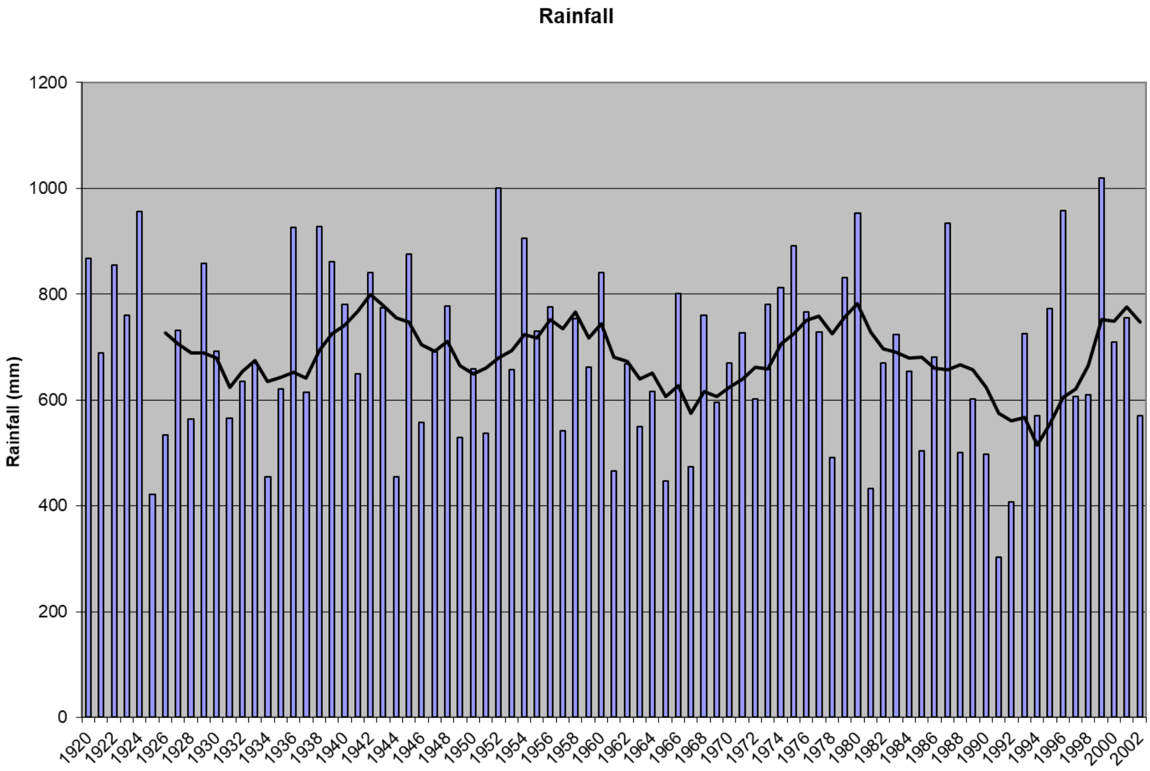


Figure 1-3: Rainfall data within the study area (GRA II, 1990).

1.2.3 Topography, Hydrology and Vegetation

Based on the topographical map of site 2230 CD (Thohoyandou), the hills and valleys in the region are elevated between 800–1400 meters above sea level (NGI, 1999). Thengwe River Sub-catchment and a tributary to Mutale River Catchment characterize the area's drainage system. The research location is in the Mutale River Catchment's A92A quaternary catchment. Thengwe River tributaries flow from the north into the Mutale River through the steep mountain slopes that lead to the Thengwe River valley. Thengwe River runs in the southerly direction (**Figure 1-4**).

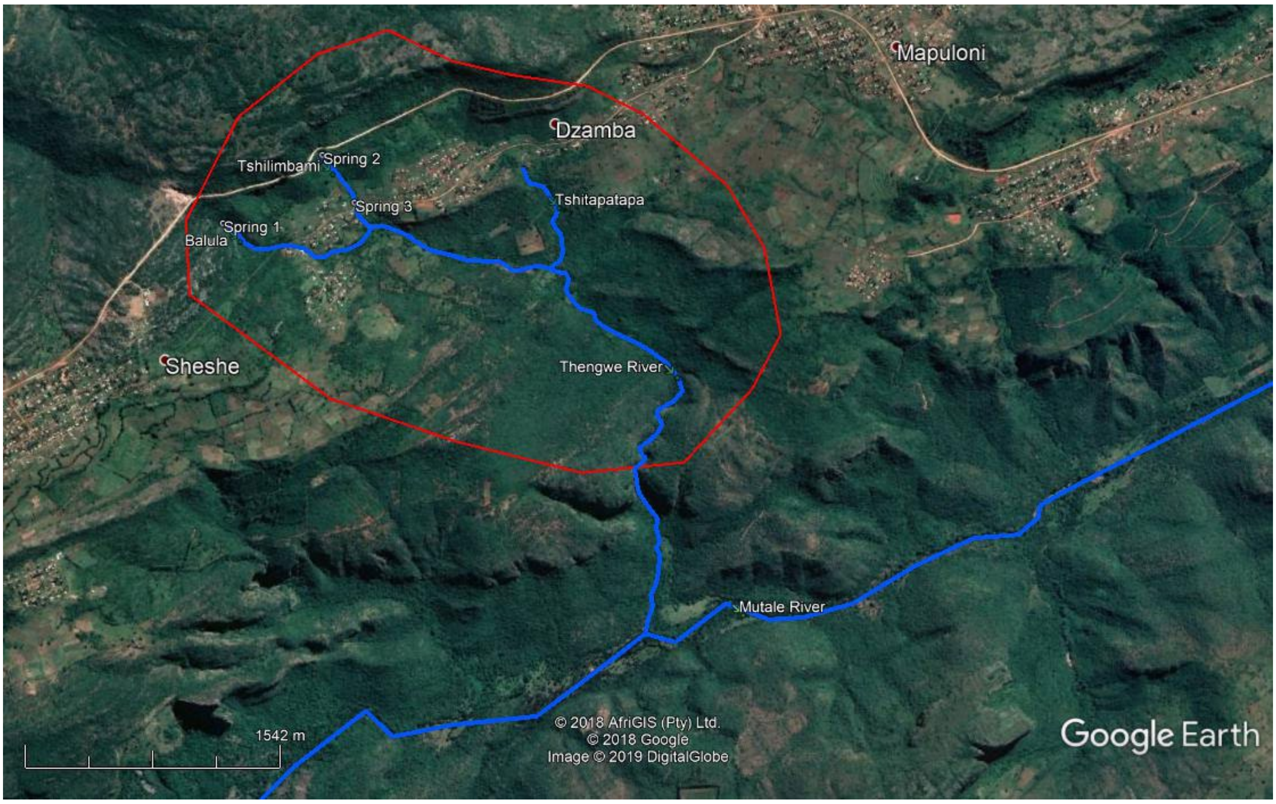


Figure 1-4: Google image depicting the locality of the research site (Google Earth Pro, 2018).

The lowveld bushveld of the Savanna Biome makes up the vegetation in the research area. Most of the research site's natural vegetation has been cleared for residential or farming purposes.

1.2.4 Regional Geology

The research site lies within the Soutpansberg Basin in the Limpopo Province (Figure 1-5). The landscape that spans from the east of Kruger National Park (KNP) to the west of Blouberg is formed by the Soutpansberg rocks that are rugged and wedge-shaped. Soutpansberg Basin stretches out against the notable Melinda and Senotwane Faults near Blouberg. In the northern area of the Limpopo province, the rocks of the Soutpansberg Group are extensively faulted (Figure 1-6).

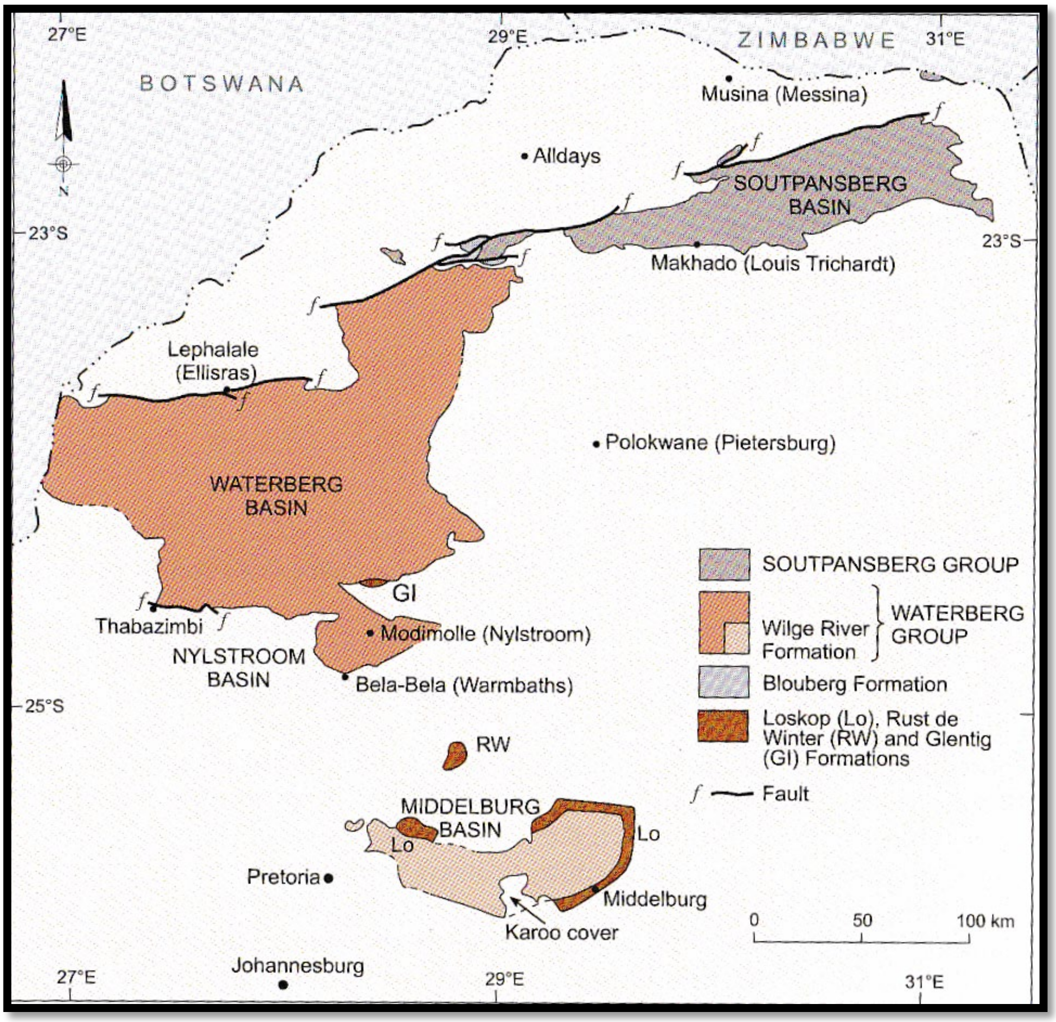


Figure 1-5: The Soutpansberg Group's regional context and the surroundings (modified from Brandl and Anhaeusser, 2006)

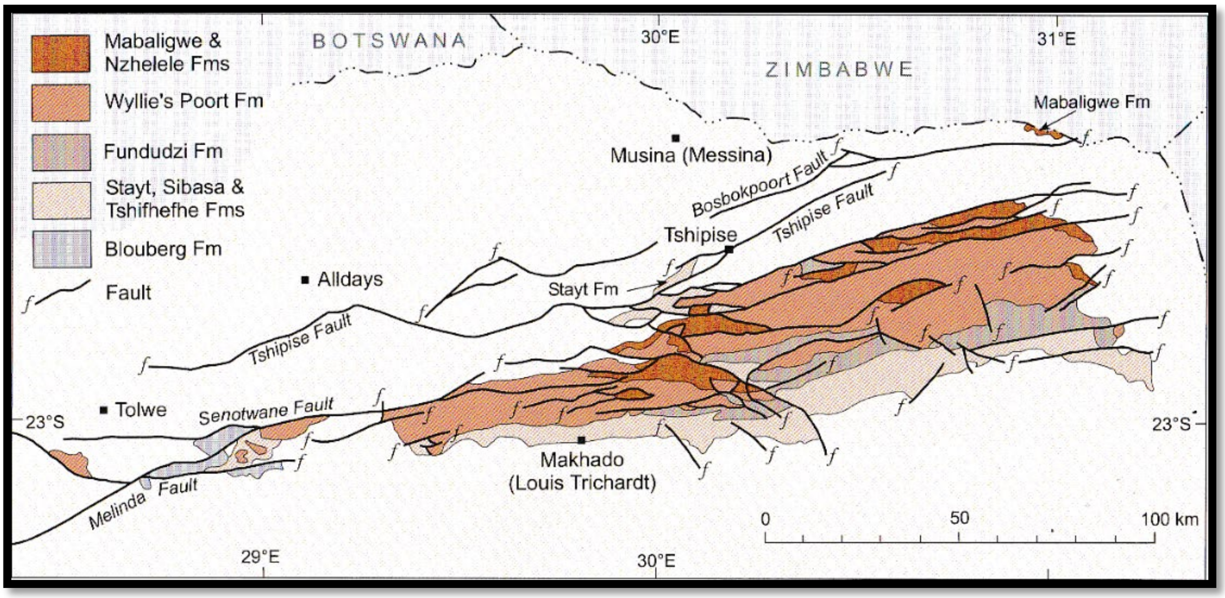


Figure 1-6: Map illustrating the Soutpansberg Group's spread and the surroundings (modified from Brandl and Anhaeusser, 2006).

The Soutpansberg Group is separated into seven formations and is classified as a volcano-sedimentary sequence, according to Brandl (1999). Shale, greywacke, and conglomerate are among the heavily epidotised clastic deposits that make up the barely a few-meter-thick base discontinuous Tshifhefhe formation.

With a maximum thickness of roughly 3 000 m, the Sibasa Formation is mostly a volcanic sequence with sporadic, fragmented clastic sediment intercalations (Barker, 1979). The volcanic rocks are composed of small pyroclastic rocks and subaerially extruded basalts. The massive, amygdaloidal basalts are usually epidotised. In places, the interbedded clastic layers, which are composed of quartzite, shale, and minor conglomerate, can be as thick as 400 m.

The Fundudzi Formation mostly develops in the eastern Soutpansberg before splintering off to the northwest and west. A few thin pyroclastic beds can be found within the formation, which is up to 1900 m thick and mostly composed of argillaceous and arenaceous rocks. Intercalated with the sediments towards the top of the sequence are up to four, roughly 50 m-thick layers of epidotised basaltic lava (Baker, 1979; Brandl, 1981).

Wyllie's Poort Formation, primarily composed of clastic succession with a maximum thickness of 1500 meters, comes after the Fundudzi Formation. Given that the formation rests on top of increasingly older units that run east to west, it is believed that its lower contact indicates a regional nonconformity (Cheney et al., 1990). An extraordinary agate conglomerate has formed at the foot of the sequence, which is covered by resistant pink quartzite and sandstone with sporadic pebble washes (Van Eeden et al., 1955; Barker, 1979). Brandl (1999) explained that “the uppermost member of the group is called the Nzhelele Formation and is composed of the 400 m thick volcanic composite (Musekwa Member) at the bottom, followed by red argillaceous and then arenaceous sediments “.

The Stayt and Mabiligwe Formations are two other units that are recognized to the north of the main Soutpansberg outcrop (Figure 1-6). The highest thickness of the Stayt Formation, which is maintained between two notable faults, is 1800 m. Argillaceous sediments with pyroclastic rock interbeds emerge at the base after basaltic lava (Barker, 1979; Brandl, 1980). The Mabiligwe Formation, which has a minimum thickness of 50 m, is confined to a small area on either side of the Limpopo River. This clastic succession is characterised by a faint tuffaceous horizon rather than established volcanic rocks (Brandl, 1981).

1.2.5 Structural Geology

Brandl and Anhaeusser (2006) state that the Soutpansberg layers typically dip at less than 30^0 in a north-northwest (NNW) direction. The fault and joint orientations can be divided into three primary groups (Barker, 1979; Brandl, 1981). The east-northeast to west-southwest trending extensional faults are the most prevalent and continuous (Figure 1-5 and Figure 1-6). These continuous structures truncate and duplicate the succession of the extensional faults at least four times (Barker, 1979), resulting in discrete, fault-bounded, elongated blocks.

The east-northeast-trending faulting is believed to be very old and has rejuvenated through geological time. The investigations suggest that shear and extensional processes possibly happened; shearing movement is believed to have occurred before Karoo's age (Barker, 1979, 1983). Evidence for a probably short-lived period of compressional tectonics is given by gentle folds developed in Wyllie’s Poort quartzites and Nzhelele shales. Although the Soutpansberg rocks are unfoliated, they have severe fractures (Van Eeden et al., 1955). According to Barker (1983), the faults were active in the post-Karoo times.

Rocks of the Soutpansberg are frequently characterised by diabase dykes and sill intrusions. In contrast to sills, which were mostly deposited along the interface between competent quartzite and shale, dykes frequently intruded along fault planes. It is possible that some diabase intrusions occurred concurrently with the Soutpansberg volcanism (Brandl and Anhaeusser, 2006).

1.2.6 Pedology and Local Geology

The research area mainly comprises conglomerate from the Wyllie's Poort Formation of the Soutpansberg group and basalt from the Fundudzi Formation (Brandl, 1981; Cheney et al., 1990). The dolerite dyke of the Karoo age cuts across the Soutpansberg group rocks in the east-west strike direction. The weathering of these rocks resulted in the reddish clay loam soil, which dominated the area.

1.3 PROBLEM STATEMENT

Due to population expansion, economic development, and climatic change, the Limpopo Province in South Africa has relatively insufficient water (Matshidiso et al., 2014). Sarbeswar et al. (2015) state that "every geographic area has specific inherent reasons for water scarcity related to its genesis, structure, geographical setting, and arrangement". The study area is in Thulamela Local Municipality (TLM) of the Vhembe District Municipality (VDM), Limpopo province, South Africa. It has several challenges, one of which is a sustainable water supply. The primary water supply to the communities in the research area is predominantly from boreholes. Considering where these communities are located (in the most rural areas), essential service delivery, i.e., water, is a severe problem. Dzamba-Mabulo Communities rely on rivers, streams, and springs for water supply (DWA, 2011). With the effects of drought and climate change, these water sources often dry up, leaving these communities in a water crisis. Using the study area as a case study, the investigation will establish strategies for effectively developing and managing groundwater resources in South African rural villages to address the water crisis in the investigation site.

1.4 RESEARCH QUESTIONS

The primary question the present investigation aimed to study was whether the utilisation of groundwater could reliably augment the existing water resource to supply Dzamba-Mabulo communities.

The following individual research questions were selected to address the primary research question:

- What are the hydrogeological characteristics of the research site?
- Where are groundwater potential zones in the Dzamba area?
- What are the aquifer hydraulic characteristics of the area?
- What are the strategies that can be implemented for sustainable groundwater use in the Dzamba area?

1.5 AIMS AND OBJECTIVES

The main objective of this research was to develop a sustainable groundwater source that would augment the current water sources.

The specific objectives of the investigation were:

- Gather and evaluate the existing geological and hydrogeological data.
- Delineate groundwater potential zones of the study area.
- Geochemical analysis of groundwater resources for the study area.
- Develop sustainable groundwater sources to supply water to two villages.

1.6 JUSTIFICATION OF THE STUDY

The communities under investigation rely on unsustainable water sources (rivers, streams, and springs), which usually dry up during drought periods. This leaves the Dzamba-Mabulo communities without any source of water. Water being one of the most critical basic needs for human livelihood, so it is essential to have reliable water supply in any community. This research identifies groundwater as the most feasible and reliable water supply source for Dzamba-Mabulo Communities.

The research will explain potential areas for groundwater and provide a sustainable groundwater resource management plan for the research area. It will also contribute to a deeper comprehension of Dzamba's present groundwater resources and management strategies and, therefore, to the body of knowledge in this regard.

1.7 HYPOTHESIS

The following are the hypotheses under consideration:

- Sufficient and reliable groundwater can be developed to supply rural communities.
- Geological structures and lineaments have high groundwater potential.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This section explored existing literature on hydrogeology, geophysical techniques, pump testing, drilling methods, and scientific definitions and interpretations of relevant concepts.

Concentrations in the atmosphere are increasing of Carbon dioxide and other greenhouse gas (IPCC, 2007). An increasing amount of data suggests that this is already impacting climatic conditions, with effects on hydrological cycles being seen in certain places (IPCC, 2007). According to UN-IGRAC.org, more extended periods of drought and floods can result from increasing precipitation variability and more intense weather events brought on by climate change. This has immediate effects on groundwater availability dependence.

Aquifer depletion is more likely during extended droughts, particularly in small and shallow aquifers. Groundwater's buffering ability will make people in water-scarce areas more reliant on it (UN-IGRAC.org). Additionally, the demand for groundwater is increased by indirect effects of climate change, such as human activity intensification (UN-IGRAC.org).

Groundwater quality is also impacted by climate change in addition to quantity (UN-IGRAC.org). An increase in sea level could cause saltwater intrusion into coastal aquifers, impairing groundwater quality and contaminating freshwater or drinking supplies. This has an adverse effect on groundwater-dependent communities. Communities classified as groundwater dependents obtain their water supplies from groundwater (Craig et al., 2010). Developing nations rely heavily on groundwater because there is either a shortage of surface water resources or a lack of safe drinking water (Craig et al., 2010).

Shallow wells are frequently a major drinking water supply for rural populations in underdeveloped countries, according to Kongola (2008). Drastically rising demand and even more severe droughts could force these shallow wells to dry up. When groundwater is lost, people are forced to use harmful water sources or travel great distances in quest of water because there are few other options for safe drinking water supplies. Reduced water availability can cause severe hardships for groundwater-dependent communities (Craig et al., 2010).

Groundwater resource development can boost economic growth and lessen poverty. However, an accurate understanding of the underground water system and the presence of competent people to make the best, most informed decisions are crucial for the sustainable development of the resource (Adelana and Macdonald, 2008). Adelana and Macdonald (2008) state that in order to improve groundwater management in Africa, systematic data collection on the amount and quality of groundwater resources is required. Additionally, if data permits, groundwater models should be created to assess the groundwater system.

The insufficient monitoring and evaluation of data due to role and responsibility misalignment can also be blamed for the lack of physical data (Knuppe, 2011). Knowledge gaps and a lack of essential data on aquifers characterise the performance of the current governance systems (Knuppe, 2011).

2.2 HYDROGEOLOGY

2.2.1 Groundwater Occurrence

When it starts to rain, water (**Figure 2-1**) may:

(i) be lost as vapor from the surface of the earth or from plant leaves (evapotranspiration) for plants that absorb moisture from the soil through their roots;

(ii) flow along progressively larger watercourses that run parallel to or beside the earth's surface until they reach the ocean;

(iii) infiltrate the earth's mantle through its pores or fissures, either at the base of the fall or at a distance where surface movement has transported it. When water evaporation occurs from the surface of the earth or from water bodies, precipitation is ready to restart the process (Koegel, 1985).

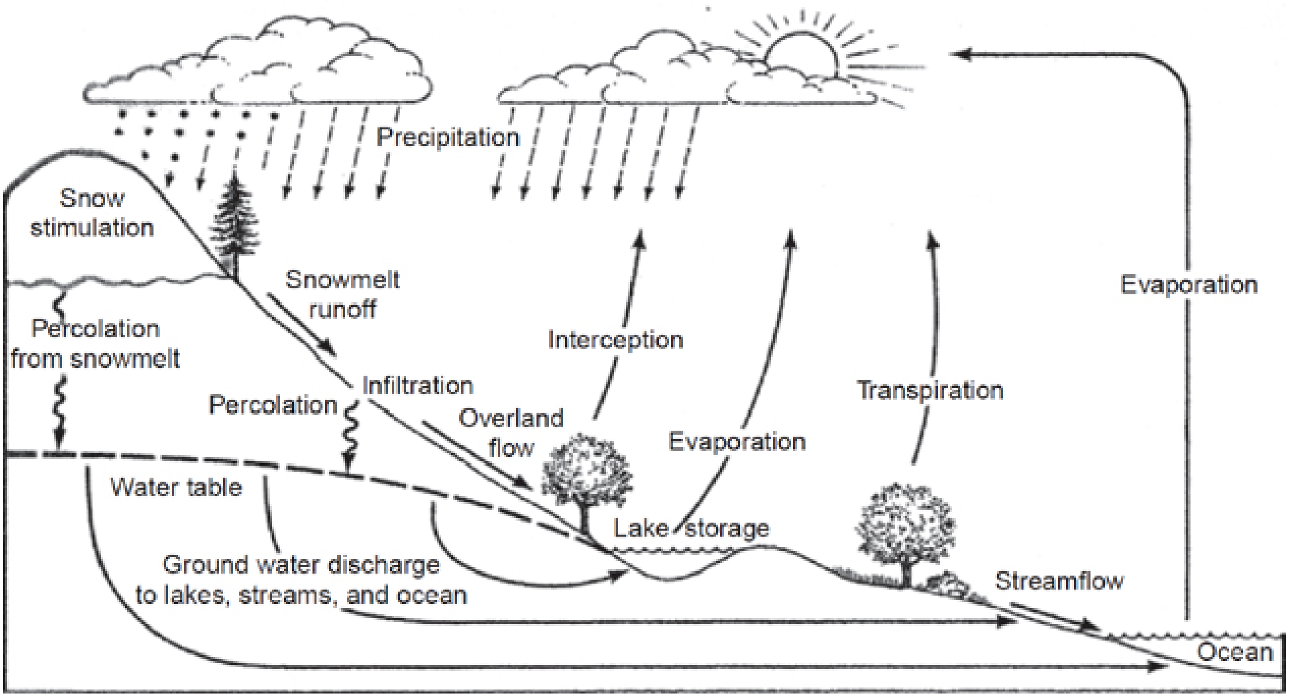


Figure 2-1: Hydrogeological Cycle (Source: https://sk.sagepub.com/books/environmental-sciences/n126.xml).

When applied to dry or unsaturated soil, water is retained in the voids between soil particles by capillary forces. However, gravity releases the water after the spaces are saturated, allowing it to drop below surface level. Water will continue to drop as long as there is enough water to keep it saturated until it reaches an impermeable layer, like very impermeable clay or rock. Water can then move laterally through gaps and fissures in the rock above the barrier. A spring is a lower place along the impermeable layer where water flows out if there are notable variations in surface elevation at a point where it intercepts the water table. Water will flow into a hole drilled vertically down into the saturated layer. If there are enough interconnected spaces in the saturated layer, water will pass through it really quickly. An aquifer is characterised as a saturated layer capable of yield economically adequate quantities of water, and any hole that is constructed in it has the potential to become a well.

Permeability is the absence of resistance to flow through a porous material. Fine-grained materials like silt or clay typically have low permeability, sand has medium permeability, and gravel has the highest permeability. Permeability of fractured rock varies according to the degree and pattern of fracture (**Figure 2-2**). The total volume of spaces between the solid particles in an aquifer determines how much water may be stored there. The term porosity refers to the proportion of voids in an aquifer's total volume. Aquifers with high porosity also typically have high permeability if the voids are interconnected (Koegel, 1985).

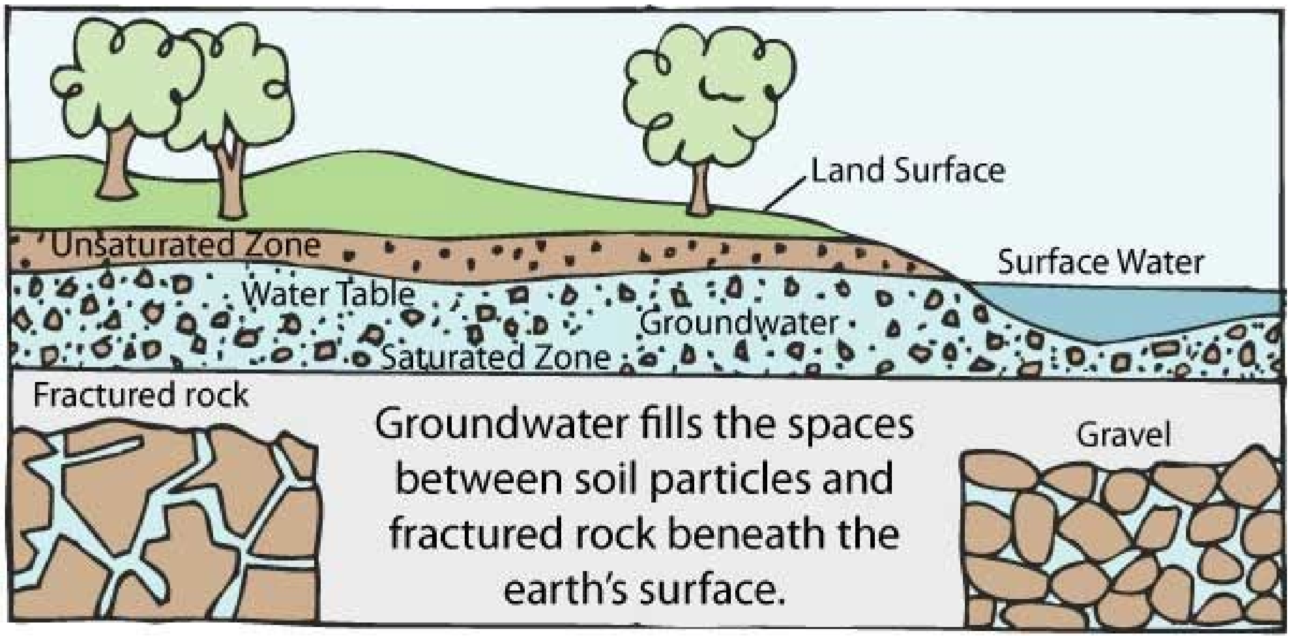


Figure 2-2: Groundwater Occurrence (Source: https://www.groundwater.org/get-informed/basics/whatis.html).

There are situations where an impermeable layer traps groundwater. A confined aquifer is one that has been found in this manner. In confined aquifers, if the inflow area is greater than in the confining layer where a well penetrates it, the water rises because of pressure within the well to a particular level above the confining layer. Such kind of a well is known as artesian. When water reaches the well's top, a "flowing well" is formed (Koegel, 1985).

2.2.2 Groundwater in different hydrogeologic areas

Groundwater is found in nearly all sedimentary materials, including weathered and fractured igneous and metamorphic rocks (Block et al., 1995). Prasad (2002) states that the porosity and permeability of a geological formation determine the presence of groundwater and the extent to which it can develop.

2.2.2.1 Crystalline Basement Rocks

In Crystalline Metamorphic and Igneous rocks, groundwater is found in the shallow weathering (regolith) zones in the top few tens of metres of the rock, usually around 50m deep and/or in the deeper fracture zones (MacDonald et al., 2002, Pietersen, 2004). According to Holland (2011), crystalline basement rocks occur in South Africa in the Archean Cratons, Mobile belts, and orogenic granite intrusions. The degree of weathering and stress that crystalline rocks have endured since their original creation determines how valuable they are as aquifers (Block et al.,1995).

2.2.2.2 Volcanic Rocks

Groundwater is found in areas where individual lava flows are fracturing and inside volcanic rocks that are porous or heavily fractured (Block et al.,1995). Although yields are highly variable, they are often adequate for small-scale irrigation and residential use in rural areas. Boreholes, wells, and springs can all be used to access groundwater in mountainous regions. Only boreholes are feasible in areas where the fracture zones are deep and the rocks are hard (Block et al.,1995). The higher the density of those fracture zones, the higher the potential for groundwater.

2.2.2.3 Sedimentary Material

The unconsolidated, granular sedimentary layer that covers the consolidated rocks over a large percentage of the earth's surface contains groundwater in coarse-grained, saturated areas (Block et al.,1995). Conglomerates and sandstones, which are sedimentary rocks with larger grains and are cemented, are common examples of good aquifers. Sandstones have the potential for both primary (within particle) and secondary (fracture) permeability (Block et al., 1995).

Good aquifers could also be discovered in some massive sedimentary lithologies, such as gypsum, limestone, and dolomite. Due to the relative solubility of these rocks, voids of different sizes, from millimetres to a few hundred meters, may occur as a result of solution along the fractures over time (Block et al.,1995).

2.2.3 Aquifers and Aquifer Properties

2.2.3.1 Aquifers

- **Unconfined Aquifers**

Unconfined does not have an overlying confining layer. Water penetrating the ground surface seeps into the groundwater body through the material's air-filled fissures above the saturated zone **(Figure 2-3)**. The unconfined aquifers are also known as "water table aquifers”, according to Block et al. (1995). The topmost level of the saturated groundwater layer is always in balance with the atmospheric pressure. It directly interacts with the atmosphere because the substance above has open pores. Groundwater moves in direct proportion to gravity (Prasad, 2002).

❖ **Confined Aquifers**

Confined Aquifers have a layer of lesser permeability that covers them, and their only access to the atmosphere is through indirect or remote means (Block et al., 1995). Water in the confined aquifer **(Figure 2-3)** is under pressure, and the water rises above the confining bed's bottom when an aquifer is penetrated by a well with a tight casing. The water from the well is referred to be an artesian well if it rises above the surface of the ground (Prasad, 2002). The confining bed may be completely or partially impermeable and the types of confining beds includes, aquiclude, aquifuge and aquitard (Todd, 1980).

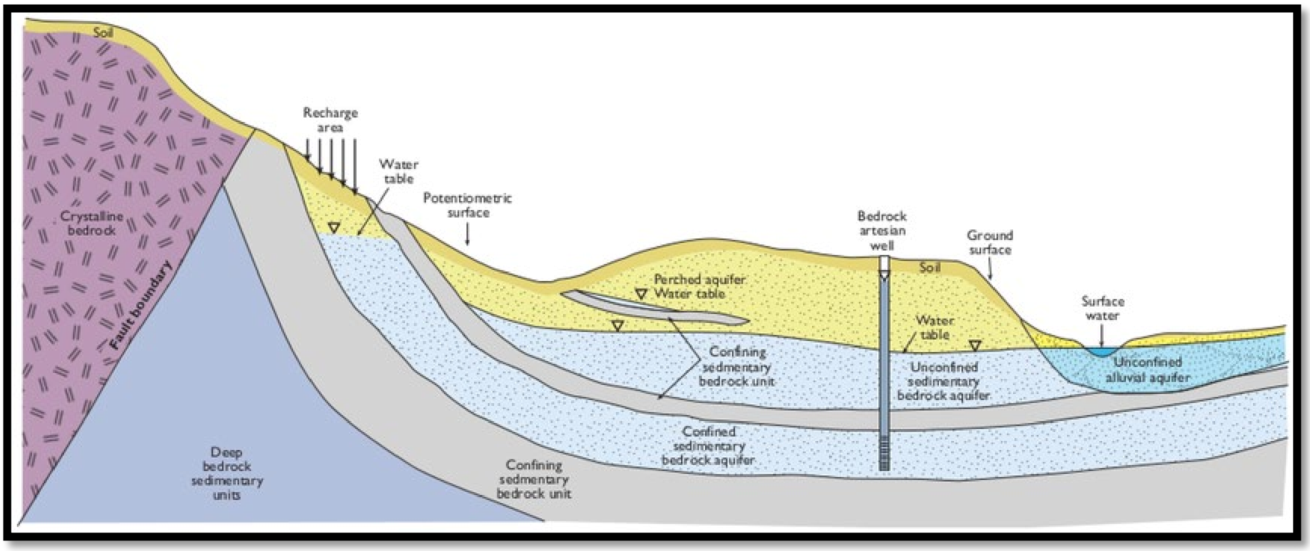


Figure 2-3: Simplified diagram showing aquifer types (Source: Barkmann et al., 2020).

2.2.4 Aquifer Properties

Malefane (2016) emphasised/highlighted the importance of aquifer parameters especially transmissivity and storativity without undermining the others in sustainable yield estimation. The aquifer hydraulic parameters are essential in providing data on underground water storage potential for sustainable utilisation (Makungo et al., 2021). The sections below describe some general aquifer properties;

2.2.4.1 Porosity (η)

A necessary condition for groundwater's existence is a sufficient "void volume" in pores or fissures, which may be measured using the porosity coefficient (η), which is the ratio of a porous medium's total volume to all of its voids:

$$\textbf{POROSITY } (\eta) = \frac{\textit{Volume of pores } (Vv)}{\textit{Volume of rock } (VT)} \text{..} \textbf{Equation 2-1}$$

2.2.4.2 Permeability

The ability of a porous media to transport a fluid is measured and referred to as permeability. This is a feature of the medium that is unrelated to the characteristics of the fluid. Mathematically, it may be defined as:

$$\mathbf{k} = \frac{K\mu}{g\rho} \text{......................................} \textbf{ Equation 2-2}$$

Where g is the acceleration caused by gravity, ρ is the fluid density, μ is the dynamic viscosity, and **K** is the hydraulic conductivity.

The following factors influence the permeability's magnitude:

- **Sand grain shape and size:** If the rock is made up of large, flat grains that are consistently organised with the longest dimension, the permeability along the horizontal axis will be different from that along the vertical axis.
- **Lamination**: Vertical permeability is inhibited by the platy minerals like muscovite and shale lamination.
- **Cementation:** Permeability is decreased when there is too much cement in the pore space.

2.2.4.3 Transmissivity

Aquifer thickness that is totally saturated and has a hydraulic gradient of one can transfer a certain amount of water horizontally over a unit width, measured by a property called transmissivity T. Transmissivity can be calculated by multiplying the hydraulic conductivity by the saturated thickness of the aquifer and is given by:

$$\mathbf{T = Kb} \text{......................................} \textbf{Equation 2-3}$$

Where K represents hydraulic conductivity [LT^{-1}], and b is the saturated thickness of the aquifer [L]

"Transmissivity is dependent on both hydraulic conductivity and saturated thickness, so its value varies depending on whether an aquifer is bounded by sloping confining beds, composed of heterogeneous material, or unconfined, where the saturated thickness varies with the water table," as shown by Freeze and Cherry (1979) and USAC (1999). According to Malefane (2016), transmissivity aids in estimating the capacity or yield of a borehole.

2.2.4.4 Specific Yield and Specific Retention

The ratio of the water that will drain from a saturated rock due to gravity to the media's overall volume is known as the specific yield (*Sy*). The ratio of the volume of water that a unit of media can hold against gravity's pull to the media's overall volume is known as specific retention (*Sr*). The total of the media's specific yield and specific retention determines a rock's porosity. Effective porosity can be thought of as having the same value as specific yield for most real-world applications in sands and gravels. Clays have a significantly larger surface area and, hence, higher water molecule adhesion (USAC, 1999).

2.2.5 Darcy's law

Henry Darcy, a French hydraulic engineer, experimented to find water flow rate via sand filters in an effort to purify water sources. His findings, published in 1856, have formed the cornerstone of every contemporary study of groundwater flow. He carried out the column experiments that proved Darcy's law for sand flow. Through his experiment, he proved that the head loss ($-\Delta h$) and cross-sectional area (A) are directly related to the rate of flow (Q), or the volume of water per unit time, and inversely proportional to the flow path's length (L) shown in **Figure 2-4** (Freeze and Cherry, 1979; USAC, 1999).

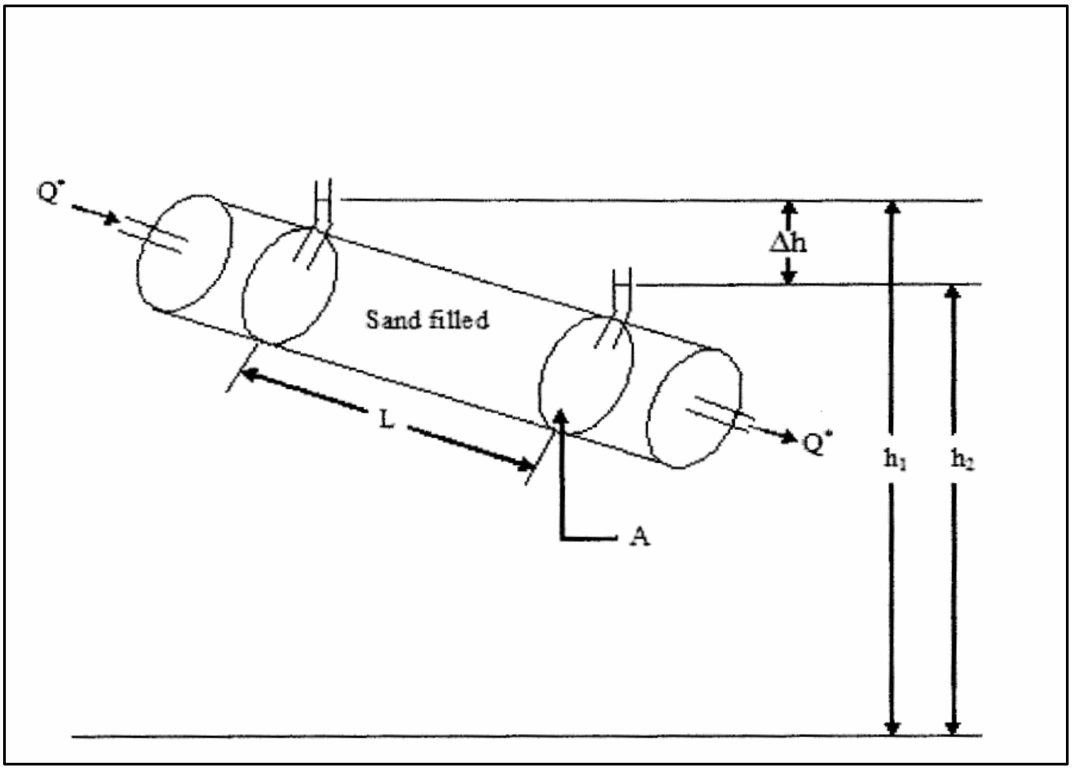


Figure 2-4: Darcy's experiment with sand column (Source: USAC, 1999).

This can be expressed mathematically as:

$$\boldsymbol{Q \propto A\frac{(-\Delta h)}{L}} \text{.................................. } \textbf{Equation 2-4}$$

Where Q is the water discharge rate, A is the cross-sectional area, Ah is the hydraulic head, and L is the distance between lowest to highest points (Figure 2-4).

The law of Darcy can be expressed as:

$$\boldsymbol{Q = -KA\frac{\Delta h}{L}} \text{.................................. } \textbf{Equation 2-5}$$

Where the -ve sign denotes that Q occurs in the direction of decreasing head and K is the porous medium's hydraulic conductivity.

Here, $\frac{\Delta h}{L}\left(\approx \frac{\partial h}{\partial L}\right)$ = Hydraulic gradient.

Darcy's law may also be equated as:

$$\boldsymbol{q = \frac{Q}{A} = -K\frac{\partial h}{\partial L}} \text{.............................. } \textbf{Equation 2-6}$$

Where q is the specific discharge, also referred to as the Darcian velocity. According to Freeze and Cherry (1979) and USAC (1999), equation 2-6 demonstrates that the specific discharge can be defined as the amount of water that flows through a unit cross-sectional area normal to the flow direction in a unit of time.

2.2.6 Groundwater Exploration Methods

Balasubramanian (2007) asserts that groundwater is a naturally occurring resource that is invisible. On the earth's surface layer, it can be found in a variety of amounts, types of rocks, and depths. In the past, people would dig small trenches in the alluvium of rivers when there was no visible flow of water. They would then wait for seepage to occur, collect groundwater, and utilize it for drinking and other household requirements. The inhabitants who lived in mountainous areas also derived their water supply from natural springs. Any groundwater system will eventually seep out, producing springs in areas with hills or limestone (Balasubramanian, 2007).

According to studies, overexploitation causes groundwater, which was previously present in open wells at shallow depths, to typically descend (Balasubramanian, 2007). For geoscientists, investigating these water sources becomes a difficult undertaking. To solve this issue, it is usually necessary to investigate several factors, including the local geology, structural features, and physical parameters utilizing geophysical techniques.

To improve borehole drilling success rates, research on identifying and evaluating groundwater potential continues to receive enormous consideration globally (Gomo et al., 2024).

2.2.6.1 Geological and Structural Methods

The process of starting a geologic investigation involves gathering, examining, and interpreting hydrogeological data from aerial images, logs, topographic maps, geologic maps, and other related records (Freeze and Cherry, 1979). Geologic field research, an evaluation of the hydrologic data on springs and streamflow, borehole productivity, groundwater replenishment, discharge and levels, and water quality should all be included, where necessary. Minor and significant structural features like lineaments, faults, and joints may ultimately influence the drainages in certain locations. These areas are suitable and worth exploring for groundwater. These serve as the groundwater flow conduits (Balasubramanian, 2007).

Ideal locations for groundwater are along the valley plains that cut across a boundary between two strata, where relatively impermeable strata are layered above porous layers that contain water (Balasubramanian, 2007). Spring presence signals the existence of groundwater over steep terrain and can be found on or near basin terrain, local ridges, and the base of hillsides. A good way to stop groundwater flow is through dykes. The location of the dykes and an analysis of their strike and dip aid in the identification of the upstream side groundwater potential zones.

According to Holland (2011), geologists frequently use remote sensing, such as ASTER (Advanced Spaceborne Thermal Emission and Reflectance) or Landsat satellite imagery, to map and identify geological linear structures such dykes, faults, and fractures with a high density of fractures. Remote sensing in combination with geology is used to delineate groundwater potential zones. Geophysical methods are routinely used to target these linear structures for groundwater development.

2.2.6.2 Geophysical methods

Physical properties, including resistivity, density, conductivity, velocity, electromagnetic, magnetic, and radioactive phenomena, are monitored in geophysical investigations to examine the groundwater resources on Earth's surface (Balasubramanian, 2007). Utilising geophysical methods, signals from induced or natural phenomena relative to the physical properties of the subsurface formation are measured. The physical nature of the earth's crust can be varied or anomalous, and they can be found using geophysical methods. Elasticity, electrical resistivity, density, and magnetism are the characteristics that are most frequently measured. The ultimate goals of exploration are to identify potential zones for exploitation and locate indirect indicators. Electrical, seismic, gravity, and magnetic techniques are essential geophysical methods for addressing hydrogeology-related situations (Balasubramanian, 2007).

2.2.6.2.1 Magnetic Method

The earth's magnetic fields may be detected and mapped through the magnetic method of detection. Instruments that are utilised to measure magnetic fields and fluctuations are known as magnetometers.

The technique is not very useful for investigating groundwater since magnetic differences are not always linked to the presence of groundwater. This method may be utilised to gain indirect information relevant to the groundwater investigations, such as the existence of dykes that define aquifer boundaries or limits of a basaltic flow or faults and joints (MacDonald et al., 2002).

2.2.6.2.2 Seismic Method

Seismic methods are classed into two categories: seismic reflection and seismic refraction (Freeze and Cherry, 1979). The seismic refraction method measures time needed for the sound, or shock, wave to travel known distances after producing a tiny shock at the earth's surface through the impact of a heavy object or a small explosive charge (Balasubramanian, 2007). Similar to light rays, seismic waves can be reflected or refracted at any interface with a change in velocity. While seismic refraction devices are useful for studying groundwater, they only reach approximately 100 metres below the surface. Seismic reflection methods can reveal information on geologic structures thousands of meters below the surface. A seismic wave's travel duration is contingent upon the medium it travels through. The velocities are negligible in unconsolidated materials and excellent in solid igneous rocks. The subsurface zones of lineaments, faults, fissures, and fractures can be identified using these indicators (MacDonald et al., 2002.

2.2.6.2.3 Electrical resistivity method

Electrical surveys aim to ascertain the subsurface resistivity arrangements by taking measurements on the ground surface. It is possible to estimate the sub-surface's true resistivity using these measurements. Numerous geological characteristics, including the amount of water saturated in the rock, porosity, and mineral and fluid content, are connected to the ground resistivity. Hydrogeological, mining, and geotechnical studies have employed electrical resistivity surveys for many years. It has been used more lately for environmental surveys (Balasubramanian, 2007).

Balasubramanian (2007) states, "Each electrical property is the basis for a geophysical method". Standard methods for measuring resistivity involve injecting current into the ground through two current electrodes (C1 and C2) and measuring the voltage difference that results at two potential electrodes (P1 and P2). From the current (I) and voltage (V) values, an apparent resistivity (ρa) value is calculated using:

$$\rho a = k\ V / I \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation 2-7}$$

where k represents the geometric factor subject to the distribution of the four electrodes. In these studies, the arrangement of electrodes is referred to as an array. Wenner, Schlumberger, pole-pole, pole-dipole, and dipole-dipole arrays are a few of the most popular electrode arrays (MacDonald et al., 2002).

2.2.6.2.4 Vertical electrical sounding

Vertical electrical sounding (VES) measures the resistivity fluctuation with depth. A single VES should only be used in locations where it is anticipated that the ground would be horizontally layered with minimal lateral variation, as the sounding curves can only be comprehended using a horizontally layered earth (1D) model. A resistivity meter determines the apparent resistivity values (MacDonald et al., 2002).

Typically, resistivity metres provide a resistance value,

$$R = V/I, \ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation 2-8}$$

Therefore, in practice, the value of apparent resistivity is determined by

$$\rho a = k\ R \ldots\ldots\ldots\ldots\ldots\ldots \textbf{Equation 2-9}$$

The resistivity value that has been determined is not the actual resistivity of the subsurface; instead, it is the "apparent" resistivity of a homogenous ground that will yield a similar resistance value for a similar electrode setup. The correlation between the "actual" and the "apparent" resistivity is intricate. To determine the true subsurface resistivity, computer software must be utilised to correct the observed apparent resistivity values. Typically, a log-log graph paper is utilised to plot the measured apparent resistivity values. To evaluate the results of a survey like this, it is generally assumed that horizontal strata make up the subsurface (MacDonald et al., 2002).

2.3 GROUNDWATER SUSTAINABILITY AND MANAGEMENT

Developing groundwater sustainably is essential to ensuring that everyone has access to clean drinking water. Groundwater is a finite resource that is under serious threat from pollution, which causes permanent aquifer damage in some countries. In others, over-abstraction results in reduced water availability (Furey and Danert, 2014).

According to Cobbling (2014), evidence suggests that “the physical availability of groundwater may be only one of many factors in determining whether groundwater-based rural water supply schemes in South Africa are reliable or sustainable."

Sophocleous (2000) states that the volume of recharge to an aquifer was formerly believed to equal the quantity of water that could be sustainably withdrawn from the aquifer. However, it is recognized that to maintain sufficient water supplies to support the quantity and quality of wetlands, streams, springs, and groundwater-dependent ecosystems, the sustainable yield of an aquifer must be far lower than the recharge.

Quantifying these environmental provisions is a critical research requirement since sustainable resource management requires managing groundwater for both current and future generations and providing suitable amounts of water for the environment (Sophocleous, 2000). According to Sophocleous (2005), groundwater sustainability requires protecting both the natural ecosystem that depends on the resource and the future resource from exploitation and depletion. However, to assess or re-evaluate the long-term behaviour of the aquifer and its sustainable yield, managers must have precise data in relation to inputs (such as recharge) and outputs (natural discharge or pumping of wells) within each groundwater basin. Therefore, with a reliable estimate of recharge, it is possible to accurately analyse the effects of taking groundwater from an aquifer or predict how an aquifer would behave over time under various management plans (Sophocleous, 2005).

2.4 GROUNDWATER RECHARGE

Malefane (2016) states that estimation of recharge is the foundation for effective management of groundwater resources. Aquifer recharge can be estimated using a variety of techniques, each of which has its own limitations and accuracy requirements. Rainfall is the main means for replenishing moisture underground, and the movement of moisture underground is dependent on hydraulic conductivity and capillary pressure (Sun, 2005).

The following were enumerated and characterised by Kircher et al. (1991) as the main contributing causes to the aquifer's replenishment:

- Rainfall: intensity, magnitude, spatial distribution, and duration

- Geologic environment: hydraulic conductivity and storativity properties of the formation, and boundaries
- Evapotranspiration: meteorological parameters and vegetation system
- Hydrology: rivers and run-off
- Unsaturated zones: hydraulic parameters of the various soils, thickness, physical properties of soil formations, crust development
- Flow mechanism: soil matrix and flow along preferred pathways

Malefane (2016) further emphasised the impact geomorphology variations which includes topography, vegetation, and soil type has in aquifer recharge. While recharge takes place in topographic low areas in arid regions, recharge locations in humid climates are in topographic highs, with discharge occurring in topographic low areas (Toth, 1963). The importance of plant cover for aquifer recharge was shown by Gee et al. (1994) and Prych (1998), who noted that recharge is typically higher in non-vegetated areas than in vegetated ones.

According to Woodford and Chevallier (2002), it is challenging to predict recharge accurately, and multiple methods are frequently used. According to Xu and Beekman (2003), a user-friendly framework for recharge estimates is not yet available. Chilton and Foster (1995) state that recharge estimation is problematic in some terrains due to the complexity of groundwater flow systems and the variability and discontinuity of aquifers.

An overview of the techniques for recharge estimation that are frequently employed in Southern Africa was given by Xu and Beekman (2003). Among many other methods, the chlorine Mass Balance (CMB) method is user-friendly, less expensive and highly favoured in geohydrological studies (Malefane, 2016; Xu and Beekman, 2003). Recharge may be estimated utilising the equation 2-10 below:

$$\text{Groundwater Recharge (mm/a)} = \frac{\text{Rainfall (mm/a) x Chloride of rainfall (mg/l)}}{\textbf{\textit{Chloride of Groundwater (mg/l)}}} \quad \textbf{Equation 2-10}$$

Some researchers use “qualified guess” to estimate groundwater recharge. The phrase "qualified guess" refers to broad approximations produced through projections in the absence of enough data or information. These approximations are grounded in mathematical theories, easily accessible data, and an understanding of the field and its particulars. This study calculates the groundwater recharge rate using the maps given by Vegter (1995), the groundwater component of harvest potential, and river base flow. The study region is found on the maps by Vegter (1995), and its position on the maps determines its recharge value. These maps show the estimated recharging of the entire country of South Africa. The expert judgments and formulas presented by Kirchner et al. (1991) and Bredenkamp et al. (1995) are the basis for qualified estimates for recharge from geology and vegetation/soil.

2.5 GEOCHEMISTRY ANALYSIS

Groundwater quality data were presented through tables, a Durov diagram, and a Piper diagram. The Durov (1948) and Piper (1944) plots were utilised in this investigation to comprehend the hydrochemical processes associated with the study area's underlying aquifers. Interpretations of the Durov diagram also help determine the type of aquifer (dynamic, static, or stagnant water) and its corresponding water quality. A Piper diagram was employed to visually define different forms of water and differentiate among them in the study area.

According to Todd (2001), both Durov and Piper diagrams reveal similarities and differences among the water samples since samples with similar qualities tend to plot together as groups. On the Durov diagram, the intersection of lines extended from the points in ternary diagrams and projected on the sub-divisions of the binary plot defines the hydrochemical processes involved along with the water type (Figure 2-5; Figure 2-6 and Table 2-1). However, in Piper diagrams, Todd (2001) indicated that data is plotted on the diamond-shaped field subdivisions that decide the water type or hydrochemical facies in a water sample (Figure 2-7 and Table 2-2).

2.5.1 Durov Diagram

The Durov diagram considers Cations (i.e., Na + K, Ca, and Mg) and Anions (i.e., Cl, HCO_3, and SO_4) and total cations vs. total anions only (Durov, 1948).

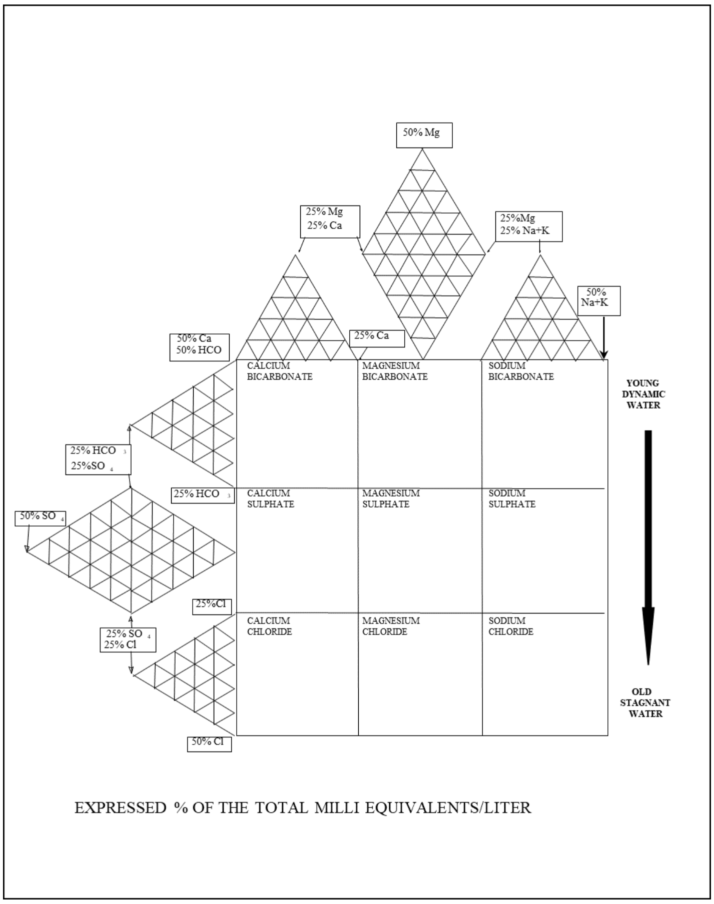


Figure 2-5: Durov diagram water quality classification (WSM, 2015)

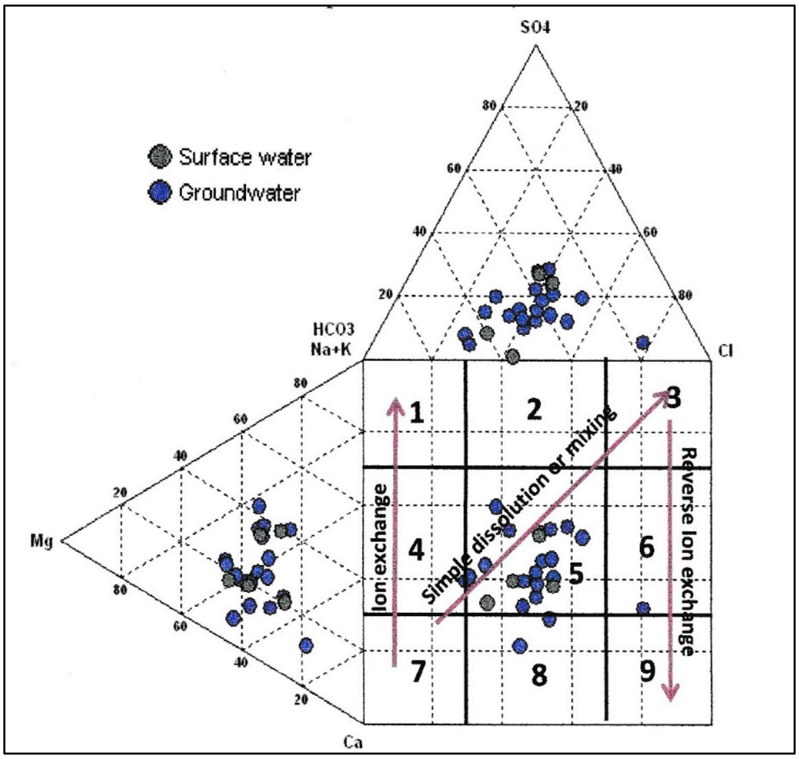


Figure 2-6: Durov plot depicting hydrochemical processes involved (Lloyd and Heathcoat, 1985)

Table 2-1: Classification of water based on the Durov diagram (Lloyd and Heathcoat, 1985)

Sl. No	Water Types
1	HCO_3 and Ca dominant, frequently indicates recharging waters in limestone, sandstone, and many other aquifers
2	This water type is dominated by Ca and HCO_3 ions. Association with dolomite is presumed if Mg is significant. However, those samples in which Na is significant, an important ion exchange is presumed
3	HCO_3 and Na are dominant, normally indicates ion exchanged water, although the generation of CO_2 at depth can produce HCO_3 where Na is dominant under certain circumstances
4	SO_4 dominates, or anion discriminant and Ca dominant, Ca and SO_4 dominant, frequently indicates recharge water in lava and gypsiferous deposits, otherwise mixed water or water exhibiting simple dissolution may be indicated.
5	No dominant anion or cation, indicates water exhibiting simple dissolution or mixing.
6	SO_4 dominant or anion discriminate and Na dominant; is a water type that is not frequently encountered and indicates probable mixing or uncommon dissolution influences.
7	Cl and Na dominant is frequently encountered unless cement pollution is present. Otherwise the water may result from reverse ion exchange of Na-Cl waters.
8	Cl dominant anion and Na dominant cation, indicate that the ground waters be related to reverse ion exchange of Na-Cl waters.
9	Cl and Na dominant frequently indicate end-point down gradient waters through dissolution

2.5.2 Piper Diagram

The chemistry of a water sample or samples can be shown graphically using a piper diagram. The anions and cations are displayed in different ternary graphs. The potassium cations, together with calcium, magnesium, and sodium cations, form the apexes of the cation plot. Sulphate, chloride, and carbonate anions combined with bicarbonate anions are the apexes of the anion plot.

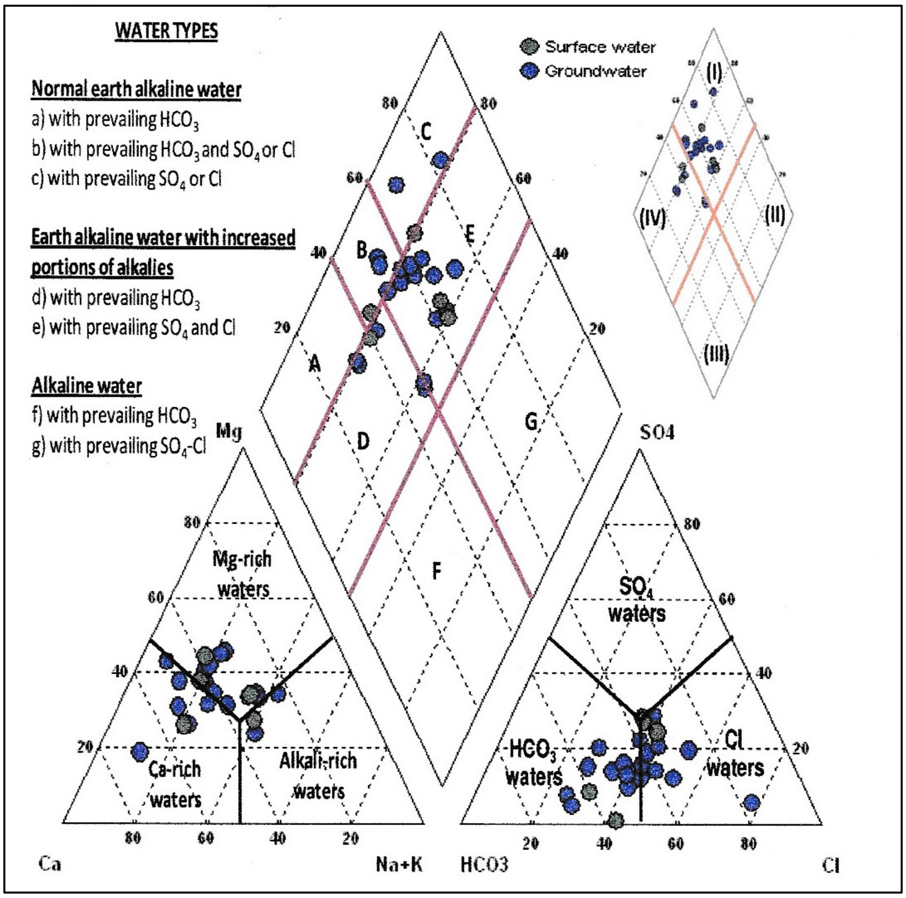


Figure 2-7: Piper Trilinear diagram classifying major hydrochemical facies (Langguth, 1966)

Table 2-2: Classification of water based on Piper diagram (Langguth, 1966)

Sl. No.	Water Types
A	Normal earth alkaline water with prevailing bicarbonate
B	Normal earth alkaline water with prevailing bicarbonate and sulfate or chloride
C	Normal earth alkaline water with prevailing sulfate or chloride
D	Earth alkaline water with increased portions of alkalis with prevailing bicarbonate
E	Earth alkaline water with increased portions of alkalis with prevailing sulfate and chloride
F	Alkaline water with prevailing bicarbonate
G	Alkaline water with prevailing sulfate or chloride

2.6 SUMMARY

Ramathieledza et al. (2017) state that "water is an essential resource for livelihood (humans, animals, and plants), and without water, there is no life on earth." Sustainable water resource availability is a worldwide challenge, and the challenges vary from one country to another depending on its geographic location, climate, rainfall, geology, hydrogeology, et cetera.

Matukane (2016) in his study demonstrated the importance of geophysical methods in groundwater exploration. With the aid of geophysics, Matukane was able to successfully drill high yielding boreholes to enhance the existing Matoks Bulk Water Supply Scheme. The application of Geophysical Methods as a tool for successful groundwater exploration was further revealed by Munyai (2018), Mukhwathi and Fourie (2020), Du Toit et al. (2012), and Ratshiedana et al. (2018).

After groundwater exploration is complete, groundwater resources are developed through borehole drilling, pump testing, and quality analysis. Matukane (2016) states that high-yielding boreholes drilled in Matoks lie in the Nthabalala fault zone, lineaments, or associated structures. Boreholes drilled along these geological lineaments, structures, and fault zones have a higher potential than those drilled without proper investigation (Du Toit et al., 2012).

Pump testing manuals and guidelines were developed to aid in the assessment of sustainable groundwater supplies to communities (Pietersen et al., 2002; DWS, 1997; USAC, 1999). The long-term use of developed groundwater resources should be determined by analysing the aquifer's characteristics. The developed groundwater resource must also meet the water quality standards as outlined by WHO for water supply in the communities (SANS) 241: 2011 and WHO (2011).

To achieve groundwater Resource Supply Augmentation in rural communities (Dzamba-Mabulo Villages), the following factors must be understood: climate, topography, geology (stratigraphy, structures, faults and lineaments), and hydrogeology (groundwater occurrence, aquifers and their properties, recharge, groundwater laws, and exploration methods).

The study has identified the following gaps within the project area and in the broader groundwater studies generally:

- Lack of data regarding yields, aquifer parameters/characteristics, and groundwater quality
- Lack of information on groundwater recharge

CHAPTER 3: METHODS AND METHODOLOGY

The sections in this chapter explain the materials and methods used for this investigation.

3.1 DESKTOP STUDY

The desktop study began with a literature search to determine what knowledge already existed on the hydrogeology and geology of the study area. Subsequently, it explored the existing borehole data across many databases created and overseen by the Department of Water and Sanitation (DWS).

3.1.1 Existing geological and geohydrological information

Satellite images and maps were utilised to establish an insight and the hydrological representation of the research site as a tool for comprehending its physical attributes. The following were also considered:

- The 1:250 000 geological sheets (which were used to determine the regional and local geology of the area, viz):
  - 1:250 000 scale, 2230 Messina geological map compiled and partly revised by Brandl (1981);
- Using National Geospatial Information (NGI) (1999), the published 1:50 000 topographic sheet 2230 CD (Thohoyandou) served as the research site's base map.
- The hydrogeological conditions of the area were ascertained using the 1:500 000 map, 2127 Messina (first edition) hydrogeological map, which was created in 2002 by the Department of Water Affairs and Forestry (DWAF).
- Google satellite imagery was used for lineament mapping and analysis.

Several papers assembled as part of earlier development of the local groundwater resources provided comprehensive geological and hydrogeological information for the study area.

3.1.2 Records of borehole information on databases

Records of boreholes in the Limpopo province are preserved in various DWS databases. Drillers, geohydrological firms, engineering firms, and private borehole owners were the primary sources of the borehole data currently stored in the databases.

In order to find records of current borehole data within the research area, existing Department of Water and Sanitation (DWS) databases were explored. Although the province (Limpopo) has multiple databases containing borehole records, the groundwater data and information used in this study were only obtained from the Groundwater Resource Information Project (GRIP) and National Groundwater Database (NGDB) databases:

- **Groundwater Resource Information Project (GRIP) Database**

The Limpopo province established the GRIP database to gather data (borehole point data) for groundwater management, with an emphasis on aquifer features and water availability. Over time, GRIP has improved and raised awareness of the significance of groundwater resources in the majority of the Limpopo province's municipalities. The GRIP database data was utilized as a baseline to determine the locations of the boreholes.

- **National Groundwater Database (NGDB)**

The most comprehensive borehole dataset in South Africa is the National Groundwater Database (NGDB) dataset, which has an estimated record of 225,000 boreholes (http://www.dwaf.gov.za/geohydrology/database). Each borehole's geographic location is associated with a site ID, which is an allocated identifier used to identify the site where the borehole data is stored in the NGDB. The National Groundwater Archive (NGA), which began operations after 2004, supplanted the non-Internet-based NGDB.

3.2 HYDROCENSUS AND DATA VERIFICATION

A thorough hydrocensus was necessary to capture the locations of the wells within the research site. After examining the current information from the databases, it became clear that most of the information was not fully recorded. Their field position was not verified for accuracy, and other relevant data was not captured.

In the Dzamba-Mabulo research area, a hydrocensus (groundwater reconnaissance) was conducted to confirm the locations of the groundwater sources that had been reported, as well as to capture new groundwater sources that had not been included in the databases. The geological and topographical conditions of the site where the source (borehole, spring, et cetera) is found were also examined using the hydrocensus.

After the hydrocensus, the original borehole dataset underwent extensive data-quality filtering to eliminate erroneous and dubious data before it could be deemed final and shown on a map. It was crucial that the position, geology, and topographical conditions be accurately represented in the borehole dataset. Furthermore, private springs and boreholes were included in the research. The springs were thought to be surface-level groundwater discharge locations.

Appendix B and section 4.2.1 of Chapter 4 outline the groundwater sources visited in the area. Figure 4-1 depicts the location of the study area's current boreholes and springs.

3.3 GROUNDWATER DEVELOPMENT

The groundwater source development was conducted in accordance with DWS standards and guidelines for sustainable groundwater sources and a continuous monitoring framework. These include:

- Identification of suitable geological targets using aerial imagery, statistics, field mapping, and geophysical methods;
- Drilling and Pump testing programs;
- Hydro-chemistry evaluations; and
- Borehole recommendations and technical reporting for the entire project.

3.3.1 Borehole siting

Geological field mapping was conducted within the research site for this investigation. The study area is considered a residential area, and mapping can only be done along rivers and road cuttings to get outcrops and other geological structures. Using the geological base map, the geological structures and lineaments were traced and mapped for geophysical surveys. The geophysical traverse lines were planned to target the geological structures, fractures and lineaments, as these features are known to have high groundwater potential (Tessema et al., 2011; Shamuyarira, 2017; Magakane, 2019).

3.3.1.1 Geophysical survey

For this investigation, ground magnetic and electrical resistivity geophysical surveys were conducted. The ground magnetic survey was conducted using the Geotron Model G5 Proton Magnetometer while the PQWT TC300 model (telluric electric frequency selection method, TEFSM) was used for resistivity survey. The Geotron Model G5 Proton Magnetometer measures the magnetic intensity by measuring the total magnetic field. The magnetic intensity profiles were used to delineate the geological structures along the surveyed profiles. Three traverse lines were conducted, targeting the identified structures and lineaments in a 10m survey interval spacing (section 4.4, Table 4-2, Figure 4-6, and Figure 4-8).

PQWT TC300 model (telluric electric frequency selection method, TEFSM) equipment was also utilized along the same traverse line with the sole objective of confirming the geological structures and or geological lineaments. The PQWTC device studies electrical features inside the ground by using the earth's natural electromagnetic field as the working field source (Gomo et al., 2024). The earth's electromagnetic response sequence identifies the presence of underground geological bodies by analysing the electrical variations of geological entities at various subsurface depths (Daniels and Alberty, 1966). The electromagnetic waves are directed towards the earth, where they propagate according to the Maxwell equation through the soil (Benyu et al., 2017). The majority of subsurface geotechnical soil is assumed to be non-magnetic, and consistently conductive macroscopically, accumulation-free, then Maxwell's formula can be revised to:

$\nabla^2 H + K^2 H = 0$……………………………Equation 3-1

Where k represents wave number (or propagation coefficient), and H represents the magnetic field component

$K = (\omega^2 \mu\varepsilon - i\omega\sigma\mu)^{1/2}$………………………Equation 3-2

Where ω is frequency, μ is magnetic permeability, σ is electrical conductivity, and ε is dielectric permittivity

Given the complex nature of the propagation coefficient k, we can write: k = b = ia, where a denotes the phase coefficient and b the absorption coefficient. The displacement current is often insignificant, the electromagnetic frequency measured by the PQWTC spans from 0.1 Hz to 5 KHz, and k is further simplified as:

K= -iωσμ…………………………………Equation 3-3

A magnetoelectric relationship results when a magnetic field changes and the Helmholtz equation is altered (GeoSci Developers, 2018):

$$\frac{E}{H} = -\frac{i\omega\rho}{K}$$ **……………………………………. Equation 3-4**

Where E is an electrical field, and **ρ** is electrical resistivity

The ratio of the surface electric field to magnetic field's horizontal component is known as the surface impedance Z. This impedance is related to the earth's resistivity and the electromagnetic field's frequency in the case of uniform earth and is independent of the incident field's polarization:

$$Z = \frac{E}{H} = \sqrt{\omega\mu\rho\varepsilon^{\frac{i\pi}{4}}}$$ **………………………………Equation 3-5**

One can use equation (3-5) to find the earth's resistivity:

$$\rho = \frac{1}{5f}\left(\frac{E}{H}\right)^2$$ **………………………………………Equation 3-6**

In media that are not magnetic, the skin depth is:

$$\delta \approx 503\sqrt{\frac{\rho}{f}}$$ **…………………………………Equation 3-7**

where f is the frequency, ρ is the AC resistivity, and δ is the penetration depth.

The preceding equation (Equation 3-7) shows how frequency and resistivity are related to the depth to which electromagnetic waves can penetrate. There is no doubt about the frequency, the deeper the penetration, the higher the resistance. After data recording, the PQWTC machine automatically stores the data and, following automated data processing, generates subsurface resistivity profiles.

3.3.1.2 Drilling targets

The data from the two geophysical methods (Magnetic and TEFSM) were overlaid over each other to delineate and identify areas with groundwater potential as the drilling targets (see section 4.4, **Figure 4-6** to **Figure 4-8** and **Appendix B** for geophysical survey conducted for this study). Low resistive materials from 0 to 120 m deep and from 120 to 180 m deep enabled station 40 m on traverse line 3 (Table 4-2), the drilling location for the new borehole at Dzamba Village (Figure 4-8).

3.3.2 Borehole drilling

The design, drilling, and construction of the borehole were completed according to the document by DWS (1997). The DWS document ensures that the drilled boreholes meet the internationally accepted best practices. Additionally, it mandates the collection of data for future reference that will be included in the DWS database. These include borehole logging, water strikes, and blow yield measurement data records. Using a down-the-hole (DTH) hammer, the rotary air percussion drilling method, best suited to hard rock formations, was adopted in this investigation.

After evaluation of the survey sites, a new borehole was drilled at a selected site to a standard diameter of 165 mm inside diameter and steel casing along the collapsible material of 177 mm outside diameter. In addition, for the installation of casings, the borehole was reamed to 216 mm diameter along the loose formations encountered. Before the completion of the borehole drilling process, the borehole was flushed to remove all loose material and drill cuttings resting on the bottom of the borehole.

3.3.3 Yield Assessment

Pump testing was conducted on one borehole, mainly to ascertain the sustainable abstraction rate for the Dzamba water supply program. Section 3.3.3.1 and 3.3.3.2 details the principles that were followed to conduct the test and analysis during the yield assessment phase of the study.

3.3.3.1 Pumping test

The pumping test is achieved by pumping water out of a borehole and measuring the drawdown with corresponding times. The hydraulic properties of the aquifer were computed by substituting these values into the relevant well-flow equation (Kruseman and de Ridder, 1994). A pumping test can be used to determine how much groundwater can be "sustainably" collected from a borehole. In the context of this investigation, sustainable pumping yield refers to the maximum amount of water that can be extracted from an aquifer or aquifer network without depleting its resources over time. This amount is directly influenced by the aquifer's hydraulic properties, like permeability and storage, which determine how quickly water can be replenished and how much it can hold, according to Sophocleous (2005). Essentially, it's the pumping rate that can be maintained indefinitely without long-term impacts on the aquifer's water storage and recharge. When a borehole exhibits low-yielding or poor aquifer performance, pump testing can provide information about its success or whether it should be discarded (Sakala et al., 2014).

The data reliability needed, depends on how dependent the water consumer is on the borehole or boreholes and the potential financial ramifications of borehole failure, usually dictates how long the tests must last. The purpose of the pumping test in this study was to gather data on the aquifer's hydraulic properties and the sustainable yield of boreholes, both of which are crucial for groundwater management. The DWS (1997; 2003) test pumping criteria were followed in the execution of the pumping test and the following tests were included in the pumping test program:

- "**Step Drawdown Test (SDT):** During the SDT, the borehole was pumped at a constant yield for a 60-minute interval, thereafter at a higher discharge rate until the borehole reached a pump suction. A minimum of one step and a maximum of five steps at 60-minute intervals, respectively, were carried out. The drawdown over time was recorded in the pumping borehole. Once the pump was stopped, a recovery test was conducted, and the residual drawdown was measured until 95% recovery of the water level was reached. This was then followed by a Constant Rate Discharge Test (CRDT).
- **Constant Rate Discharge Test (CRDT):** During the CRDT, the borehole was pumped for a scheduled period of time between 8 and 72 hrs at a constant rate as per DWS guidelines (DWS, 1997). The discharge rate for the CRDT was estimated from the interpretation of the time drawdown data generated during the SDT. The drawdowns over time were recorded in the pumping borehole. To ensure that the continuous discharge rate is maintained during the test duration, discharge measurements were obtained at scheduled intervals. All changes in the discharge rate were precisely documented for further analysis. Normally, the aquifer systems are adequately stressed during CRDT to detect boundary impacts that can affect long-term aquifer usage.
- **Recovery Test (RT):** The RT is performed after the pump shuts off at the end of the SDT and CRDT. In the pumped and observation boreholes, the remainder drawdowns in a regular basis (water level recovery) are recorded until 95 percent recovery is achieved or for a period of time at least equal to the pumping duration.

Chapter 4, section 4.6, presents the pump testing for this project. The pump testing datasheet and interpretations are shown in Figures 4-16 to 4-17 and Appendix C.

3.3.3.2 Pumping test data analysis

3.3.3.2.1 Method

The pumping test data were evaluated for this investigation using the flow characteristics (FC) method. The Institute of Groundwater Studies (IGS) at the University of Free State created the FC-Method, an Excel-based program for interpreting pumping tests, on behalf of the Water Research Commission (WRC) to analyse pumping tests conducted in fractured rocks (Van Tonder et al., 2002).

Mathematical models correlating drawdown reaction to abstraction borehole discharge serve as the foundation for the interpretation of the FC-method. The performance of the borehole over a longer duration can then be projected using the findings of these brief tests.

It should be highlighted that the permeability and geometry of the lithology greatly influence the drawdown in a fractured rock aquifer. The traditional models created for homogenous porous aquifers might not work in fractured rock networks because the scale of heterogeneity in a fractured rock network might be enormous in comparison to the test's scale. According to Van Tonder et al. (2002), the FC-Method programme was specifically designed to assess pumping tests conducted in fractured rock. It determines the sustainable yield of the borehole, which is the discharge rate that keeps the water level above the prescribed limit (also called the critical level), which is usually when a significant water strike occurs.

3.3.3.2.2 Recommended abstraction rate

Appendix C provides specifics on the recommended pump depth, duty cycle, and abstraction rate. The recommended sustainable yield was computed using a pumping cycle of 24 hours (See Appendix D). It should be emphasised that the surrounding groundwater use was not taken into account when recommending the pumping yields because the abstractions in the majority of the private boreholes in the investigation area were unknown.

3.3.3.2.3 Aquifer Parameters

One of the most crucial parts of any groundwater investigation is determining the permeability of the aquifer (Sun, 2018). The flow and extraction of groundwater in geological formations are governed by two parameters: storage coefficient (S) and transmissivity (T) (Birpinar, 2003; Naderi, 2019). The product of the aquifer's saturation thickness and hydraulic conductivity is known as transmissivity. According to Strerrett (2007) and Sun (2018), it is a measurement of the volume of water that can be transferred horizontally through a unit width by the aquifer's pack saturated thickness at a hydraulic gradient of 1. The hydraulic parameters of the aquifers, namely conductivity and transmissivity, can be evaluated using pumping test analysis (Maréchal et al., 2008; Dausse et al., 2019).

Nevertheless, several traditional and computer-based techniques can be used to analyse aquifer parameters (Kruseman and De Ridder, 1991; Birpinar, 2003). One of the primary methods for estimating aquifer parameters, such as storage coefficient and transmissivity, which are crucial factors for assessing and exploiting groundwater resources, is to analyse the data from unsteady pumping tests that are conducted in the aquifer (Theis, 1935; Hongfei & Jianqing, 2012). Dausse et al. (2019) state that, in addition to its hydraulic characteristics, hydraulic tests, like pumping tests, can be performed to determine the flow pattern at the small scales to offer information on reservoir geometry (Gringarten, 2008). At the regional level, possible compartments under various hydrological circumstances are frequently identified through water level monitoring in multiple observation wells that are suitably spaced across the system (Guihéneuf et al., 2014).

Theis analytical method used for computing the aquifer parameters for this study considered the following equations:

$$\boldsymbol{T = \frac{6{,}9Q}{s} W(u)} \text{..................................... } \textbf{Equation 3-8}$$

$$\boldsymbol{Sc = \frac{4Tu}{r^2/t}} \text{..................................... } \textbf{Equation 3-9}$$

Where T = transmissivity (m^2/day), Q = well discharge (l/sec), s = drawdown (m), W(u) = well function, Sc = storage coefficient, r = distance of observation well from production (m), and t = time since pumping began (days).

When determining the transmissivity values, the Cooper-Jacob (1946) analytical technique makes the assumption that the confining layer and the aquifer in question are homogenous, isotropic, and uniformly thick. However, these presumptions are inaccurate in the majority of actual situations. Because of the complicated geology at the research site, the aquifer is heterogeneous, the aquifer's thickness changes with the geology, and the flow through it is not isotropic. Assumptions can be made in these situations to simplify complex heterogeneous settings. To shed light on the behaviour of drawdown in heterogeneous formations, such assumptions can help to streamline the intricate structure of actual heterogeneous formations. The non-uniform aquifer was conceptualised by Butler and Liu (1993) as a uniform matrix that contained a disc with anomalous features.

There are two systems in a fractured aquifer: the fracture and the matrix. Through a pumping test, groundwater is drawn out of the matrix, flows vertically to the fracture, and then proceeds towards the abstraction borehole along the fractured zone. Nevertheless, this scenario is not taken into account by either the Cooper-Jacob or Theis approaches (van Tonder et al., 2002). With these methods, the analytical answer takes into account only the portion of groundwater released outside the radius of the observation borehole. On a regional scale, this component becomes smaller as the observation borehole gets farther away. This explains why the calculated S-values decrease with increasing distance (van Tonder et al., 2002). The calculated T and S-values combine the matrix and fracture properties as a consequence of using the Cooper-Jacob and/or Theis techniques (Chiang and Riemann, 2001).

3.3.3.2.4 Diagnostic plots

To identify the conceptual model of the hydraulic scenario, this investigation uses the diagnostic plots to ascertain the aquifer features of the pump-tested boreholes. A diagnostic plot, which generates straight lines on specialised plots, can be used to identify the prevalent flow regimes (Kruseman and de Ridder, 1994). Diagnostic plots are available for unconfined, leaky, and confined aquifers. This study uses diagnostic plots for confined fractured aquifers, such as the doubled porosity type confined fractured aquifer, a single vertical fracture, and permeable dyke in the poorly permeable aquifer.

By carefully identifying the inner and outer boundary conditions, the log-log plot of drawdown against time of pumping, the semi-log plot of drawdown against time, and the log-log plot of the derivative of drawdown and time can be used to determine the characteristics of the aquifer. In some cases, the drawdown log-log plot may not be able to identify the aquifer's response to pumping; however, the derivative of the drawdown plot will show this (Woodford and Chevallier, 2002). Figure 3-1 demonstrates the different slope responses and relevant properties on a log-log plot of the drawdown derivative and time plot against time.

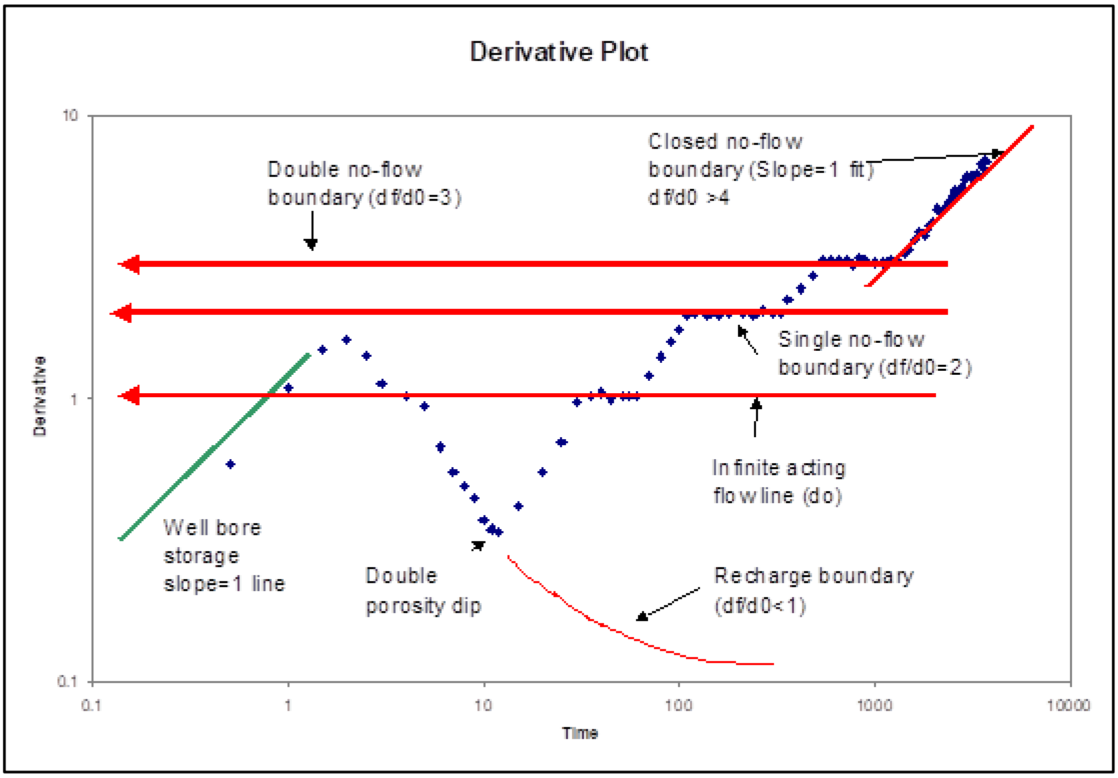


Figure 3-1: Possible derivative graph characteristics (van Tonder et al, 1998)

From the log-derivative graph, the following can be deduced (Van Tonder et al., 1998):

- The fracture network is presumably limited if the log derivative is less than 0,5% (linear flow often predominates in the early stages of fracture).
- When the log derivative is less than 0,25, it indicates a well-functioning fracture network, meaning that early on, bi-linear flow is predominant.
- A very good fracture network and aquifer are indicated by a log derivative value less than 0,1 (radial flow predominate).

The following vital characteristics could be achieved if the second derivative of drawdown—let's say d"—is taken (Van Tonder et al., 1998):

- In the case of a closed no-flow boundary, d" approaches exactly 1.
- In the case of a homogeneous infinite aquifer, d" equals zero (Theis model).

The properties of the log-log plot of drawdown and the semi-log plot of drawdown against time are provided in Table 3-1 and Table 3-2, respectively.

Table 3-1: Summary of a log-log plot drawdown (van Tonder et al, 1998 and Malefane, 2016)

Feature	Characteristic
Slope = 1 at early time	Well Bore Storage.
Slope = 0,5 at early time	Linear flow in fracture, water derived from fracture only.
Slope = 0,25 at early time	Bi-linear flow dominant, where water is leaking from the matrix into the fracture.
Horizontal line	Recharge boundary or leakage from matrix = abstraction rate or position of fracture is reached.

Table 3-2: Summary of a semi-log plot drawdown (van Tonder et al, 1998 and Malefane, 2016)

Feature	Characteristic
Straight line segment	Indication of radial flow.
Two parallel lines	Dual porosity.
Horizontal line	Recharge boundary or period where leakage from matrix = abstraction rate or water level has reached position of a fracture.
Steepening segment during late times	Boundary reached or matrix flow becomes dominant.

According to Woodford and Chevallier (2002), a semi-log plot can be a useful tool for determining specific boundary types and fracture locations, as well as for displaying a straight line that represents infinite-acting radial flow. The most popular plot is the log-log plot of drawdown, which makes it simple to identify the aquifer responses. A log-log derivative plot is then used to corroborate the responses identified. Van Tonder et al. (1998) used the FC Program to characterize the flow in this manner, especially when plotting the derivative curve.

3.3.4 Water quality assessment

The local boreholes found during hydrocensus phase and newly drilled boreholes (during this study) were sampled for water quality analysis. The water quality compliance for these boreholes was measured against the South African National Standard (SANS) 241: (2011) and WHO (2011). To ensure accurate results, proper sampling procedures were followed for sample collection, preservation, and laboratory preparation.

3.3.4.1 Water Sampling

All boreholes visited during hydrocensus were sampled and sent to Muratho Laboratory within 24 hours for chemical analysis. At the conclusion of the constant discharge test, a water sample was collected for a newly drilled and tested borehole (B1). Equipment used during water sampling included water sampling bottles (1 Litre plastic bottles), a Global Positioning System (GPS), a permanent marker, and a cooler box. Before sampling, a sample bottle and cap were rinsed and completely filled to prevent air bubbles.

3.3.4.2 Laboratory work

To meet the study's aims, laboratory work entails sample preservation and analysis to determine chemical constituents present in the water. The samples were also verified to ensure that the documentation was correctly completed, including the location, date/time, and the collector's name, through the sample register at Muratho Laboratory. At Muratho Laboratory, two analytical techniques are used: Inductively Coupled Plasma Mass Spectrometry (ICM-MS) and Ion Chromatography (IC).

3.3.4.3 Sample preservation/preparation

Groundwater is susceptible to changes in composition as a result of biological, physical, or chemical reactions that may take place between sampling and analysis. Reactions can be minimised or prevented through stabilisation or preservation. For this study, the samples were cooled to the temperature of ± 4 ^{0}C and submitted to the laboratory within 24 hours of sampling. The Muratho Laboratory **(Appendix E)** provided sampling bottles suitable for groundwater sampling in accordance with DWS standards and guidelines.

3.3.4.4 Sample analysis and Quality Control (QC)

The determined element composition from the samples was interpreted using Durov (1948) and Piper (1944) diagrams for this study. The water quality analysis was completed in accordance with the DWS (1997) document “Minimum Standards and Guidelines for Groundwater Resource Development for the Community Water Supply and Sanitation Programme.” The chemical components the SANAS-accredited lab analysed in all the samples were pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Total Alkalinity, Fluoride (F), Chloride (Cl), Sulphate (SO_4), Nitrate (NO_3), Iron (Fe), Manganese (Mn), Aluminium

(Al), Phosphates (PO_4), Arsenic (As), Chromium (Cr), Copper (Cu) and Zinc (Zn). The results were classified according to SANS 2011. Laboratory reagent blanks were used to assess contamination during the analysis process.

CHAPTER 4:
FINDINGS AND DISCUSSIONS

4.1 INTRODUCTION

This chapter presents the results of the hydrocensus, geophysical survey and siting, drilling, pump testing of borehole and chemical constituents of the sampled water from the boreholes under study.

4.2 HYDROCENSUS

4.2.1 Existing Borehole Data

According to Botha (2005), in 2002, Limpopo became the first province to implement Groundwater Resource Information Project (GRIP) database in South Africa. The main purpose was to improve the management and development of groundwater resources in rural villages. A systematic approach was utilised by GRIP to gather, verify, upload and use data, Botha (2005) emphasised. GRIP data was to be accessed and downloaded via www.groundwaterdata.co.za website. During hydrocensus for the current study, insufficient basic borehole data were found on GRIP database, which includes water levels, borehole depth, water strikes and water quality (see **Table 4-1**, **Figure 4-1** and **Appendix B**).

Nine (9) boreholes were found in the Dzamba and Mabulo communities, of which only two (2) are community boreholes, with seven (7) being private boreholes. From the two community boreholes, one was functional, and the other was identified as an unused or unequipped borehole (see **Table 4-1**, **Figure 4-1** and **Appendix B**).

Hydrocensus information suggests that the borehole depth in these communities ranges from 40 m to 80 m, with the water strikes around 21 m to 27 m. However, the data does not have all the information for all the boreholes, as seen in Table 4-1. This is because private borehole owners are not concerned about water strikes or borehole depth. Their main interest is the borehole that has water. Some owners do not even know the type and size of the equipment installed in their boreholes. Of all the boreholes surveyed during hydrocensus, none was found to have been sampled for water-quality analysis.

Table 4-1: Dzamba – Mabulo Hydrocensus Data

DZAMBA-MABULO HYDROCENSUS DATA							
Borehole Number	Ownership	Latitude	Longitude	Borehole depth	Water strike	Lithology dominant	Comments
BH 1	Ramarumo (Dzamba Village)	-22,812621	30,320249			Dolerite	Equipped with submersible
BH 2	Nemakonde (Dzamba Village)	-22,812636	30,321159	40m	21	Dolerite	Sampled and equipped with submersible
BH 3	Dzamba Community	-22,812983	30,323649			Sandstone	Tested and eqipped with submersible
BH 4	Mabulo Community	-22,810419	30,324921			Sandstone	Casing only - unused
BH 5	Maalakano (Mabulo Village)	-22,809917	30,328664	80m		Sandstone	Equipped with submersible
BH 6	Dzamba Primary School	-22,810209	30,329118			Sandstone	Equipped with submersible
BH 7	Musanda Mabulo Village	-22,809554	30,330343			Sandstone	Equipped with submersible
BH 8	Ndou (Mabulo Village)	-22,808473	30,32967	42m		Dolerite	Equipped with submersible
BH 9	Maalakano (Mabulo Village)	-22,808569	30,332162	60m	27	Sandstone	Sampled and equipped with submersible

Figure 4-1: Google map showing existing borehole localities

4.3 GEOLOGY

In chapter 2 of this study, it was illustrated that the area's geology plays a significant role in groundwater occurrence and development. Furthermore, lithology and rock types are believed to affect the rates of fracturing and weathering, which tend to influence the yield of boreholes (Balasubramanian, 2007; Mukheli, 2018; Matukane, 2016; Freeze and Cherry, 1979). For this study, the geology was further described and presented in the section below, using GIS to generate detailed maps of the research area.

The research site is underlain by the Fundudzi Formation of the Soutpansberg Group, which is composed mainly of arenaceous and argillaceous rocks with thin pyroclastic beds (Brandl, 1981). The resistant pink quartzite and sandstone dominate the area (**Figure 4-2**).

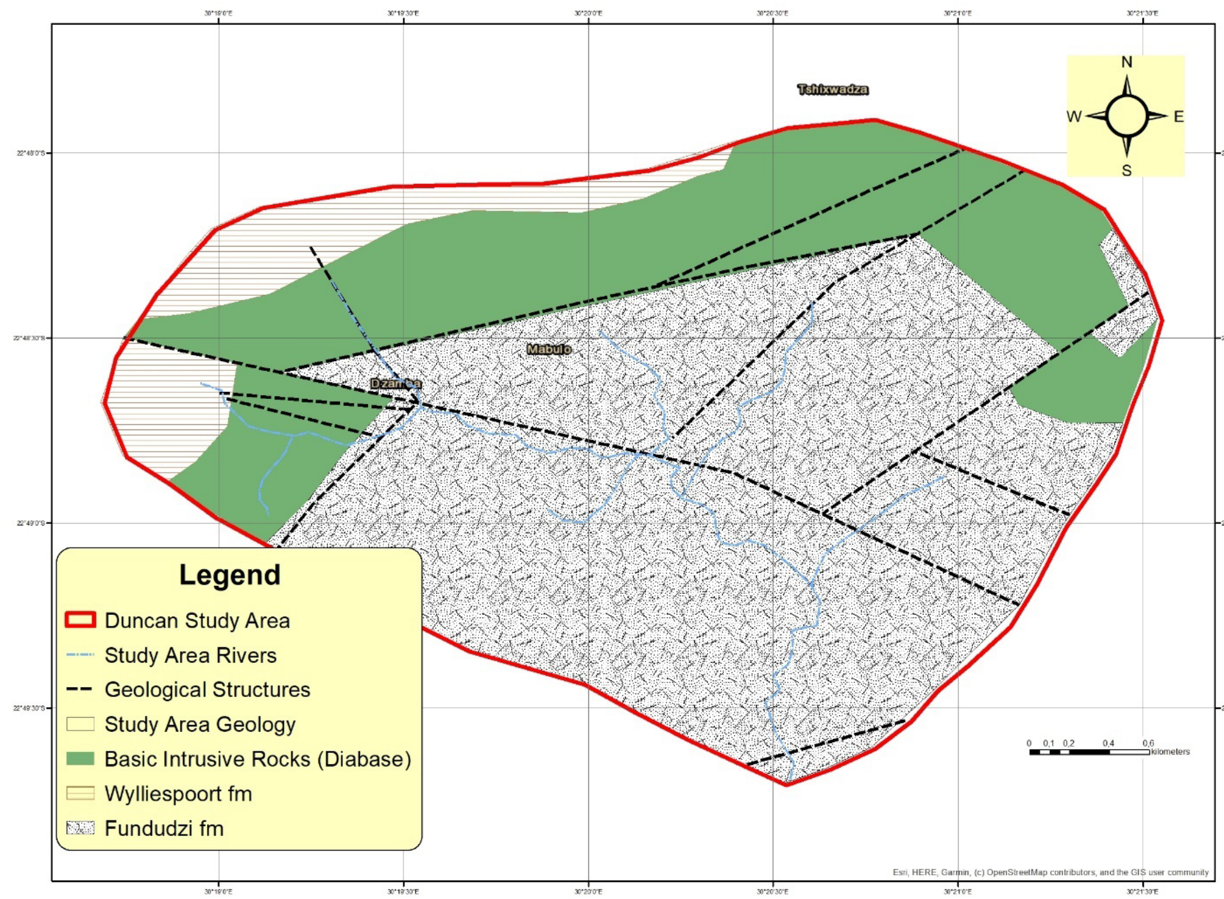


Figure 4-2: Geology map of the research site (Modified from 1:250 000 2230 Geological Map Series)

Geological structures (dolerite dyke, faults, fractures, contacts, and joints) trending in an east–west direction are visible from the geological map (See **Figure 4-3**). Geological features such as fault zones and fractures are good groundwater potential areas (Balasubramanian, 2007).

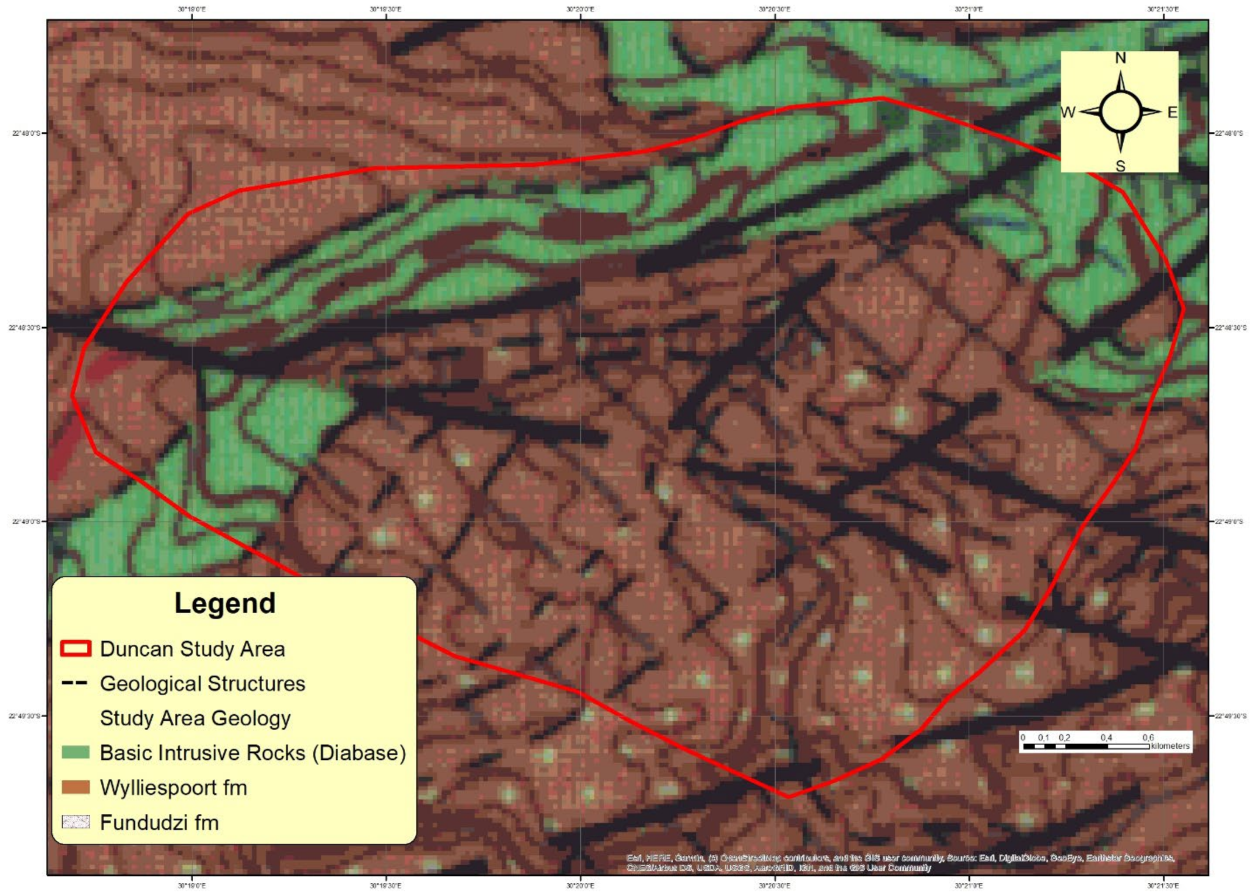


Figure 4-3: Geological map showing geological structures (Modified from 1:250 000 2230 Geological Map Series)

4.4 GEOPHYSICS AND BOREHOLE SITING

According to Malefane (2016), groundwater flows mainly through secondary features such as fractures, faults, and joints in the bedrock in fractured rock aquifers. Other studies have confirmed this, implying that for groundwater exploration, geophysical traverse lines, fractures, fault zones, and joints should be the main targets, with these lines planned properly (Hollard, 2011; Balasubramanian, 2007; Rao, et al.,2001).

The geophysical traverse lines were planned in a way that structures or lineaments can be detected. For this study, three geophysical traverse lines were conducted nearly or perpendicular to the identified geological structure (see Table 4-2, Figure 4-4, Figure 4-5 and pictures in **Appendix B**).

Table 4-2 Dzamba – Mabulo Geophysical Traverse Lines

Dzamba Mabulo Geophysical Traverse Lines						
Traverse Lines		**Latitude**	**Longitude**	**Distance (m)**	**Line Target**	**Comments**
Line 1	Line 1 Start	-22,813248	30,323619	250	Lineament	Drill Target at 80 m & 230 m
	Line 1 End	-22,811144	30,322746			
Line 2	Line 2 Start	-22,810107	30,325099	110	Fault zone	Drill Target at 40 m & 100 m
	Line 2 End	-22,810571	30,324183			
Line 3	Line 3 Start	-22,811073	30,322919	150	Weathering	Drilled at 40 m (-22,812983 & 30,323649)
	Line 3 End	-22,811877	30,321757			

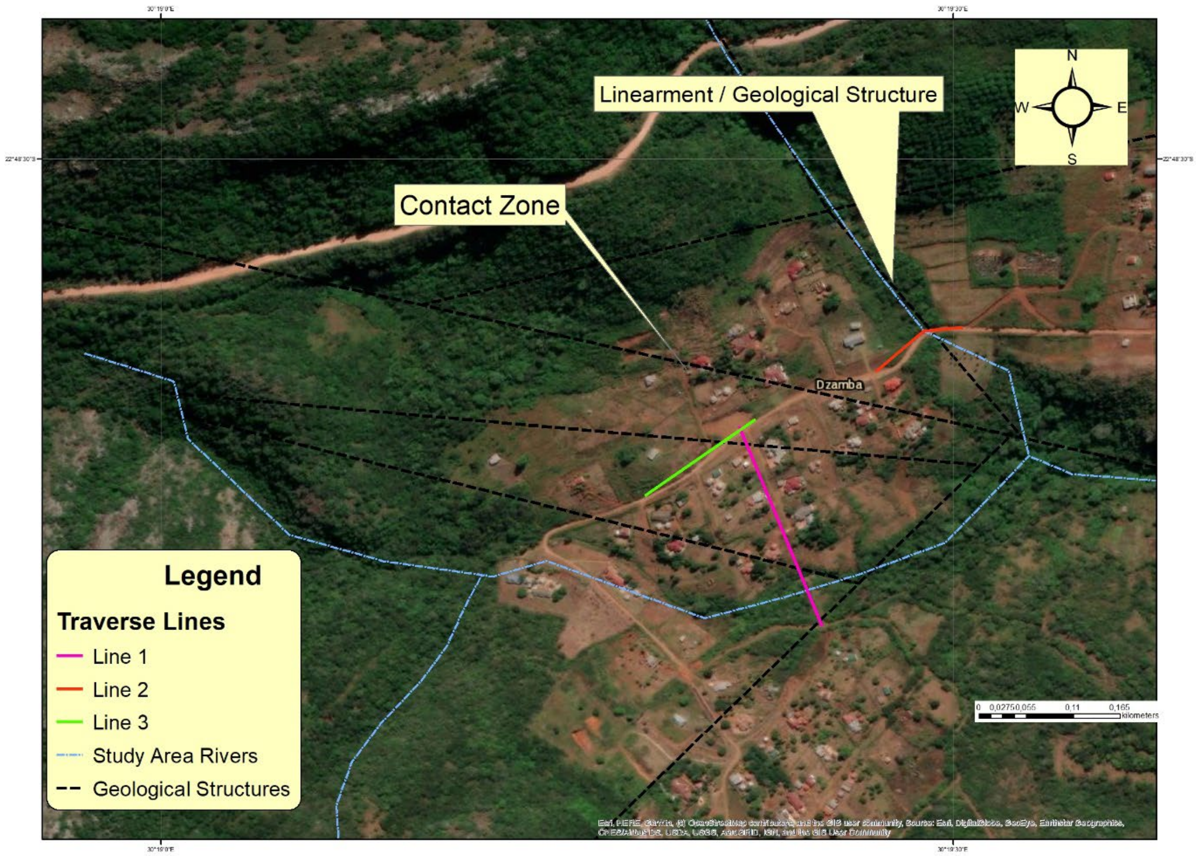


Figure 4-4: Google map showing geophysical traverse lines

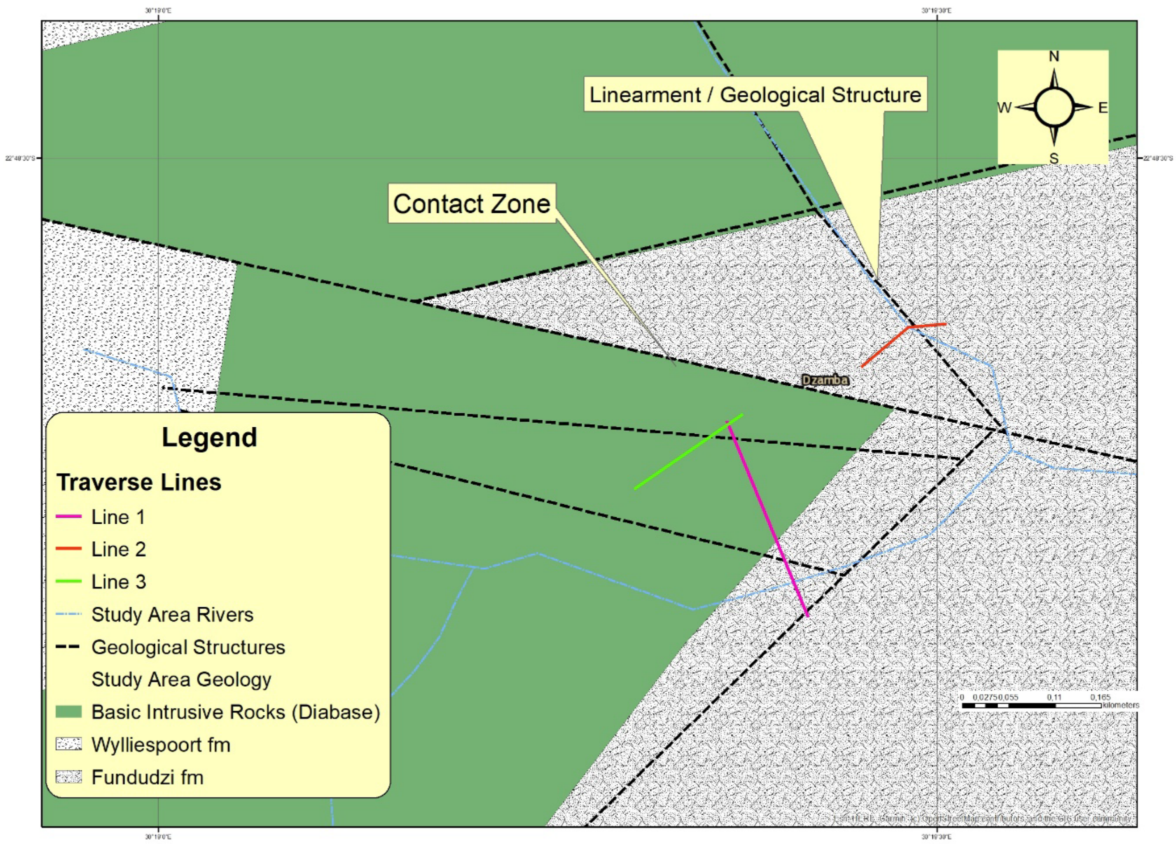


Figure 4-5: Geological map showing lineaments and contact zones

Traverse Line 1 was conducted in the S to N direction, targeting dyke trending in the NW to SE direction (Figure 4-5). Telluric electric frequency selection method (TEFSM) conducted on traverse line 1 confirmed two possible drilling sites (Figure 4-6). This is shown by the V-shape of the anomaly at stations 80 m and 150 m.

Gomo et al. (2024) demonstrated the effectiveness of TEFSM in identifying potential drilling sites and selecting weathered areas suitable for groundwater exploration. Compared with Gomo et al. (2024) findings, Line 1 shows a potential weathering at stations 80m and 150m on the TEFSM profile (Figure 4-6), confirmed by an anomaly on the proton magnetometer profile (Figure 4-6). In Traverse Line 1, the magnetic field signature decreases in stations 80 m and 150 m, confirming the TEFSM anomalies. According to Malefane (2016), a decrease in magnetic field signature might represent the contact zone, a discontinuity within an intrusion, or underlying features. The V-shape suggests the presence of a fracture system or a weathered channel that narrows with depth. Therefore, this is the most likely region for water to be struck (Gomo et al., 2024). According to the TEFSM profile, the site could be weathered to the depth of 160 m (Drill Option 1) and 130 m (Drill Option 2), see Figure 4-6. The vertical structure and shape of the blue anomaly are critical. The narrowing towards the base implies limited depth continuity, and the presence of flanking high-resistivity zones suggests this is a semi-confined aquifer. The reliability of this interpretation is supported by alignment with borehole lithology and pumping results; therefore, the drilling target was selected at station 160 m (Drill Option 1) and 130 m (Drill Option 2).

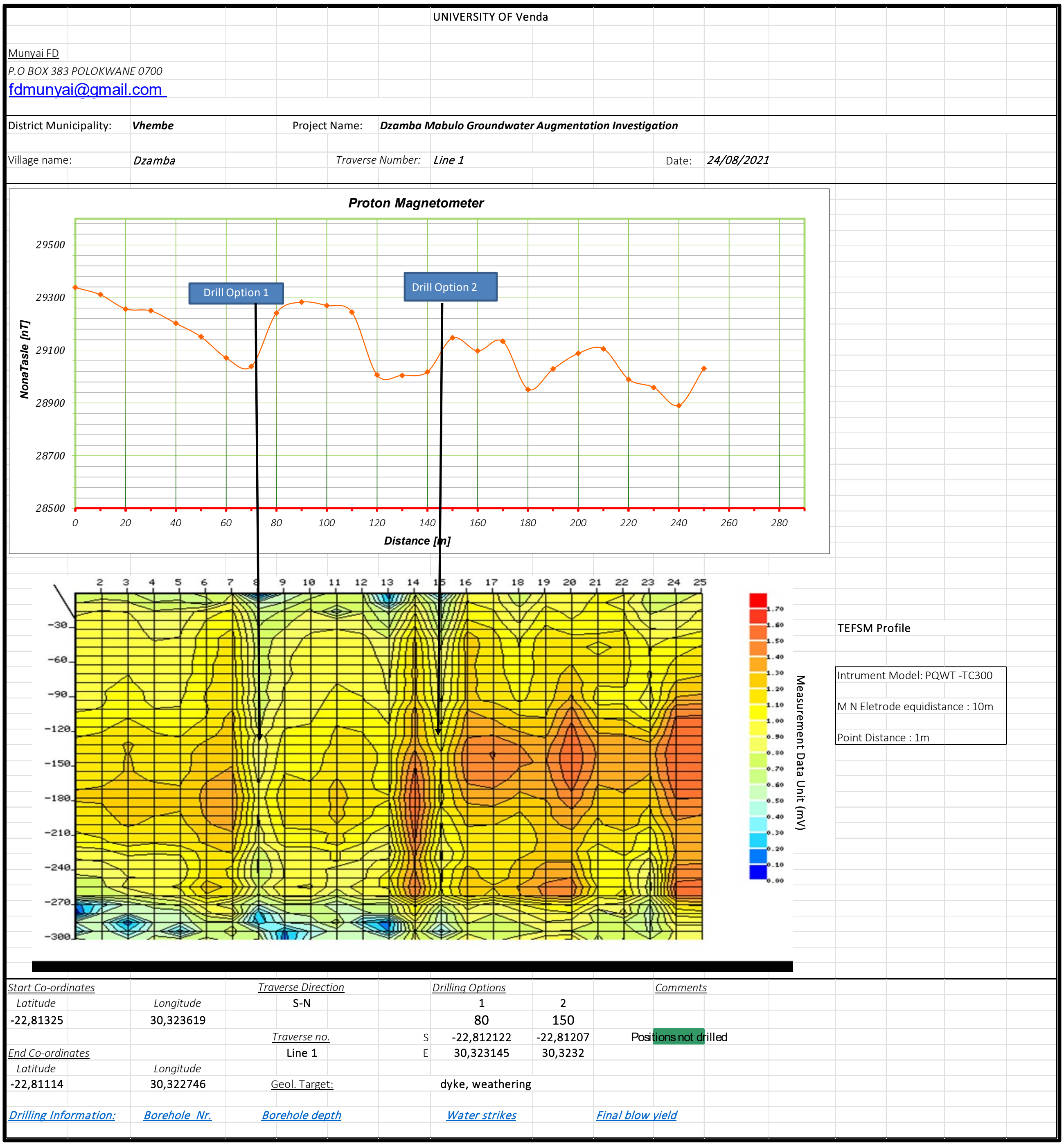


Figure 4-6: Dzamba Village Traverse Line 1 (Proton Magnetometer and TEFSM profiles)

The same geophysical survey interpretation principle used for traverse line 1 was applied to traverse line 2 and traverse line 3.

Traverse Line 2 was conducted in the E to W direction, targeting N to S trending geological structure (Figure 4-5). The geophysical methods conducted on traverse line 2 confirmed two possible drilling sites, marked as Drill Option 3 and Drill Option 4 (Figure 4-7). Drill Option 3 on Line 2 suggests that the area might be weathered at 40 m from the surface to 120 m deep, whereas Drill Option 4 may be weathered from 90 m to 160 m. In the area (Drill Option 3), there is potential for weathering from the surface to a depth of 120 m. It may be difficult and costly to develop a borehole near this area. It becomes expensive as it may require specialized drilling methods that manage collapsible lithologies from the start of the borehole to completion with casings. However, the site may be suitable for groundwater development in the research area since the traverse line 2 confirms the existence of potential geological structure and weathering (Figure 4-5 and Figure 4-7).

An existing borehole (BH 4, Table 4-1) was identified at Mabulo village adjacent Drill Option 4 on Line 2 (Figure 4-4, Figure 4-5 and Figure 4-7) and was considered for refurbishment for the purpose of this study.

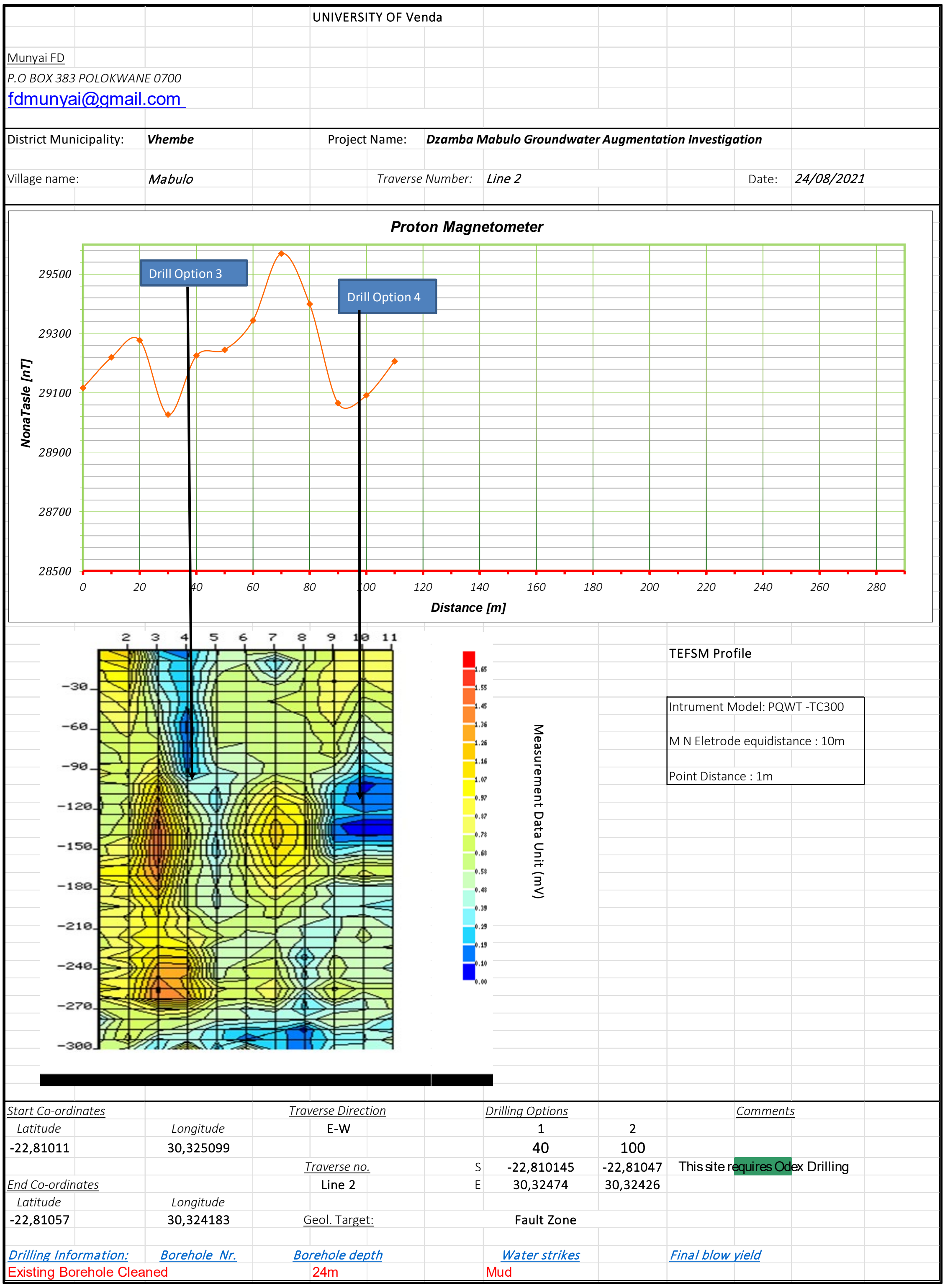


Figure 4-7: Mabulo Village Traverse Line 2 (Proton Magnetometer and TEFSM profiles)

Traverse line 3 was conducted in the E to W direction, aiming for an NW to SE striking lineament (Figure 4-5). The geophysical methods conducted on traverse line 3 confirmed one possible drilling site (Figures 4-10 and 4-12). According to the TEFSM and Proton Magnetometer profiles in Line 3, the Drill Option 5 may be weathered at 40 m and on the edge of a vertical-dipping 30 m width dyke (See Appendix F).

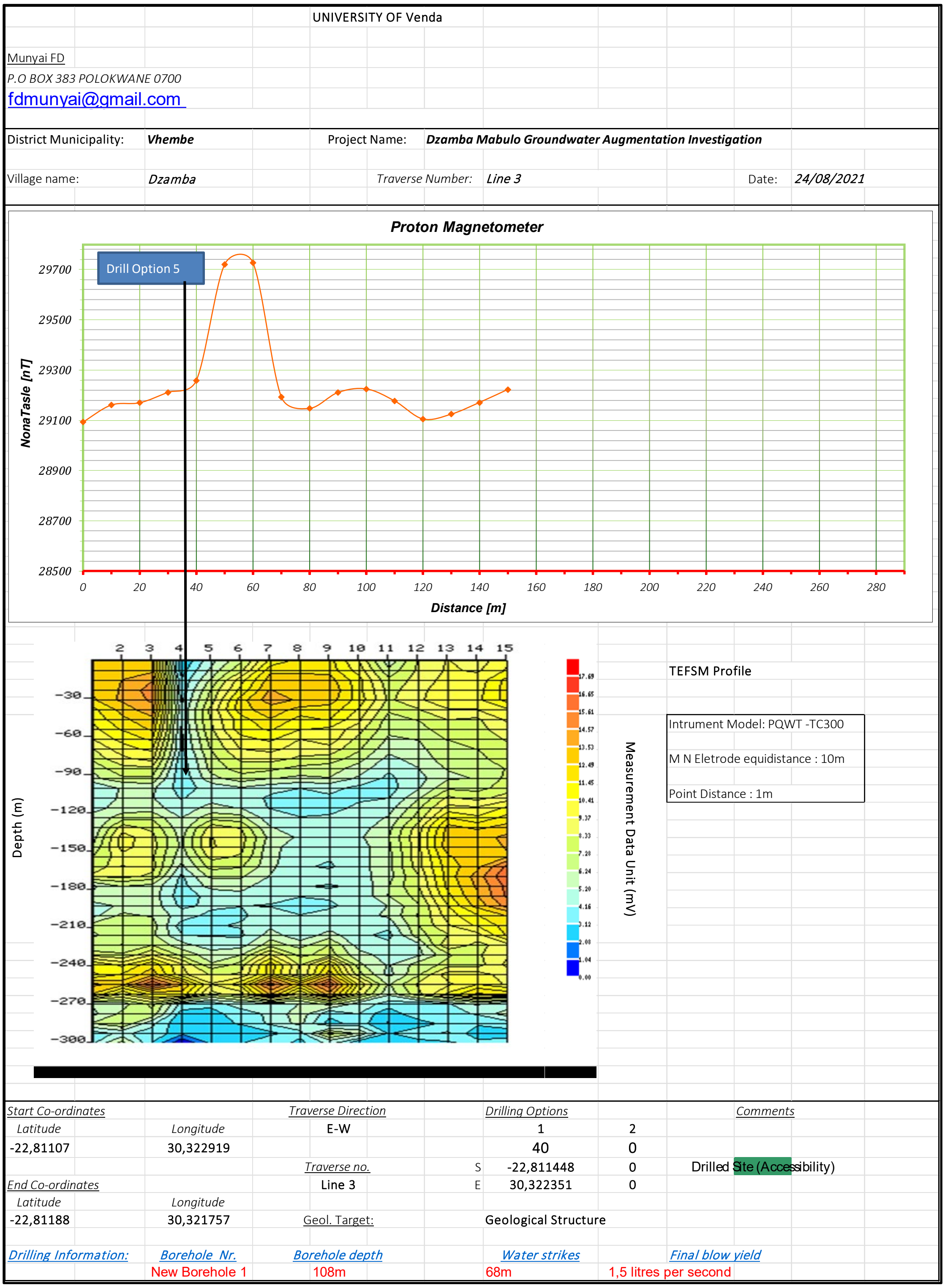


Figure 4-8: Dzamba Village Traverse Line 3 (Proton Magnetometer and TEFSM profile)

During this phase of the project, five drill options were identified. The drill options were marked and numbered according to the sequence in which the traverse lines were conducted and the geophysical results (see Figures 4-6 to 4-8). For drilling purposes, other factors, such as accessibility, access to power supply sources, et cetera, were considered in selecting the drilling sites.

The site identified for groundwater development for the Dzamba community was Drill Option 5 because of easy access, adjacent to the power supply source (Figure 4-8) and the low electrical resistivity values observed at this point. This low electrical resistivity appears to be on the contact with a geological structure (dolerite dyke). This contact zone can be noted from the overlain Proton Magnetometer profile at 40 m starting to pick in the magnetic intensity profile which may be a sign of subterranean geological features that are likely to store groundwater, like a dolerite dyke or fault (Malefane, 2016; Basubramanian, 2007; Freeze and Cherry, 1979). The positive anomaly from 40 m to 70 m (Figure 4-12) indicates the extent of the geological structure (a dolerite dyke) and is about 30 m wide (Roux, 1980). However, an existing borehole located near Drill Option 3 (Figure 4-7) which was reported as blocked during the hydrocensus phase, was identified for refurbishment and developed for water supply augmentation in the area.

Table 4-2 and Figure 4-8 summarize the drilling targets from the surveyed areas. The traverse line number, line start and end coordinates, line length, targeted structures, and drilling target stations are all listed in Table 4-2 for this investigation.

4.5 DRILLING

This section details the drilling of the new borehole and one attempted rehabilitation of borehole under this investigation. Geological information and borehole data from drilling operations provided insights on hydrostratigraphic units for the study area (Nyakeni, 2021).

Drilling of the new borehole was guided by the DWS (1997) document, “Minimum Standards for Groundwater Resource Development for Community Water Supply and Sanitation Programme”, to ensure that the borehole met the internationally accepted best practices. The rotary air percussion drilling method was employed in this study, as it is widely recognized as the most economical method for groundwater development, particularly in hard rock formations (Woodford and Chevallier, 2002).

Malefane (2016) also emphasized the advantage of rotary air percussion drilling: water is blown out to the surface when the water-bearing structure is encountered. It therefore makes it easier to measure the blow-out yield, assess the drill cuttings, record the depth of the strike, and make informed decisions on whether to proceed or terminate the drilling. It must also be noted that the blow yield measured during drilling can only provide the cumulative yield of an individual water-bearing structure (Malefane, 2016). Furthermore, according to DWS (1997), the borehole log record must have information including lithology or rock types, weathering and fracturing, water strikes, casings details, et cetera. The borehole logs are described below.

4.5.1 Borehole 1 (B1)

The new borehole (B1) was drilled on traverse line 3 at Drill Option 5 due to easy access and proximity to the power supply source. Drilling of the new borehole commenced on the 24th of September 2021. Figure 4-9 shows the B1 borehole log of the borehole drilled for the purpose of this study. B1 intersected loose top clayey overburden soil to the depth of 6 m. The highly weathered dolerite from 6 m to 10 m; yellowish clay from 10 m to 20 m; weathered and fractured quartzite of Fundudzi formation with a layer of siltstone from 20 m to 97 m; hard and competent basalt of Sibasa formation from 97 m to the final borehole depth of 108 m. B1 borehole logs show the dolerite intrusion in the study area, and this intrusion is an important target for high-yielding boreholes (Matukane, 2016; Malefane, 2016; Woodform and Chevallier, 2002).

The water strike for B1 was encountered at 67 m within the fractured quartzite of the Fundudzi formation with the measured blow-out yield of 1 l/s. The blow-out yield is within a range (0,5 – 2 l/s) of findings by Lalumbe et al. (2022) in the fractured aquifer of the Soutpansberg Group (Fundudzi formation). The water strike for B1 was found to be deeper compared to the average from the hydrocensus (see section 4.2.2). The casings (177 OD, 4 mm) were installed to the total depth of 30 m, covering the loose and highly weathered encountered clay and dolerite from the top of the borehole (Figure 4-9).

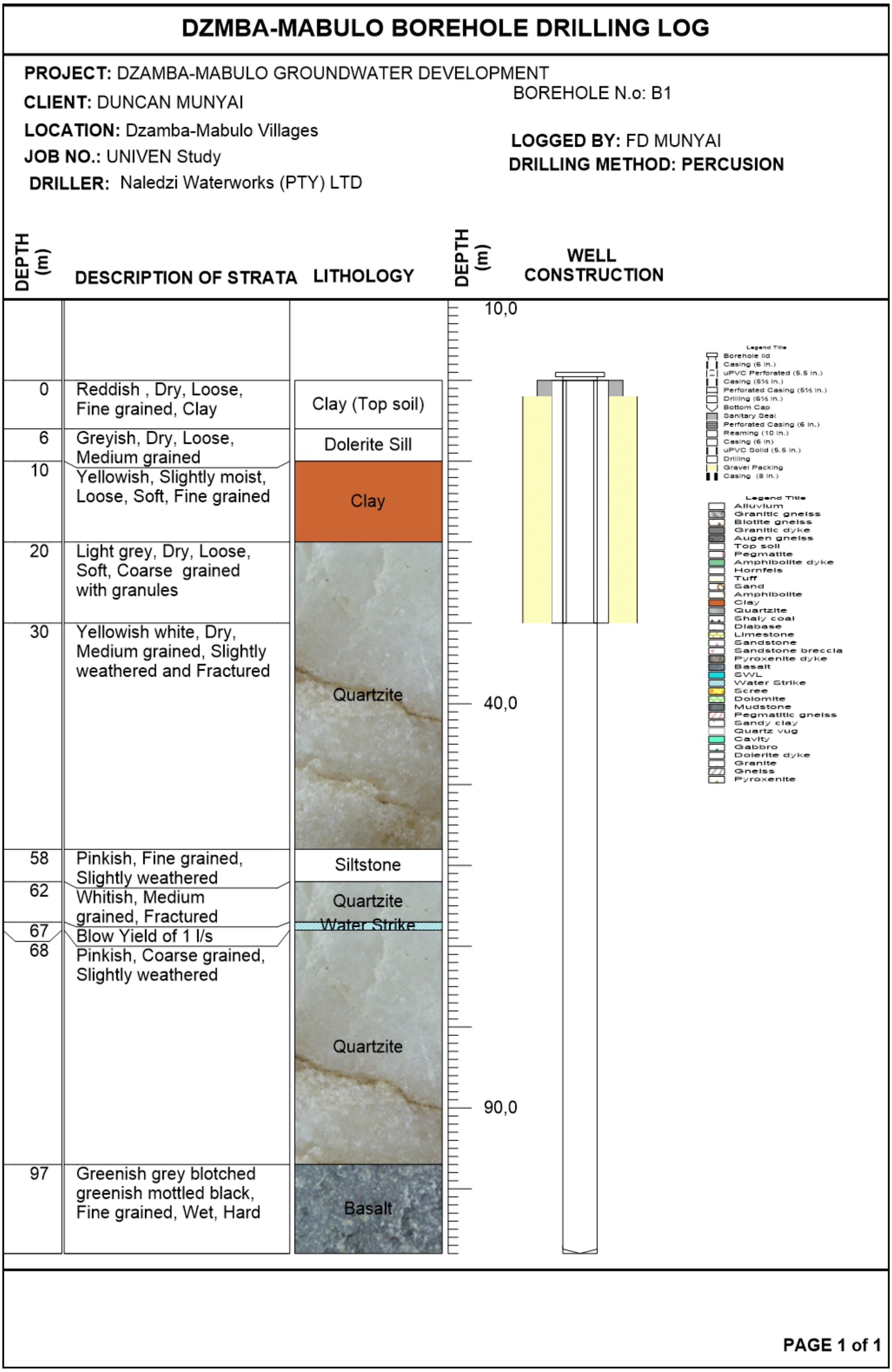


Figure 4-9: Dzamba Village New Borehole (B1) drilling log

4.5.2 Rehabilitation of Existing Borehole (B2)

An existing borehole located near Drill Option 3 (Figure 4-7) which was reported as blocked during hydrocensus phase was attempted for rehabilitation. The borehole blew yellowish, moist and muddy clay from the top of the borehole to about 24 m deep (Figures 4-10 and 4-11). The borehole kept on collapsing and required a change of drill method to a specialised and costly odex drilling method. Due to budget constraints, the rehabilitation process of this borehole was not completed.

Figure 4-10: Mabulo Village Existing Borehole (B2) rehabilitation

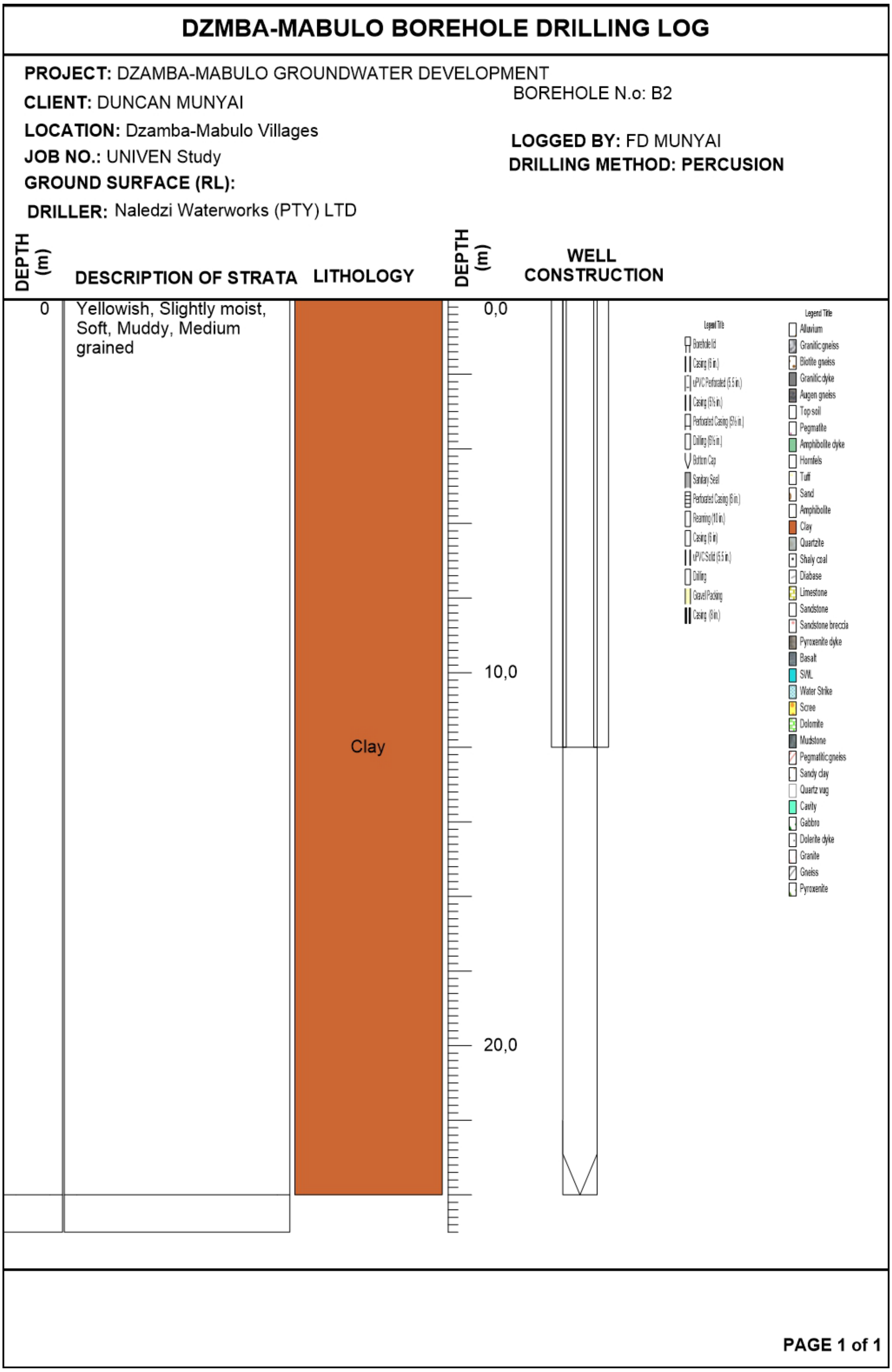


Figure 4-11: Mabulo Village Existing Borehole (B2) drilling log

4.6 PUMP TESTING AND INTERPRETATION

Kruseman and De Ridder (1994) state that aquifer pump testing is the most straightforward method for determining the aquifer parameters and understanding the physical behaviour of the aquifers. This investigation aimed to use pump testing to assess the sustainable production of the area's boreholes. Nonetheless, additional aquifer characteristics, including transmissivity and storativity, were also determined from the pump test data (Devlin and Sophocleous, 2005).

DWS test pumping criteria (DWS, 1997; DWS, 2008) and van Tonder et al. (2002) guidelines were followed to execute the pump testing program (see Chapter 3). It is also important to note that blow yields more significant than 1.0 L/s are considered as the threshold for assessing whether it is worthwhile to conduct other tests, such as constant discharge on the borehole DWAF (2003). Pump testing can reveal whether a borehole is successful or needs to be abandoned if it yields poorly from the aquifer (Sakala et al., 2014).

4.6.1 Step Discharge Test (SDT)

Three-by-sixty-minute step discharge tests (SDTs) were conducted on the newly drilled borehole (B1) in accordance with the exploration guideline for town water supply boreholes (DWS, 1997). To ascertain the appropriate rate for the subsequent constant discharge test. An SDT test over time (60 minutes) was carried out to determine which step has the most stabilised (flattening) slope, from which the rate needed for constant-discharge testing was calculated using the identified step discharge test. The rate at which the borehole can be stressed without exhausting or collapsing the aquifer's preferred channels, such as fractures, is considered the most stabilised slope of the steps (Malefane 2016; van Tonder et al. 2002).

The pump testing data (Figure 4-12) were analysed using the FC Method (Appendix C) and the Theis Method (Appendix D). During the first- and second-step tests at 20–60 and 90–100 minutes, respectively, well-flattening flow conditions are observed in the step discharge test (Appendices C and D) for borehole B1. The pumping rate varied from 0.24 L/s to 1.11 L/s for the first and second-step tests. For this borehole, a continuous discharge rate of 0.80 L/s was employed subsequently.

PROJECT	MUNYAI FD UNIVEN STUDY				DATE				30/01/2022		TIME STARTED	12:10:00 PM	
BOREHOLE No	BH 1 NEW BOREHOLE				AVAIL. DRAWDOWN				65,66 m		JOB NO		
BOREHOLE DEPTH		108 m,			PUMP DEPTH				98,50 m		LAT	S-22,8115054	
STATIC WATER LEVEL		32,84 m			PUMP TYPE				WA23-3		LONG	E30,3224128	
		STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	T/T'		RECOVERY	CD	T/T'	RECOVERY
AVERAGE YIELD (l/s)		0,24	1,11	1,48						1,29	0,80		0,80
TIME(hrs)	TIME(min)												
	1,00	-1,74	-13,38	-33,01				136,00	1,00	-56,01	-2,08	721,00	-17,77
	2,00	-2,38	-15,73	-34,52				68,50	2,00	-53,46	-2,51	361,00	-14,10
	3,00	-2,61	-17,50	-36,09				46,00	3,00	-48,92	-2,72	241,00	-11,42
	5,00	-3,01	-19,59	-39,38				28,00	5,00	-41,52	-3,08	145,00	-7,79
	7,00	-3,24	-21,30	-43,47				20,29	7,00	-35,80	-3,28	103,86	-5,39
	10,00	-3,43	-23,46	-48,73				14,50	10,00	-25,01	-4,10	73,00	-2,95
	15,00	-3,81	-26,80	-56,41				10,00	15,00	-18,25	-6,71	49,00	-1,29
	20,00	-7,41	-27,42					7,75	20,00	-11,10	-9,56	37,00	-0,91
	30,00	-9,75	-29,50					5,50	30,00	-2,80	-14,91	25,00	-0,85
	40,00	-10,64	-30,36					4,38	40,00	-0,32	-12,98	19,00	-0,82
	50,00	-10,89	-31,04					3,70	50,00	-0,21	-13,68	15,40	-0,79
	60,00	-11,05	-31,90					3,25	60,00	-0,20	-14,24	13,00	-0,77
	90,00							2,50	90,00	-0,16	-14,90	9,00	-0,74
	120,00							2,13	120,00	-0,14	-15,65	7,00	-0,70
	150,00							1,90	150,00	-0,12	-17,46	5,80	-0,65
	180,00							1,75	180,00	-0,10	-17,81	5,00	-0,61
	210,00								210,00		-18,14	4,43	-0,56
	240,00								240,00		-18,75	4,00	-0,52
									300,00		-19,23	3,40	-0,48
									360,00		-20,11	3,00	-0,43
									420,00		-20,46	2,71	-0,39
									480,00		-20,10	2,50	-0,35
									540,00		-21,35	2,33	-0,31
									600,00		-23,54	2,20	-0,28
									720,00		-23,60	2,00	-0,25
				EXISTING EQUIPMENT									
MOTOR :						COLUMN SIZE :							
PUMP :						No OF COLUMNS :							
CONDITION :													

Figure 4-12: Pump Test data for Borehole 1 (Dzamba Village)

4.6.2 Constant Discharge Test (CDT)

A constant discharge test program was carried out to calculate the sustainable yield of the borehole for the Dzamba village water augmentation. The hydraulic parameters of the aquifer at the research site were also estimated from pump test data. In primary aquifer systems, various models and associated analytical techniques have been developed and applied to estimate hydraulic parameters (Pacome, 2010); however, applying these techniques to secondary (fractured) aquifer systems typically yields inconclusive results (Malefane, 2016).

Analytical models established by Theis (1935) and Cooper-Jacob (1946) can be used to estimate hydraulic parameters, such as transmissivity and Storativity. The combination of matrix and fracture characteristics is represented by these models. Investigations by Botha et al. (1998) and van Tonder et al. (2002) demonstrate how these analytical models can be applied in fractured-rock aquifers, where the fracture network's shape is typically unknown. Three types of analytical models are most frequently used to analyse constant-discharge hydraulics test results in fractured-rock aquifers

(Kruseman and De Ridder, 1994). The models comprise the generalized radial acting flow, single fracture, and double porosity models (Kruseman and De Ridder, 1994).

The van Tonder et al. (2002) handbook for pump testing analysis in fractured rock aquifers was considered to evaluate sustainable yields and aquifer parameters. In the constant discharge test, the decline of the pumped borehole and any adjacent boreholes, if any, were observed while the discharge rate was kept constant (Malefane, 2016; van Tonder et al., 2002; Kruseman and De Ridder, 1994; Woodford and Chevallier, 2002). It should be noted that there were no pumping or observation boreholes in the study area adjacent to the new borehole B1. The pump test duration for B1 lasted 12 hours (Figure 4-13, Appendix C and Appendix D). It is mandatory to perform pump tests lasting more than 8 to 72 hours for community water supplies (DWS, 1997).

DATA sheet: Enter general info and data of constant rate pumping test and recovery (optional)

Country:	RSA	Main	**Depth of BH:**	108
Region:	Limpopo Province	Diagnostic Plots / Derivative	**Water strikes & yields:**	68 & 1,5
Owner:	Dzamba Village		**Total Casing Depth (m)**	32,84
Latitude:	22.8115054 (S)	Sust_Q	**Date of Test:**	18/10/2021
Longitude:	30.3224128 (E)		**Contractor:**	Waterworks (PTY) LTD

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Borehole: Dzamba New Borehole (B1)

Distance from Rest WL to main water strike (m) = 35,16 | s_{max}= 23,6 | Recom. AD = 28,8

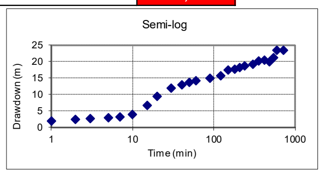
Q (l/s)= 0,8

t (min)	s (m)	avg s'	avg s''	avg T	avg S	Time t'	Res_s	t/t'	Wl rise	s'	Rec_T
						Recovery data					
1,00	2,08					1,00	17,77	721	5,83		
2,00	2,51					2,00	14,1	361	9,5	13,19	
3,00	2,72	2,55	0,05			3,00	11,42	241	12,18	15,88	
5,00	3,08	2,32	0,83	6,68	1,00E-06	5,00	7,79	145	15,81	16,38	0,8
7,00	3,28	4,41	1,73	2,79	1,00E-06	7,00	5,39	103,9	18,21	16,07	0,9
10,00	4,1	8,71	1,54	1,27	1,00E-06	10,00	2,95	73	20,65	12,32	1,1
15,00	6,71	13,30	0,70	0,86	1,00E-06	15,00	1,29	49	22,31	6,95	2,6
20,00	9,56	14,76	-0,06	0,78	1,00E-06	20,00	0,91	37	22,69	1,39	8,9
30,00	11,91	12,73	-0,74	0,93	1,00E-06	30,00	0,85	25	22,75	0,30	26,2
40,00	12,98	9,58	-1,18	1,35	1,00E-06	40,00	0,82	19	22,78	0,27	44,4
50,00	13,68	6,95	-0,94	1,35	1,00E-06	50,00	0,79	15,4	22,81	0,28	51,7
60,00	14,24	6,11	-0,23	1,35	1,00E-06	60,00	0,77	13	22,83	0,19	54,5
90,00	14,9	6,71	0,55	1,35	1,00E-06	90,00	0,74	9	22,86	0,23	48,6
120,00	15,65	8,33	0,50	1,35	1,00E-06	120,00	0,7	7	22,9	0,40	35,1
150,00	17,46	9,14	-0,20	1,28	1,00E-06	150,00	0,65	5,8	22,95	0,51	25,2
180,00	17,81	8,11	-0,64	1,28	1,00E-06	180,00	0,61	5	22,99	0,61	20,8
210,00	18,14	7,38	-0,43	1,28	1,00E-06	210,00	0,56	4,429	23,04	0,72	20,8
240,00	18,75	7,15	-0,21	1,28	1,00E-06	240,00	0,52	4	23,08	0,51	22,2
300,00	19,23	6,88	-0,40	1,28	1,00E-06	300,00	0,48	3,4	23,12	0,51	23,4
360,00	20,11	6,19	0,39	1,28	1,00E-06	360,00	0,43	3	23,17	0,62	21,6
420,00	20,46	7,42	2,37	1,28	1,00E-06	420,00	0,39	2,714	23,21	0,64	19,1
480,00	20,1	11,37		0,96	1,00E-06	480,00	0,35	2,5	23,25	0,73	18,1
540,00	21,35			0,62	1,00E-06	540,00	0,31	2,333	23,29	0,72	20,1
600,00	23,54			0,62	1,00E-06	600,00	0,28	2,2	23,32	0,47	
720,00	23,6			0,62	1,00E-06	720,00	0,25	2	23,35		

AD= available drawdown for managing the borehole

AD =	**65,66**	**Time (y) =**	**2**
T (m^2/d) : Logan eq.		time = extrapolation time	
1,6			

Date captured	
Theoretical Inflow L/s	0,40
Static Water Level	32,84
Test Pump Depth	98,50
REC %	98,94
Available Drawdown	65,66



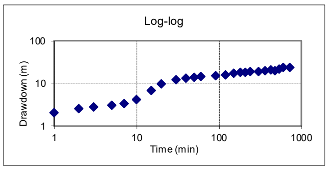


Figure 4-13: Borehole 1 (B1) Pump testing Constant Rate Drawdown Test data using FC software

4.6.3 Diagnostic plots analysis for Dzamba New Borehole (B1)

During the pumping test for B1 (Dzamba new borehole), a constant discharge rate of 0,80 L/s was used (Figure 4-12, Appendix B and Appendix C). No boreholes were found to monitor for this particular aquifer test within 250 m radius, as recommended by Van Tonder et al. (1998) and DWS (1999) from the pumping borehole. The geological environment was assumed to be homogeneous for the borehole B1.

From the pumping test data, the log-log plot (Figure 4-14), and the semi-log plot (Figure 4-15), the following deductions can be made for B1 (Dzamba new borehole):

- Positions of fracture were reached at 15 m (90 minutes), 21 m (420 minutes), and 24 m (600 minutes).
- The fracture at 21 m has been de-watered, but the flattening at the end of the test suggests a good fracture was reached at 24 m.
- Linear flow in a fracture which suggests that water is derived from fracture only
- Straight line segment on semi-log plot, which is an indication of radial flow

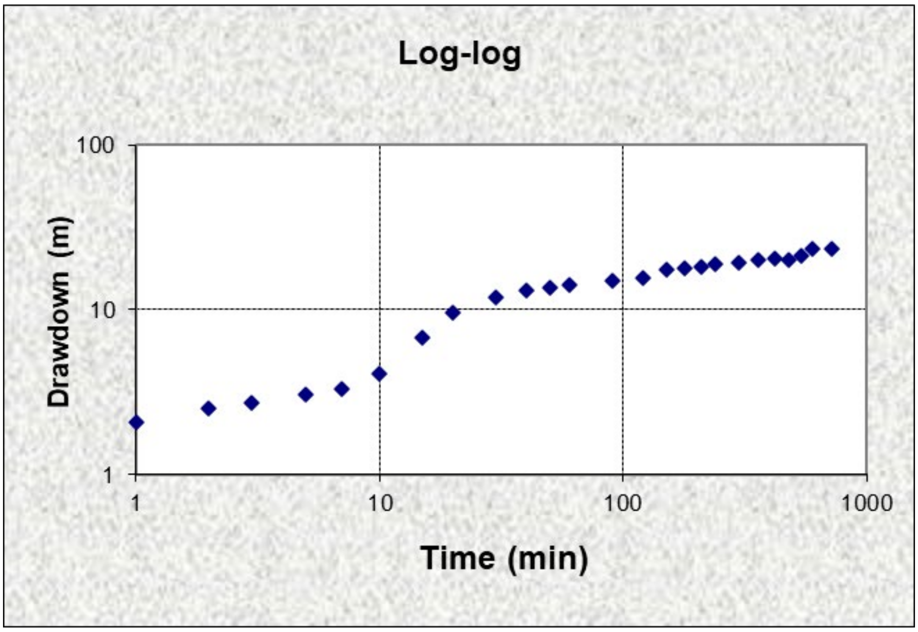


Figure 4-14: Log-log drawdown plot for B1 (Dzamba new borehole)

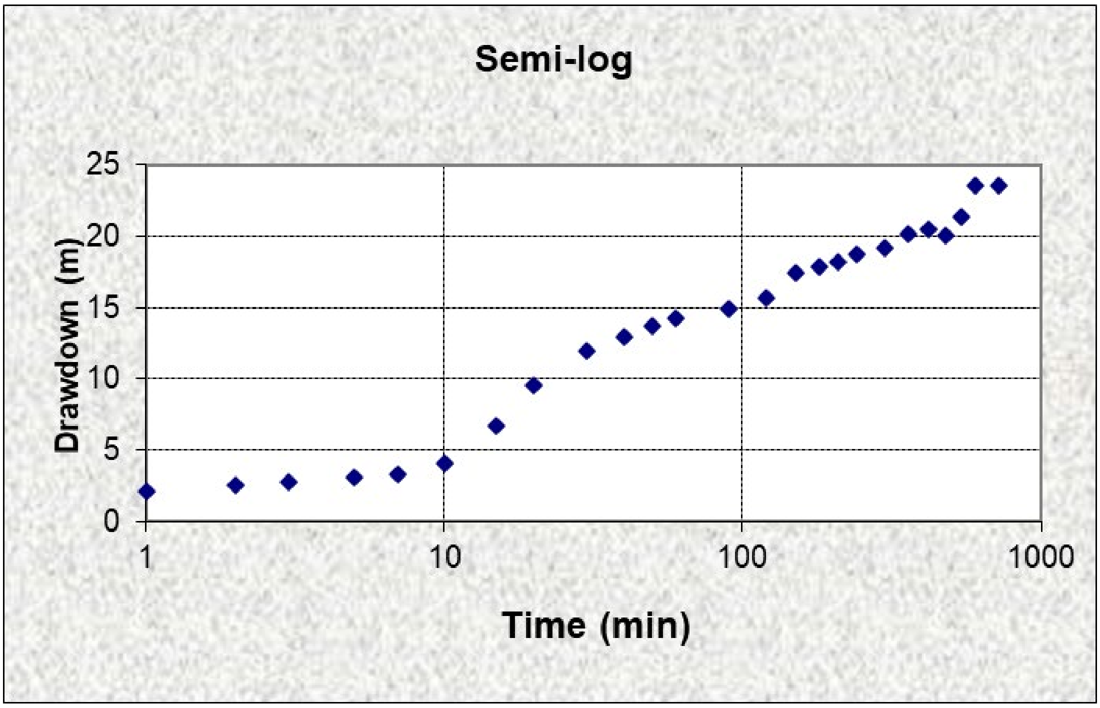


Figure 4-15: Semi-log drawdown plot for B1 (Dzamba new borehole)

From the log-derivative plot (Figure 4-16), it can be deduced that the aquifer at borehole B1 has a good fracture network with a value of 0,16. The fracture network value in hydrogeology or reservoir engineering refers to a parameter that characterizes the geometry and connectivity of fractures in a fractured reservoir system. This value is normally estimated by interpreting pressure transient data, especially from pressure drawdown or recovery tests using log-derivative plots. According to van Tonder et al. (1998), if the value of the log-derivative is smaller, it implies that the aquifer has a good fracture network (i.e., a log-derivative value of about 0,1 indicates a very good aquifer while a value of 0,5 indicates a limited fracture network and aquifer). The log-derivative plot also suggests a double porosity aquifer (Figure 4-16). It has two radial flow patterns: one associated with the fracture system at early times and one with the fracture-matrix system at late times.

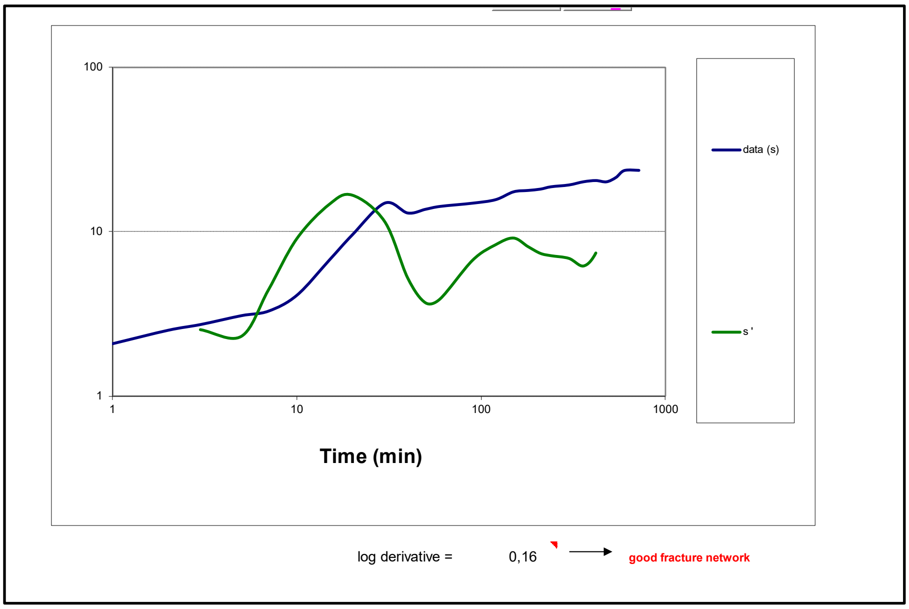


Figure 4-16: Log-derivative plot for B1

4.6.4 Recovery Test

After the continuous discharge test, the pump was turned off, and the borehole was given time to recover under observation. According to van Tonder et al. (2002), the recovery inside the abstraction borehole was monitored for as long as it took to reach 95 percent of the rest static water level or time equal to the pumping test. A horizontal flattening or plateau at the later stages of recovery suggests that the fracture system functions as a semi-closed boundary (i.e., low formation transmissivity value) if the borehole is thought to have fully recovered. Typically, a comparison is made between the aquifer parameters obtained from pump and recovery test data (van Tonder et al., 2002).

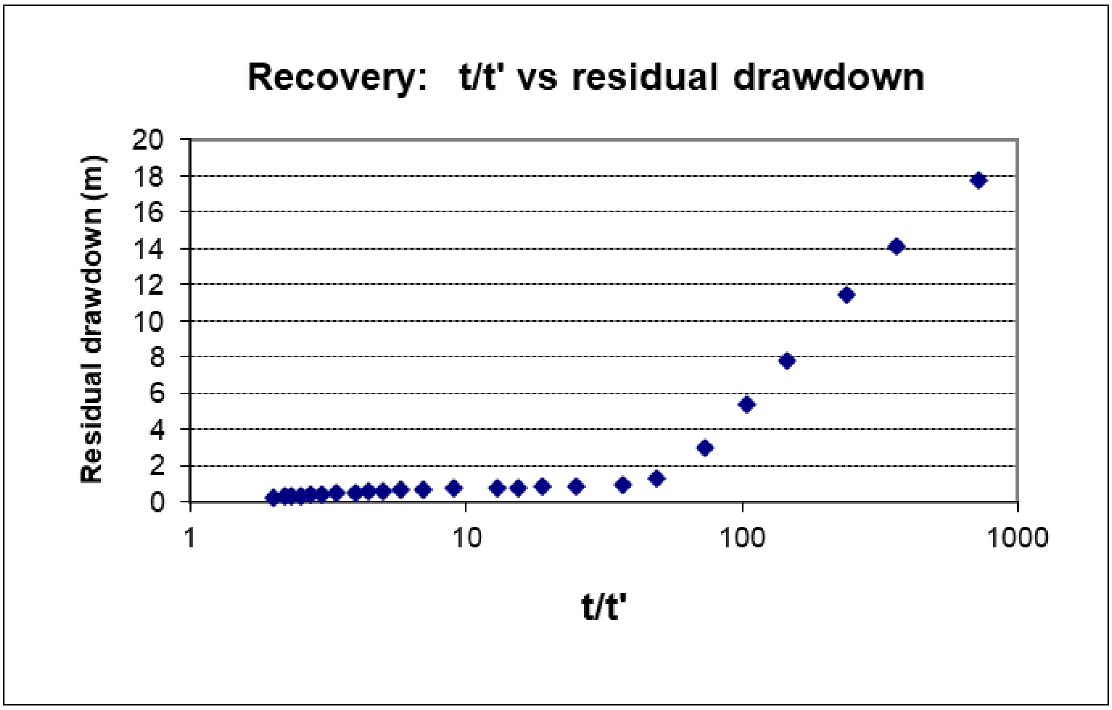


Figure 4-17: Recovery data of B1

Analysing the behaviour of water level fluctuations requires establishing and comprehending the influence on water levels during the recovery phase. From the recovery plot in Figure 4-17, borehole B1 provided a residual drawdown of 0,25 m in 12 hours after the constant discharge rate test was stopped. Its 99% recovery affirms the deduced fact that we are dealing with a good fracture network in the B1 aquifer (van Tonder et al., 1998). The relatively steep recovery gradient suggests that the aquifer may experience seasonal variability, and abstraction should be carefully managed.

4.6.5 Aquifer Parameters

Using both Theis and Cooper-Jacob methods (Figure 4-18 and Figure 4-19), the Transmissivity (T) of the aquifer was obtained as 2,0 m^2/day and 1,59 m^2/day, respectively. While the Storativity (S) was 0,00003 (Theis method) and 0,4 x 10^{-7} (Cooper-Jacobs). According to Hall and Chen (1996), the Storativity values in confined and leaky aquifers range within 0,00001 to 0,001. High Storativity values suggest a better possibility for water storage, according to Makungo et al. (2021).

When comparing the estimated parameters from Theis and Cooper-Jacobs, the transmissivities were very close, and the Storativity values fell within the confined and leaky aquifer ranges. The obtained transmissivity is relatively good, given that the area is underlain by quartzite as the dominant lithology (van Tonder et al., 2002), and storativity was not considered in this study because no existing monitoring borehole was found.

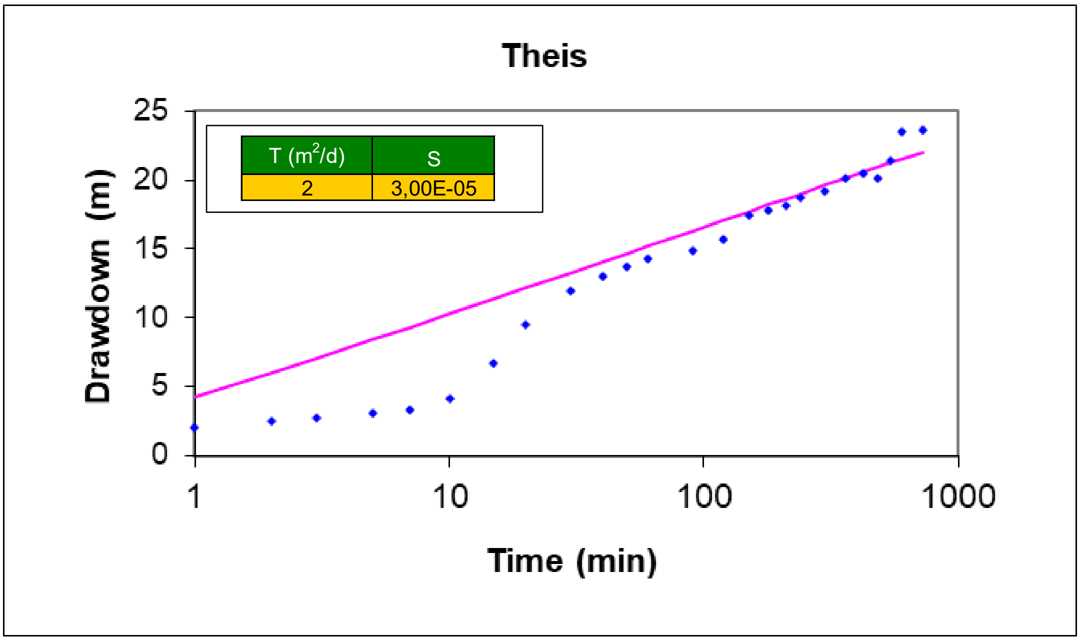


Figure 4-18: Computed Aquifer Parameters for B1 on Theis Method

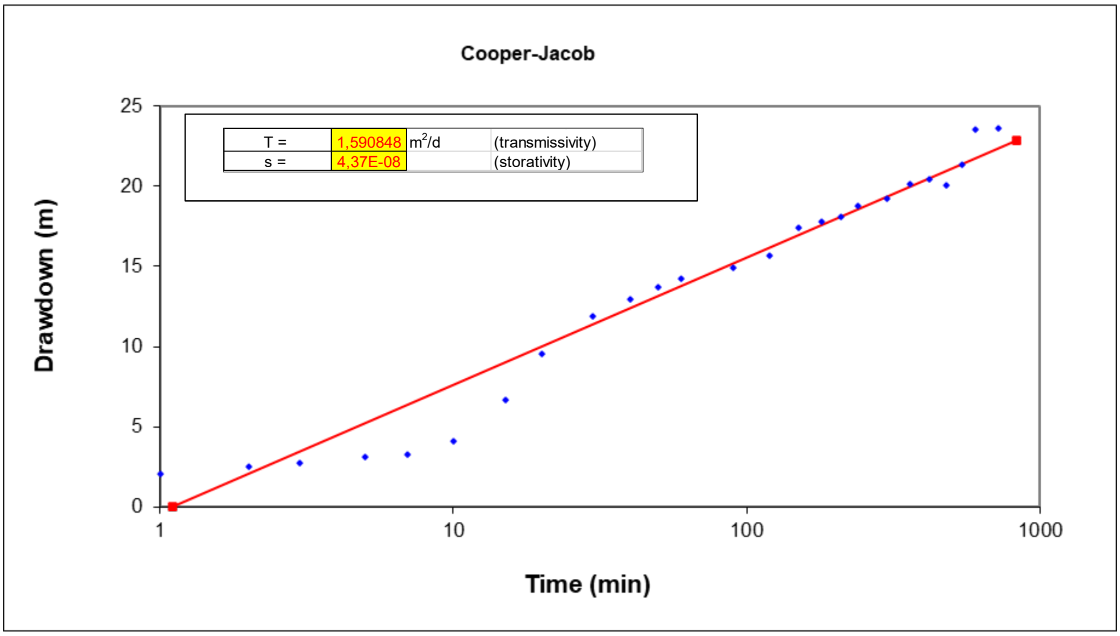


Figure 4-19: Computed Aquifer Parameters for B1 on Cooper-Jacob Method

4.6.6 Sustainable Yield of the research site

4.6.6.1 Aquifer Storage

Aquifer storage can only be determined accurately through costly tests or intensive monitoring. Given that fractured aquifers are the most prevalent type of aquifer, Vegter's maps indicate that the storage is around 0,001 (Vegter et al., 1995; GRA II). The Storativity values computed from the Theis and Cooper-Jacob method were not considered for the purpose of this study because no observation borehole was monitored during the pump testing of B1 (Guihéneuf et al., 2014; Theis, 1935; Cooper–Jacob, 1946).

The storage capacity would be computed as follows if we assume that the exploitable portion of the fractured aquifer is only 10 m thick (we would prefer to limit drawdown to 10 m maximum to limit potential impacts);

$$\text{Storage Volume} = S \cdot A \cdot b$$

Where S is either Specific Yield (for unconfined) or Storage Coefficient (for confined), A = Area of aquifer, and b = Saturated thickness. The storage capacity was calculated at 100,000 m^3 for 10 km^2 of the study area.

4.6.6.2 Aquifer Recharge

The replenishment of aquifers through rainwater is known as recharge (Malefane, 2016). Records from the Groundwater Resources Assessment Study (GRA II) conducted by the Department of Water Affairs and Forestry in 2003 for the A92A catchment give the annual average recharge to groundwater as 8 mm, and the total area of the research site was calculated as 10 km^2. Using the GRA II results thus gives:

$$\begin{aligned} \text{Recharge} &= \text{Area x Annual average recharge} \\ &= 10 \times 10^6 \text{ m}^2 \times 8 \text{ mm/annum} \end{aligned}$$

Therefore, the recharge in the research site was calculated at <u>80,000</u> m^3/<u>annum</u>, equivalent to <u>219,2</u> m^3/day.

4.6.6.3 Sustainable Yield

In times of drought or little precipitation, recharge may be severely reduced, necessitating the withdrawal of water from storage for any abstraction. According to the evaluation of drought indices (WSM, 2015), there is a 7–8 year potential for drought episodes in the research area. Recharge would be 0.70 x 80,000 = 56,000 m3/annum or 153 m3/day if we consider that it would only be 70% of the average annual recharge for these 7–8 year intervals.

In the event that there is only 20% of the typical annual recharge for the two years during this dry period, the recharge would be 0.20 x 80 000 = 16 000 m^3/annum or 43,8 m^3/day.

If storage is utilised over these two years (dry period), the available yield would be 16,000 + (10 000/2) = 21,000 m^3/annum or 57,5 m^3/day.

The sustainable yield (see Table 4-3) would, therefore, be evaluated as the lesser of the above calculations and can be summarized as 21,000 m3/annum or 57,5 m3/day or about 1,33 l/s, pumping 12 hrs/day or 0,7 l/s for 24 hrs/day.

Table 4-3: Water Demand and Sustainable Yield

Area	Area (sq km)	Population	Water Demand (kl/day)	Recharge		Sustainable Abstraction		Developed GW (kl/day)
		2021	Min	m^3/a	m^3/day	m^3/a	m^3/day	
Study Area	10	548	18,950	80 000	219,2	21 000	57,5	32,10

The developed average sustainable yield for pump tested newly drilled according to FC method is 0,37 L/sec for 24 hours of pumping per day (Figure 4-21). The FC method considers different methods for analysis, which include Advanced, Inflation point, Cooper-Jacob, FC Non-Linear and Baker methods (See Appendix C).

The research area's daily water abstraction limit is 32,10 m^3, which is sufficient to meet the daily water needs of 1,284 people (25 l/day) (Figure 4-20). The allowed amount of water can be abstracted with a dynamic water level expected at 65 mbgl if pumped for 24 hours but 48,30 mbgl if pumped for 12 hours. This amount of water can be abstracted and utilised to augment the community's existing water supply.

DUNCAN MUNYAI
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PO BOX 383, POLOKWANE, 0700
RECOMMENDATION DONE BY: DUNCAN MUNYAI

DATE: 18/10/2021
CELL: 078 800 4106
EMAIL: FDMUNYAI@GMAIL.COM

Summary | Main | **Dzamba New Borehole**

Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m^2/d)		Late T (m^2/d)		S	AD used
☑	**Basic FC**	0,91	0,56	2		1,1		2,20E-03	65,7
☐	**Advanced FC**			2		1,1		1,00E-03	65,7
☑ ☑	**FC inflection point**	0,15	0,09						21,6
TRUE	**Cooper-Jacob**	0,57	0,37			1,6		4,37E-08	65,7
☑	**FC Non-Linear**	0,02	0,02			3,0		1,10E-04	65,7
☑	**Barker**	0,20	0,05	K_f =	413		S_s =	2,00E-03	65,7
	Average Q_sust (l/s)	**0,37**	**0,36**	b =	10,48	Fractal dimension n =		1,00	N=0,50

N > .5 limited fracture network and connection
N<.1 very good fracture network (radial flow dominant)
N =.25 bilinear flow (semi connective fracture network)

Recommended abstraction rate (L/s)		**0,37**	for 24 hours per day
Hours per day of pumping	**12**	**0,53**	for 12 hours per day
Expected dynamic water level [m bgl]	24 hrs duty cycle	**65,00**	*Drawdown during 24 hr pump rate [m]* ***-32,2***
Expected dynamic water level [m bgl]	12 hrs duty cycle	**48,30**	*Drawdown during 12 hr pump rate [m]* ***-15,5***
Amount of water allowed to be abstracted per day		**32,10**	m^3
Borehole could satisfy the basic human need (25 L/d) of		**1284**	persons
Is the water suitable for domestic use (Yes/No)		**Yes**	
Recommended pump depth below surface (m)		**98**	
Total Casing length		**32,84**	
Water strike depths and blow yield (L/s)		**68 & 1,5**	
Aquifer protection depth that water level must not exceeded		**65,00**	
Depth of borehole (m bgl)		**108,00**	
Static Water Level (m bgl)		**32,84**	
Management recommendations			

Transmissivity [m^2/day] = 1,59 Theoretical inflow [L/s] 0,40

Figure 4-20: FC Method Pump Testing Summary

4.7 WATER SAMPLING RESULTS AND ANALYSIS

4.7.1 Chemistry Analysis

The water quality analysis followed the Department of Water and Sanitation's “Minimum Standards and Guidelines for Groundwater Resource Development for the Community Water Supply and Sanitation Programme (1997) document. The chemical parameters the SANAS-accredited lab analysed in all the samples were pH, EC, TDS, Ca, Mg, Na, K, Total Alkalinity, F, Cl, SO_4, NO_3, Fe, Mn, Cu and Zn. The results were classified according to DWS (1997) Domestic Water Supply Water Quality Standards (Table 4-4, Appendix E and Appendix G). Three existing boreholes and one new borehole were sampled for this project.

Table 4-4 Water Quality Classification

WATER QUALITY CLASS FOR DOMESTIC CONSUMPTION										
Constituents	BH 1 (Nemakonde)	BH 2 (Maalakano)	New Boreole (B1)	Existing Borehole	Class 0	Class I	Class II	Class III	Class IV	Key
ph	7,6	7,3	7,3	7,5	5-9.5	4.5-5 or 9.5-10	4-4.5 or 10-10.5	3-4 or 10.5-11	<3 or >11	Within limits
ec	11,5	16,6	10,4	15,0	<70	70-150	150-370	370-520	>520	Out of limits
Turbidity	88,4	0,59	18,5	4,24	< 5		5 - 10	>10		
Alkalinity Total	10,0	13,0	105,0	145,0						
TH	49,18	66,72	37,67	150,70	<200	200-300	300-600	>600		
CaH	21,30	34,58	17,58	81,00						
MgH	27,88	32,14	20,09	69,70						
Ca	8,52	13,83	7,03	32,40	<80	80-150	150-300	>300		
Mg	6,80	7,84	4,90	17,00	<70	70-100	100-200	200-400	>400	
K	0,08	1,01	0,35	0,62	<25	25-50	50-100	100-500	>500	
Na	6,44	10,01	5,06	10,70	<100	100-200	200-400	400-1000	>1000	
Cl	8,7	13,2	9,7	12,2	<100	100-200	200-600	600-1200	>1200	
F	0,68	0,00	0,00	0,00	<0.7	0.7-1	1-1.5	1.5-3.5	>3.5	
NO_3	3,09	46,76	0,44	11,40	<6	6 - 10	10 - 20	20-40	>40	
SO_4	0,18	0,58	3,73	2,90	<200	200-400	400-600	600-1000	>1000	
Fe	0,00	0,00	0,06	0,64	<0.200	0.5 - 1.0	1.0 - 2.0	5.0 - 10.0	>10	
Mn	0,03	0,01	0,02	0,00	<0.050	0.1-0.4	0.4-4.0	4.0-10.0	>10	
Cu	0,00	0,00	0,01	0,01	<1.0	1.0-1.3	1.3-2.0	2.0-15	>15	
Zn	0,26	0,04	0,28	0,10	<3	3-5	5-10	10-20	>20	
Classification	Class 0	Class IV	Class 0	Class II						
Class 0	Ideal water quality-suitable for lifetime use.									
Class I	Good water quality-suitable for use, rare instances of negative effects.									
Class II	Marginal water quality-conditionally acceptable. Negative effects may occur in some sensitive groups.									
Class III	Poor water quality-unsuitable for use without treatment. Chronic effects may occur.									
Class IV	Dangerous water quality-totally unsuitable for use. Acute effects may occur.									

BH 1 and BH 2 (Nemakonde and Maalakano) boreholes, which are private domestic boreholes, were sampled with permission from the owners. The existing borehole (BH 3, Table 4-1) is owned by the Dzamba community.

Two sampled boreholes (BH 1 and New BH) suggest Class 0 (Appendix G), which is ideal for utilisation for domestic purposes. All the constituents sampled from these boreholes are classified as Class 0 and are below the SANS (2011) and WHO (2011) standards and are suitable for long-term use without treatment. BH 2 (Maalakano) has elevated Nitrates (NO_3) belonging to Class III (Appendix G) at 46,76 mg/l. According to DWS (1997), this is poor water quality and unsuitable for domestic use without treatment, as chronic effects may occur for sensitive users. Existing borehole BH 3 (Table 4-4) has Class II (Appendix G) type of water with elevated Nitrates (NO_3) belonging to Class II at 11,40 mg/l. This type of water is conditionally acceptable, with continuous monitoring required. Some adverse effects may occur to sensitive groups if consumed without treatment (DWS,1997).

4.7.2 Geochemistry Analysis

4.7.2.1 Durov Diagram

According to Durov graph plots, the subject area is characterized by dynamic and static water types (Figure 4-21 and Figure 4-22). With the exception of BH 2 (Maalakano) with stagnant kind of water (Mg+Ca+Cl type), all sampled (BH 1, Existing Borehole BH 3 and New Borehole) are composed of dynamic kind of water (Mg + Ca + Bicarbonate type).

Research has shown that at an intermediate depth, stagnant water signifies a straightforward dissolving or mixing of different cations and anions; percolation and leaching are important processes in this response (Durov, 1948; Lloyd and Heathcoat, 1985; WSM, 2015). According to Lloyd and Heathcoat (1985), dynamic water suggests that the ion exchange takes place at a shallow depth and that groundwater recharge, or both short- and long-term rainfall, is a major factor in this reaction. Additionally, the stagnant water indicates or reverses ion exchange that is taking place in the underlying aquifers at very deep depths (i.e. 300 m and above); percolation and leaching are important players in this process.

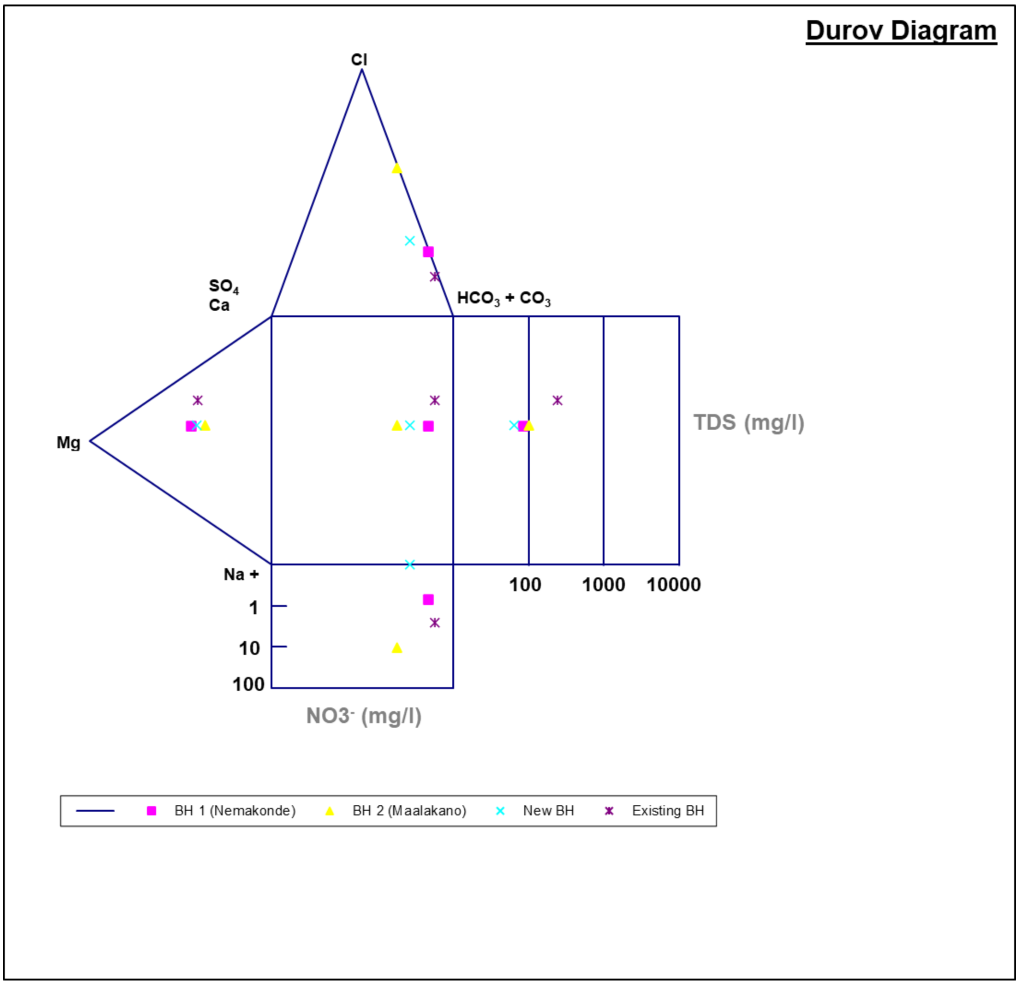

Figure 4-21: Durov Diagram analysis

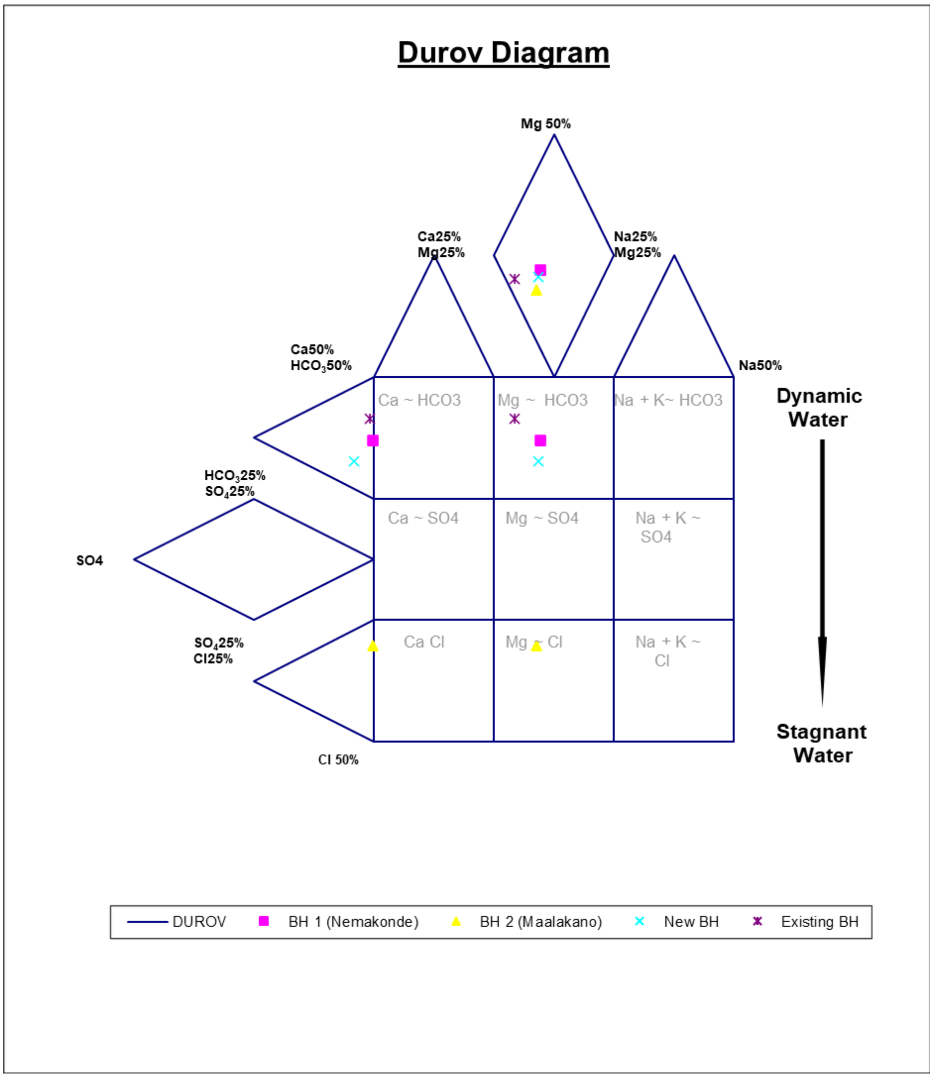

Figure 4-22: Expanded Durov Diagram of the research site

4.7.2.2 Piper Diagram

According to Piper graph plots, the boreholes (BH 1, Existing BH (Dzamba borehole), and New Borehole) within the study area are of bicarbonate water type (Figure 4-23).

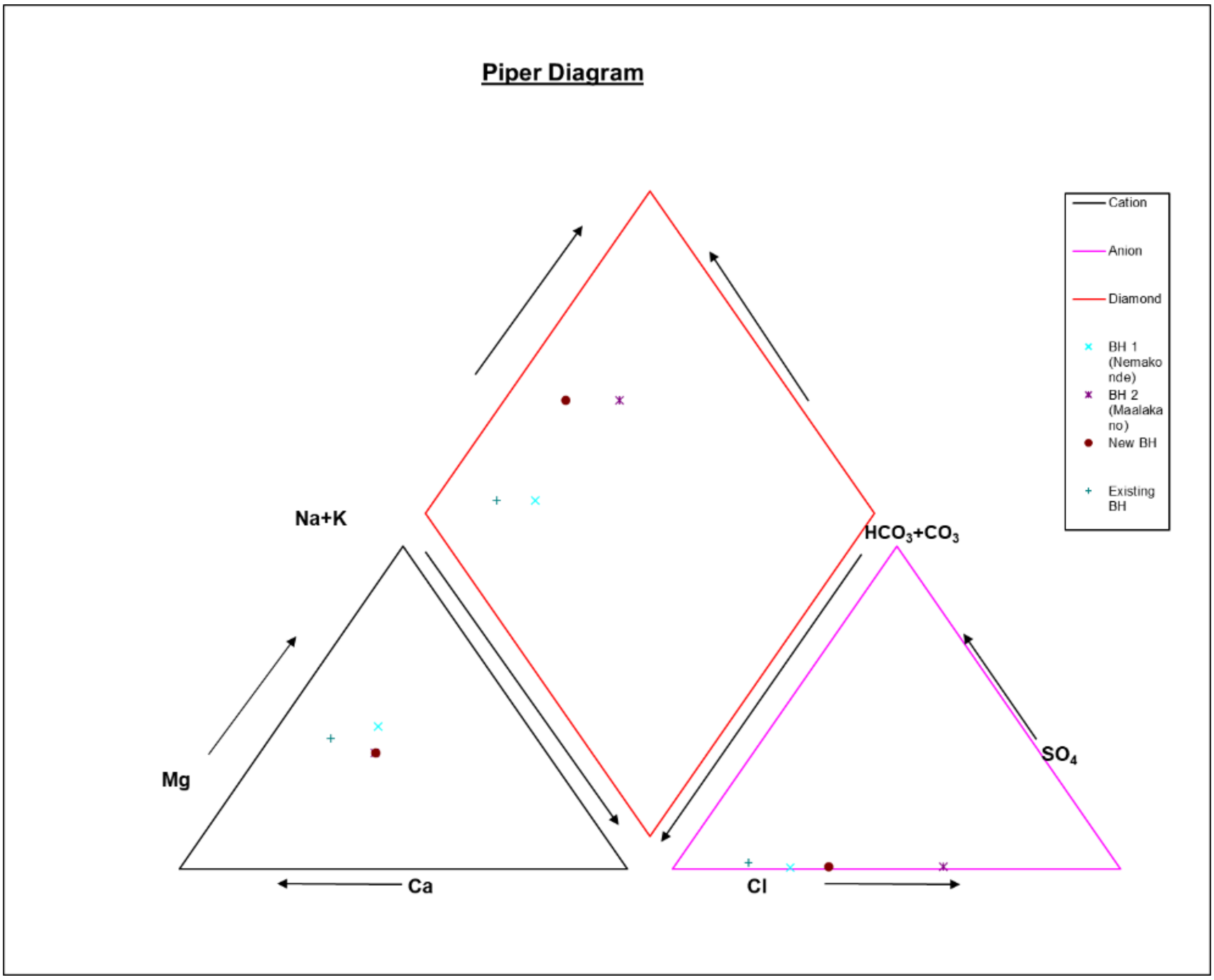

Figure 4-23: Piper Diagram of the research area

In general, the molar cation concentrations follow a trend where Ca2+ > Mg2+>Na+ > K+, while molar anions exhibit a relationship of HCO_3^{2-} > Cl_ >SO_4^{2-} > NO_3^{2-}_. The Na+/Cl_ ratio in groundwater ranges between 1.25 and 1.70, suggesting some additional Na+ inputs other than from dissolution of disseminated halite. The Na+ enrichment might be attributed to the water-rock interaction, possibly associated with the exchange of Ca2+ or Mg2+ in groundwater with Na+ in the alluvium. In contrast, the contribution of K+ to groundwater appears to be limited. Low levels of K+ in groundwater would likely be a consequence of its tendency to be fixed by clay minerals and to participate in the formation of secondary minerals (Zhu et. Al., 2008).

CHAPTER 5:
CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter describes the conclusions derived from this study's findings on groundwater resource development for supply and augmentation in Dzamba-Mabulo villages. Dzamba and Mabulo Villages have a combined population of 548 people (Stats SA, 2011). In October 2021, the Dzamba traditional leader provided the updated population of 318 people with 74 households (See Appendix A). Assuming that the population growth of these two communities is at the same rate, the estimated combined population (hydrocensus 2021) for this study was 758 people.

According to DWS (2003), the water demand for these communities at 25 litres per person per day was calculated at 18.950 m3 per day (Kelbe et al., 2004; Farrar, 2012; Van Schalkwyk, 1995). This water demand is equivalent to 0,439 L/sec at 12 hours per day. The study area relies mainly on springs (which usually dry up during dry seasons) and existing boreholes. The yields of these springs and existing boreholes are unknown and unreliable for water supply to these communities. During hydrocensus, the study findings showed that important information regarding existing boreholes within the study area, i.e., water strikes, borehole depth, yields, water quality, at cetera is missing (**Table 4-1** and **Figure 4-1**).

The goals, research questions, and findings from the investigation site form the basis of the conclusions. The recommendations were drawn from the findings and objectives of this study.

5.2 GEOPHYSICAL SURVEY

The study used the telluric electric frequency selection method (TEFSM) and a proton magnetometer for groundwater exploration. These geophysical methods have proven useful for understanding groundwater occurrence in various geological environments. The groundwater potential target areas for this study were lineaments, faults, joints, dyke intrusions, and contact zones, which play an important role in groundwater occurrence.

Geophysical methods (TEFSM and Proton Magnetometer) were plotted and overlain to confirm anomalies between the methods. Based on the interpretation and analysis of geophysical survey traverse lines, groundwater potential areas were delineated and marked for future groundwater resource development within the research area. This study targeted these areas when conducting a geophysical survey and borehole siting (Table 4-2, Figure 4-4 and Figure 4-5).

Three geophysical traverse lines (see Figure 4-6 to Figure 4-8) were surveyed, and five drilling areas were marked. The drilling options were marked and numbered according to the sequence used during the surveys along the traverse lines. For borehole development, in addition to geophysical survey results, other factors such as accessibility and access to power were considered during selection.

The site identified for groundwater development for these communities was Drill Option 5 (Figure 4-8), based on the geophysical results, accessibility, and the proximity to the power source supply to the area. However, an existing borehole located near Drill option 3 (Figure 4-7) which was reported as blocked during the hydrocensus phase, was identified for refurbishment and developed for water supply augmentation in the area.

5.3 GEOLOGY AND HYDROGEOLOGY

Groundwater resource exploration for this study was conducted using geophysical methods, drilling, and borehole pump testing. To successfully drill a borehole for water supply augmentation, a geophysical survey was necessary to investigate the parameters affecting groundwater presence in the research area.

The research site is underlain by the Fundudzi formation of the Soutpansberg Group, composed mainly of arenaceous and argillaceous rocks. The resistant pink quartzite and sandstone dominate the area (Figure 4-2). The east-west trending geological structures (dykes) are visible from the geological map of the study area (Figure 4-3). Geological structures (dykes), lithological contact zones, and fault zones are considered to have good groundwater potential.

The average borehole yield ranges from 0,5 to 2,0 l/s, which is similar to those found in similar geological environments (Lalumbe et al., 2022). The newly drilled borehole (B1) for this study intercepted the fracture at 67 m, deeper than anticipated, with a blow yield of 1 l/s. However, this investigation failed to develop and rehabilitate B2 as it required a highly specialised odex drilling method. Due to budget constraints, B2 rehabilitation could not be completed.

5.4 GROUNDWATER POTENTIAL ZONES

The study has demonstrated that integrating geological structures, lithological contacts, geophysical surveys, and prior knowledge of the existing borehole location improve the identification of areas with high groundwater potential. The newly drilled borehole B1 and existing borehole B2 are located in a good groundwater potential zone. Figure 4-3: B1 and B2 are located within an identified structure identified in geological and satellite images, which was confirmed by geophysical surveys. The areas/zones with good groundwater potential include geological structures, lithological contact zones, and fault zones within the study area.

The study, as other researchers (Holland, 2011; Balasubramanian, 2007) have shown, demonstrates that a combination of geology and imagery can be used to delineate groundwater potential zones for water supply in communities.

5.5 AQUIFER CHARACTERISTICS

The borehole pump testing conducted on B1 provided an understanding in situ groundwater flow characteristics of the aquifer within the research area. It was important to conduct pump testing analysis through specialised diagnostic plots to estimate the aquifer parameters for the study area.

The transmissivity values obtained using Theis and Cooper-Jacob methods were 2,0 m^2/day and 1,59 m^2/day, respectively. While the Storativity (S) was at 0,00003 (Theis method) and 0,4 x 10^{-7} (Cooper-Jacobs). According to Hall and Chen (1996), the storativity values in confined and leaky aquifers range within 0,00001 to 0,001. High Storativity values suggest a better possibility for water storage, according to Makungo et al., 2021.

When comparing the estimated parameters from Theis and Cooper-Jacobs, the transmissivities were very close, and the storativity values fell within the confined and leaky aquifer ranges. The obtained transmissivity is relatively good, given that the area is underlain by quartzite as the dominant lithology (van Tonder et al., 2002), and storativity was not considered in this study to calculate the sustainable yield, as no existing monitoring borehole was found.

5.6 GROUNDWATER QUALITY

The area's water quality is typically considered good, according to SANS241 (2006) and SANS241-1 (2011). The results obtained for newly drilled borehole (New BH) suggest Class 0, which is ideal for utilisation for domestic purposes (Table 4-6). All the constituents analysed for this borehole are classified as Class 0 and are suitable for long-term use without treatment. Geochemical data show that the groundwater is fresh and suitable for crops with moderate to good salt tolerance. Low sodium and negligible contents of toxic elements further suggest that the waters are largely satisfactory for irrigation. Furthermore, the results also show that the borehole is composed of a dynamic type of water (Mg + Ca + Bicarbonate type) as per Durov and Piper Analysis (Figure 4-22 and Figure 4-23).

A basic dissolution or mixing of different cations and anions at an intermediate depth is indicated by stagnant water; percolation and leaching are important processes in this reaction. Dynamic water indicates that groundwater recharge, or both short- and long-term rainfall, is a major factor in this reaction, and that ion exchange occurs at shallow depths. Additionally, stagnant water indicates or reverses ion exchange taking place in the underlying aquifers at very deep depths; percolation and leaching are important players in this process.

5.7 SUSTAINABLE YIELD

The study finds that the average estimated yield from the pump test for borehole B1 (newly developed borehole) is 0,37 l/sec for 24 hours of pumping per day (Figure 4-20, Table 5-1 and Table 5-2). The amount of water allowed to be abstracted per day is 32,10 $m^{3,}$ which can satisfy the basic human need of 25 l/day for the 1,284 persons. This is more than 1,6 times the total 18,950 m^3 per day required for the 758 population of the Dzamba and Mabulo Villages. The allowed amount of water that can be abstracted with a dynamic water level is 65 mbgl if pumped for 24 hours or 48,30 mbgl if pumped for 12 hours.

Table 5-1: Pump Testing Summary and Recommendations

FARM or VILLAGE NAME	BOREHOLE No	CO ORDINATES		DATE TESTED	DEPTH (m)	WATER LEVEL (mbgl)	WATER STRIKE (mbgl)	BLOW YIELD (l/sec)	STEP TEST	
		X	Y						Time (mins)	% Recovery
Dzamba	B1	22.8115054	30.3224128	2021-10-18	108	35.16	67	1.5	135	98

Table 5-2: Pump Testing Summary and Recommendations Cont...

FARM or VILLAGE NAME	BOREHOLE No	DATE TESTED	CONSTANT RATE DISCHARGE TEST (CRDT)				RECOMMENDATIONS			
			Duration (mins)	Q Rate (l/sec)	T (m^2/d)	% Recovery	Rate (l/sec)	Duty Cycle (hrs/day)	Supply (Kl/day)	Pump set (mbgl)
Dzamba	B1	2021-10-18	1440	0.8	1,59	98	0.37	24	32.10	100

Given the storage and recharge conditions in the research area, the developed groundwater resource can be abstracted sustainably without depleting the aquifer. With Storativity estimated from Vegter's maps (Vegter et al., 1995) of 0,001, the storage for the research area was calculated at 100,000 m^3.

The study finds that if there were a 2-year period within a drought period, there would be only 20% of the average annual recharge; the recharge would be 43,8 m^3/day within the research area. If storage is utilised over these two years, the available yield for abstraction would be 21,000 m^3/annum or 57,5 m^3/day. Comparing the developed groundwater resource of 32,10 kl/day from B1 with the calculated available yield of 57,5 kl/day, it can be concluded that the yield from B1 can be abstracted sustainably without depleting the aquifer and meeting the water demand of communities within the study area.

5.8 RECOMMENDATIONS

This study has shown that groundwater can be used to augment the shortfalls in water supply in rural communities. However, to effectively achieve successful results in groundwater resource development, the following is recommended:

- All future groundwater project reports within the study area must be submitted to the Department of Water and Sanitation or Local Municipality to update the groundwater databases

- Proper geophysical surveys must be conducted in conjunction with base maps (geological maps, satellite images, et cetera) to maximize the chances of siting successful boreholes.
- Abstraction yields, water quality, and water levels should be monitored continuously and reported to the Department of Water and Sanitation or the Local Municipality. The borehole must be pump-tested every five to ten years, and the aquifer parameters must be updated accordingly.
- The Department of Water and Sanitation or the Local Municipality, as the water custodian, must appoint the specialist to further explore and develop the groundwater resource in the area around B2, which requires a specialized odex drilling method.

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APPENDICES

APPENDIX A-1: Dzamba and Mabulo Population and Key Statistics

Dzamba is located in Mutale local municipality, within the province of Limpopo. (GPS coordinates: 22.8134 S, 30.3229 E).

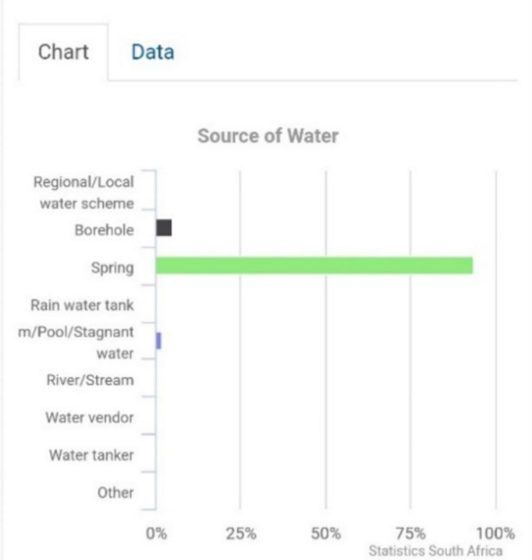
Key Statistics 2011

Characteristics	
Total population	216
Young (0-14)	34,9%
Working Age (15-64)	54,9%
Elderly (65+)	10,2%
Dependency ratio	82,2
Sex ratio	72,8
Population density	911 persons/km2
No schooling aged 20+	24,8%
Higher education aged 20+	11%
Matric aged 20+	25,7%
Number of households	64
Average household size	3,4
Female headed households	51,6%
Formal dwellings	90,8%
Housing owned/paying off	34,4%
Flush toilet connected to sewerage	0%
Weekly refuse removal	0%
Piped water inside dwelling	1,6%
Electricity for lighting	82,8%

Appendix A-2: Dzamba Village Water Sources data (Stats SA, 2011)

Chart Data

Source of water	Percentage
Regional/Local water scheme	0%
Borehole	4,7%
Spring	93,8%
Rain water tank	0%
Dam/Pool/Stagnant water	1,6%
River/Stream	0%
Water vendor	0%
Water tanker	0%
Other	0%



Appendix A-3: Mabulo Population data and Key Statistics (Stats SA, 2011)

Mabulo

Quick Fact

102,4% Dependency ratio.

Mabulo is located in Mutale local municipality, within the province of Limpopo. (GPS coordinates: 22.8084 S, 30.3317 E).

Key Statistics 2011

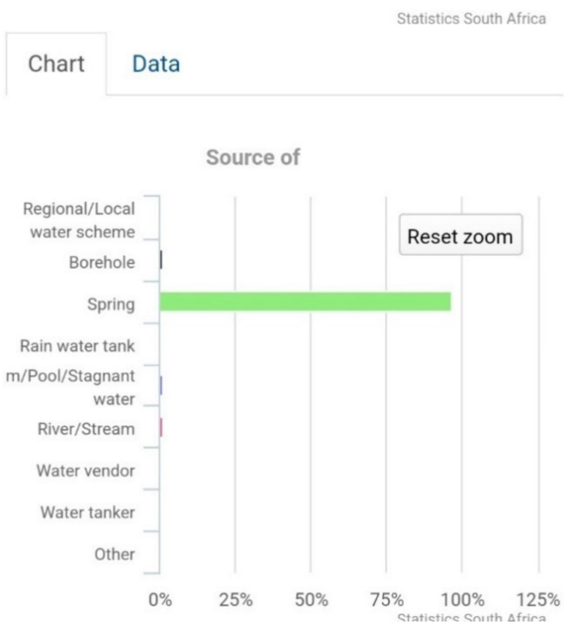
Characteristics	
Total population	332
Young (0-14)	41%
Working Age (15-64)	49,4%
Elderly (65+)	9,6%
Dependency ratio	102,4
Sex ratio	76,6
Population density	949 persons/km2
No schooling aged 20+	16,1%
Higher education aged 20+	8,1%
Matric aged 20+	18%
Number of households	89
Average household size	3,7
Female headed households	62,9%
Formal dwellings	95,5%
Housing owned/paying off	1,1%
Flush toilet connected to sewerage	0%
Weekly refuse removal	0%
Piped water inside dwelling	0%
Electricity for lighting	90%

Appendix A-5: Mabulo Village Water Sources data (Stats SA, 2011)

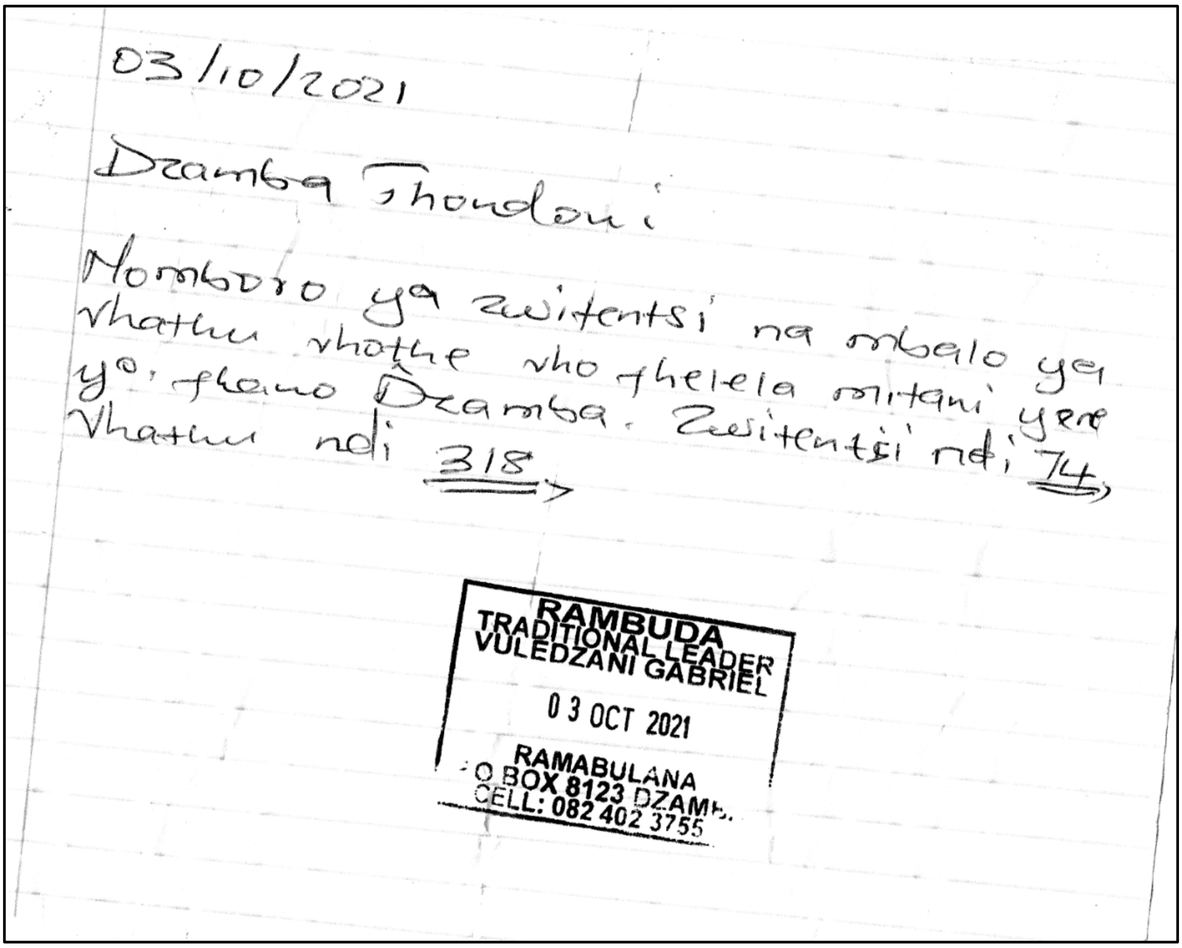
Statistics South Africa

Chart Data

Source of water	Percentage
Regional/Local water scheme	0%
Borehole	1,1%
Spring	96,6%
Rain water tank	0%
Dam/Pool/Stagnant water	1,1%
River/Stream	1,1%
Water vendor	0%
Water tanker	0%
Other	0%



Appendix A-5: Letter from Dzamba Traditional Leader updating household and population



03/10/2021

Dzamba Thondoni

Mombbro ya zwitentsi na mbalo ya vhathu vhothe vho thelela mitani yere yo, fhano Dzamba. Zwitentsi ndi 74, Vhathu ndi 318.

RAMBUDA
TRADITIONAL LEADER
VULEDZANI GABRIEL
03 OCT 2021
RAMABULANA
P O BOX 8123 DZAMBA
CELL: 082 402 3755

APPENDIX B: Geophysical Survey and Borehole Census Photos

Plate 1: Operating Magnetometer

Plate 2: Resistivity survey

Plate 3: Resistivity Survey

Plate 4: Concluding Resistivity Line

Plate 5: Marking of the target site

Plate 6: Existing Dzamba borehole (BH 3)

APPENDIX C: Pump Testing Analysis using FC Method for B1 (New Borehole)

DATA sheet: Enter general info and data of constant rate pumping test and recovery (optional)

Country:	RSA	Main	**Depth of BH:**	108
Region:	Limpopo Province	Diagnostic Plots / Derivative	**Water strikes & yields:**	68 & 1,5
Owner:	Dzamba Village		**Total Casing Depth (m)**	32,84
Latitude:	22.8115054 (S)	Sust_Q	**Date of Test:**	18/10/2021
Longitude:	30.3224128 (E)		**Contractor:**	Waterworks (PTY) LTD

CONSTANT RATE TEST DATA : enter values in cells which are coloured light yellow

Borehole: **Dzamba New Borehole**

Distance from Rest WL to main water strike (m) = 35,16 | s_{max}= 23,6 | Recom. AD = 28,8

Q (l/s)= 0,8 | **Recovery data**

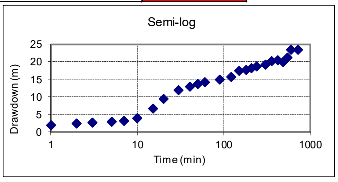
t (min)	s (m)	avg s'	avg s"	avg T	avg S	Time t'	Res_s	t/t'	Wl rise	s'	Rec_T
1,00	2,08					1,00	17,77	721	5,83		
2,00	2,51					2,00	14,1	361	9,5	13,19	
3,00	2,72	2,55	0,05			3,00	11,42	241	12,18	15,88	
5,00	3,08	2,32	0,83	6,68	1,00E-06	5,00	7,79	145	15,81	16,38	0,8
7,00	3,28	4,41	1,73	2,79	1,00E-06	7,00	5,39	103,9	18,21	16,07	0,9
10,00	4,1	8,71	1,54	1,27	1,00E-06	10,00	2,95	73	20,65	12,32	1,1
15,00	6,71	13,30	0,70	0,86	1,00E-06	15,00	1,29	49	22,31	6,95	2,6
20,00	9,56	14,76	-0,06	0,78	1,00E-06	20,00	0,91	37	22,69	1,39	8,9
30,00	11,91	12,73	-0,74	0,93	1,00E-06	30,00	0,85	25	22,75	0,30	26,2
40,00	12,98	9,58	-1,18	1,35	1,00E-06	40,00	0,82	19	22,78	0,27	44,4
50,00	13,68	6,95	-0,94	1,35	1,00E-06	50,00	0,79	15,4	22,81	0,28	51,7
60,00	14,24	6,11	-0,23	1,35	1,00E-06	60,00	0,77	13	22,83	0,19	54,5
90,00	14,9	6,71	0,55	1,35	1,00E-06	90,00	0,74	9	22,86	0,23	48,6
120,00	15,65	8,33	0,50	1,35	1,00E-06	120,00	0,7	7	22,9	0,40	35,1
150,00	17,46	9,14	-0,20	1,28	1,00E-06	150,00	0,65	5,8	22,95	0,51	25,2
180,00	17,81	8,11	-0,64	1,28	1,00E-06	180,00	0,61	5	22,99	0,61	20,8
210,00	18,14	7,38	-0,43	1,28	1,00E-06	210,00	0,56	4,429	23,04	0,72	20,8
240,00	18,75	7,15	-0,21	1,28	1,00E-06	240,00	0,52	4	23,08	0,51	22,2
300,00	19,23	6,88	-0,40	1,28	1,00E-06	300,00	0,48	3,4	23,12	0,51	23,4
360,00	20,11	6,19	0,39	1,28	1,00E-06	360,00	0,43	3	23,17	0,62	21,6
420,00	20,46	7,42	2,37	1,28	1,00E-06	420,00	0,39	2,714	23,21	0,64	19,1
480,00	20,1	11,37	#NUM!	0,96	1,00E-06	480,00	0,35	2,5	23,25	0,73	18,1
540,00	21,35	#####	#NUM!	0,62	1,00E-06	540,00	0,31	2,333	23,29	0,72	20,1
600,00	23,54	#####	#NUM!	0,62	1,00E-06	600,00	0,28	2,2	23,32	0,47	#DIV/0!
720,00	23,6	#####	#NUM!	0,62	1,00E-06	720,00	0,25	2	23,35	#DIV/0!	#DIV/0!
		#####	#NUM!	0,62	1,00E-06			#####	#DIV/0!	#DIV/0!	#DIV/0!

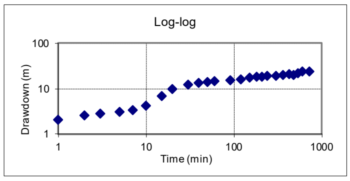
AD= available drawdown for managing the borehole

AD = 65,66 | **Time (y) = 2**

T (m^2/d) : Logan eq. 1,6 | time = extrapolation time

Date captured	
Theoretical Inflow L/s	0,40
Static Water Level	32,84
Test Pump Depth	98,50
REC %	98,94
Available Drawdown	65,66





Appendix C-1: Datasheet, which includes Constant rate pumping test and recovery

Cooper-Jacob method | **Main** | Theis | Cooper-Jacob 2

Dzamba New Borehole

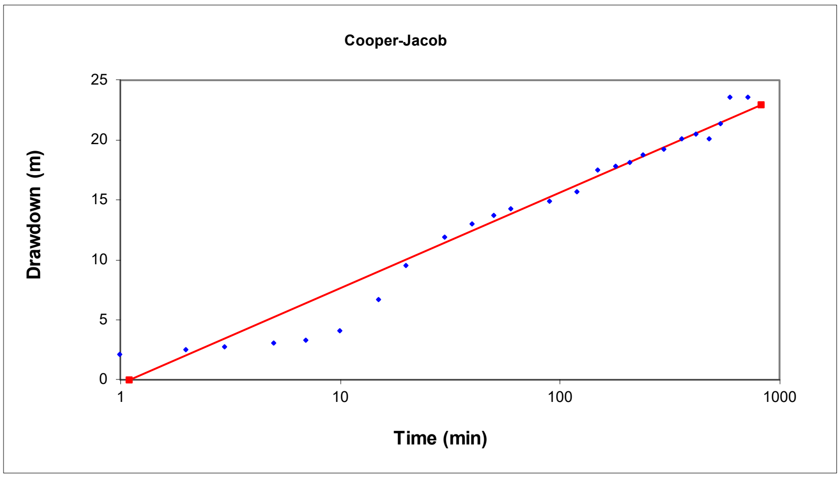
Effective radius from r(e) sheet

$T (m^2/d)$ =	1,6	r_e (m)=	250,00	250,00
S =	4,37E-08	Q (l/s) =	0,8	

effective bh radius

	No boundaries	1 no-flow	2 no-flow	Closed
Q_sust	1,10	0,55	0,36	0,28
Avg. Q_sust =	**0,57**	std. dev =	0,37	

including influence of bh's



Appendix C-2: Cooper-Jacob Method on FC Test Pumping Analysis

FC-METHOD : Estimation of the sustainable yield of
Dzamba New Borehole

Main | Deriv | Inflection point method

Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes	
Effective borehole radius (r_e) = (enter)	250,00 ←	51,97 ←	Est. r_e	From r(e) sheet
Q (l/s) from pumping test =	0,8	1,00E-06 ←	S-late ←	Change r_e
s_a (available drawdown), sigma_s = (enter)	65,7	←	Sigma_s from risk	Dow
Annual effective recharge (mm) =	65,66	131,32	s_available working drawdown(m)	
t(end) and s(end) of pumping test =	720	23,6	End time and drawdown of test	
Average maximum derivative = (enter)	11,4 ←	11,4	Estimate of average of max deriv	
Average second derivative = (enter)	0,0 ←	0,0	Estimate of average second deriv	
Derivative at radial flow period = (enter)	6,32 ←	6,32	Read from derivative graph	
	T-early[m^2/d] =	2,00	Aqui. thick (m)	40
T and S estimates from derivatives	T-late [m^2/d] =	1,11	Est. S-late =	2,20E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	2,20E-03	S-estimate could be wrong	

BASIC SOLUTION

(Using derivatives + subjective information about boundaries)

(No values of T and S are necessary)	No boundaries	1 no-flow	2 no-flow	Closed no-flow
		Maximum influence of boundaries at long time		
sWell (Extrapol.time) =	59,58	95,55	131,53	239,46
Q_sust (l/s) =	1,76	1,10	0,80	0,44
	Best case	→		**Worst case**
Average Q_sust (l/s) =	**0,91**	WARNING!! Est. Q_sust > Q during pumping test		
with standard deviation=	0,56	Suggestion:check available drawdown and rech		

(If no information exists about boundaries skip advanced solution and go to final recommendation)

ADVANCED SOLUTION

(Using derivatives+ knowledge on boundaries and other boreholes)

(Late T-and S-values a priori + distance to boundary)

T-late [m^2/d] = (enter) →	1,11			
S-late = (enter) →	1,00E-03			
1. BOUNDARY INFORMATION (choose a or b)	(Code =9999 = dummy value if not applicable)			
(a) Barrier (no-flow) boundaries →	Closed Square	Single Barrier	Intersect. 90°	2 Parallel Barriers
Bound. distance a[meter] : (enter)	9999	9999	9999	9999
Bound. distance b[meter] : (enter)			9999	9999
s_Bound(t = Extrapol.time) [m] =	0,00	0,00	0,00	#NUM!
(b) Fix head boundary + no-flow →	Closed Fix	Single Fix	90°Fix+no-flow	// Fix+no-flow
Bound. distance to fix head a[meter] : (enter)	9999	9999	9999	9999
Bound. distance to no-flow b[meter] : (enter)			9999	9999
s_Bound(t = Extrapol.time) [m] =	0,00	0,00	0,00	#NUM!
2. INFLUENCE OF OTHER BOREHOLES →	Q (l/s)	r (m)	u_r	W(u,r)
BH1	0	9999	3,08E+01	0,00
BH2	0	9999	3,08E+01	0,00
s_(influence of BH1,BH2) =	0,00	0,00	1,92E-02	3,39

SOLUTION INCLUDING BOUNDS AND BH's

Fix head + No-flow : Q_sust (l/s) =	9999,00	9999,00	9999,00	9999,00
No-flow : Q_sust (l/s) =	9999,00	9999,00	9999,00	9999,00
Enter selected Q for risk analysis = (enter) →	0,00	Sigma_s =	0,0 Up	Risk

(Go to Risk sheet and perform risk analysis from which sigma_s will be estimated : only for barrier boundaries)

FINAL RECOMMENDED ABSTRACTION RATE

Abstraction rate (l/s) for 24 hr/d = (enter)	0,91
Total amount of water allowed to be abstracted per month (m^3) =	2353

COMMENTS

Q_sust with 68% safety =
Q_sust with 95% safety =

Appendix C-3: Sustainable Yield Estimation (FC Method)

FC Inflection Point method for sustainable yield estimation

back to Sust_Q sheet **Dzamba New B** **Main**

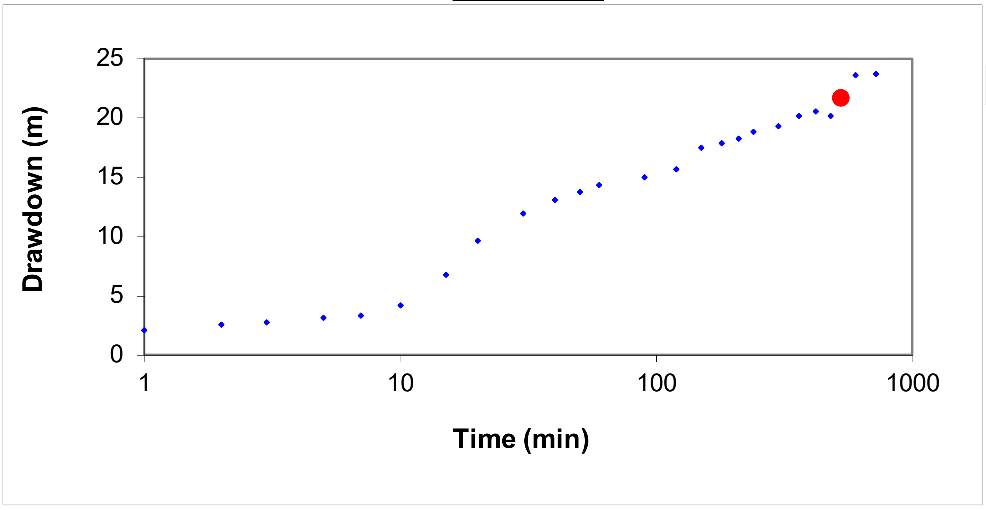
extrapolaltion time in years =	2	1051200
t(min) and s(m) at inflection point =	525,0	21,6
enter derivative value at inflection point time =	11,37 ←	11,37

	No boundaries	1 no-flow	2 no-flow	Closed
sWell(Extrapol.time)	59,14	96,67	134,21	246,82
Q_sust	0,29	0,18	0,13	0,07
	Best case			Worst case

(including influence of bh's from sust_Q sheet)

Average Q-sust (l/s)= **0,15** std. dev = 0,09

time	drawdown
525	21,6



Appendix C-4: FC Inflation Method for Sustainable Yield Estimation

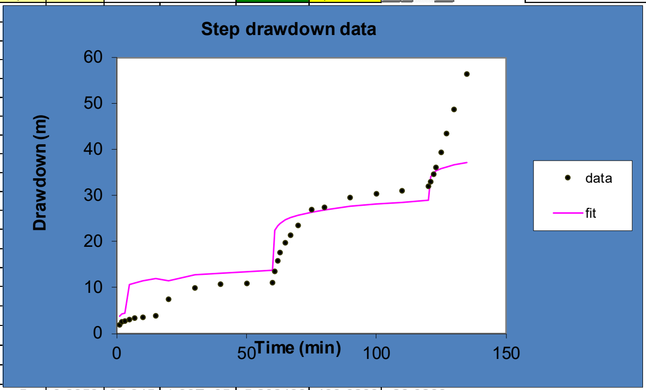
Step Drawdown Test	Borehole name	Dzamba New Borehole
	Main	FC - Non Linear

Start time of each pumping rate and rate

step	1	2	3	4	comment
t (min)	0	60	120		
Q (L/s)	0,5	1,11	1,58		

r_e (m) =	0,20	51,98 Effective radius from r(e) sheet
T (m^2/d) =	3,0	1,59 T from Cooper and Jacobs
S =	1,10E-04	

Time (min)	s (m)	Q(l/s)							
1	1,74	0,24							
2	2,38	0,24							
3	2,61	0,24							
5	3,01	0,54							
7	3,24	0,54							
10	3,43	0,54							
15	3,81	0,54							
20	7,41	0,5							
30	9,75	0,54							
40	10,64	0,54							
50	10,89	0,54							
60	11,05	0,54							
61	13,38	1,11							
62	15,73	1,11							
63	17,5	1,11							
65	19,59	1,11							
67	21,3	1,11							
70	23,46	1,11							
75	26,8	1,11							
80	27,42	1,11	5	0,2859	37,345	1,30E+05	5,202433	493,6203	26,9268
90	29,5	1,11	5	0,3076	49,209	1,48E+05	5,798925	561,7409	27,6282
100	30,36	1,11	5	0,3166	60,438	1,62E+05	6,259579	580,8303	28,1508
110	31,04	1,11	5	0,3237	71,321	1,73E+05	6,640547	595,3333	28,5717
120	31,9	1,11	5	0,3326	81,988	1,84E+05	6,968105	621,5994	28,9261
121	33,01	1,48	6	0,2581	22,304	2,65E+05	7,15371	668,5477	34,1552
122	34,52	1,48	6	0,27	27,656	2,98E+05	7,838433	711,906	34,8843
123	36,09	1,48	6	0,2822	31,476	3,19E+05	8,260725	774,4685	35,3228
125	39,38	1,48	6	0,308	37,275	3,47E+05	8,824422	933,6433	35,8961
127	43,47	1,48	6	0,3399	41,894	3,67E+05	9,221406	1172,966	36,2921
130	48,73	1,48	6	0,3811	47,729	3,91E+05	9,671871	1525,537	36,7341
135	56,41	1,48	6	0,4411	55,966	4,19E+05	10,23218	2132,391	37,2738



Appendix C-5: FC Step Test Drawdown Method for Sustainable Yield Estimation

Barker- Method	Main	Dzamba New Borehole

r =	14,10	Extpol. t (y)	2	avail. draw	65,66

Manual Fit — NO

K_f [m/d]	S_f [1/m]	b	n
48389	2,00E-03	100	3

Automatic Fit with SOLVER — YES

	Min	Value	Max
K_f [m/d] =	1	412,61512	100000
S_f [1/m] =	1,00E-07	6,22E-06	0,005
b =	0,1	10,482222	100
n =	1	1,0003627	3

Min, Max time to fit (min)

min	max
0	10000

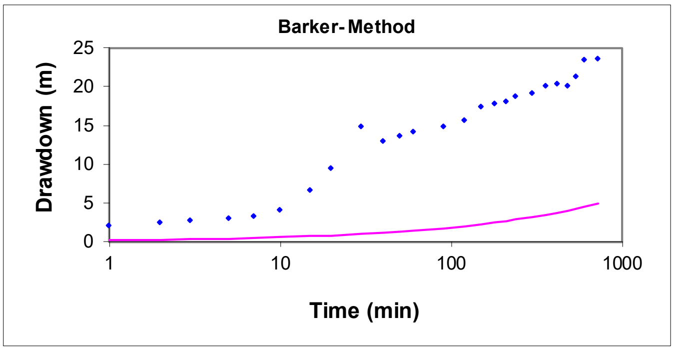
	K_f [m/d]	S_f [1/m]	b	n	N
Fit Parameters	412,62	6,22E-06	10,48	1,00	0,4998

RMSE = 4198,272

	No boundaries	1 no-flow	2 no-flow	Closed
sWell(Extrapol.time)	188,66	260,61	296,59	332,57
Q_sust	0,28	0,20	0,18	0,16

(including influence of bh's from sust_Q sheet)

Fractal n = 1,00 | Average Q-sust (l/s)= 0,20 | std. dev = 0,05



Appendix C-7: FC Method Summary and Recommendations

DUNCAN MUNYAI
29 TSHOKWANE AVE, IVY PARK, 0699, POLOKWANE
PO BOX 383, POLOKWANE, 0700
RECOMMENDATION DONE BY: DUNCAN MUNYAI
DATE: 18/10/2021
CELL: 078 800 4106
EMAIL: FDMUNYAI@GMAIL.COM

Summary | Main | **Dzamba New Borehole**

Applicable	Method	Sustainable yield (l/s)	Std. Dev	Early T (m^2/d)		Late T (m^2/d)		S	AD used
☑	**Basic FC**	0,91	0,56	2		1,1		2,20E-03	65,7
☐	**Advanced FC**			2		1,1		1,00E-03	65,7
☑ ☑	**FC inflection point**	0,15	0,09						21,6
TRUE	**Cooper-Jacob**	0,57	0,37			1,6		4,37E-08	65,7
☑	**FC Non-Linear**	0,02	0,02			3,0		1,10E-04	65,7
☑	**Barker**	0,20	0,05	K_f =	413		S_s =	2,00E-03	65,7
	Average Q_sust (l/s)	**0,37**	**0,36**	b =	10,48	Fractal dimension n =		1,00	N=0,50

N > .5 limited fracture network and connection
N<.1 very good fracture network (radial flow dominant)
N =.25 bilinear flow (semi connective fracture network)

Recommended abstraction rate (L/s)		0,37	for 24 hours per day
Hours per day of pumping	12	0,53	for 12 hours per day
Expected dynamic water level [m bgl]	24 hrs duty cycle	65,00	
Expected dynamic water level [m bgl]	12 hrs duty cycle	48,30	

Drawdown during 24 hr pump rate [m]	***-32,2***
Drawdown during 12 hr pump rate [m]	***-15,5***

Amount of water allowed to be abstracted per day	**32,10**	m^3
Borehole could satisfy the basic human need (26 L/d) of	**1235**	persons
Is the water suitable for domestic use (Yes/No)	**Yes**	
Recommended pump depth below surface (m)	**98**	
Total Casing length	**32,84**	
Water strike depths and blow yield (L/s)	**68 & 1,5**	
Aquifer protection depth that water level must not exceeded	**65,00**	
Depth of borehole (m bgl)	**108,00**	
Static Water Level (m bgl)	**32,84**	

Management recommendations

Transmissivity [m^2/day] = 1,59

Theoretical inflow [L/s] 0,40

APPENDIX D: Pump Testing Analysis using Theis Method

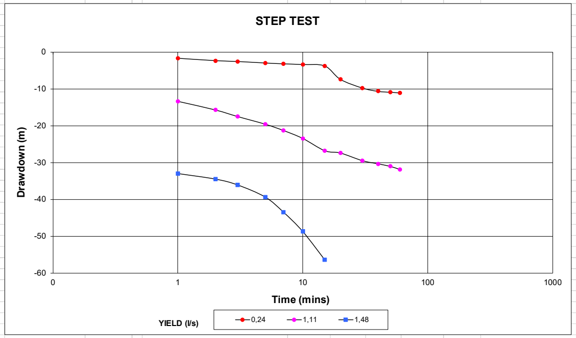
PROJECT	MUNYAI FD UNIVEN STUDY	DATE	30/01/2022	TIME STARTED	12:10:00 PM
BOREHOLE No	BH 1 NEW BOREHOLE	AVAIL. DRAWDOWN	65,66 m	JOB NO	
BOREHOLE DEPTH	108 m,	PUMP DEPTH	98,50 m	LAT	S-22,8115054
STATIC WATER LEVEL	32,84 m	PUMP TYPE	WA23-3	LONG	E30,3224128

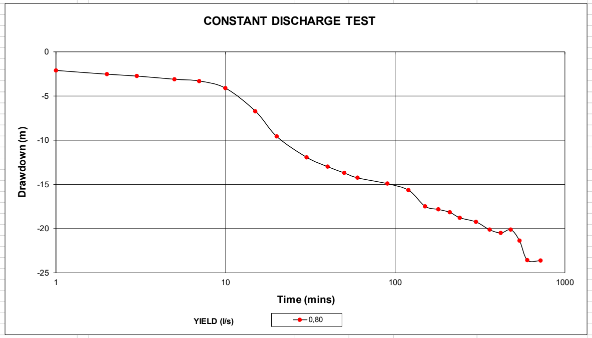
TIME(hrs)	TIME(min)	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	T/T'		RECOVERY	CD	T/T'	RECOVERY	Recovery Steps
AVERAGE YIELD (l/s)		0,24	1,11	1,48						1,29	0,80		0,80	
	1,00	-1,74	-13,38	-33,01				136,00	1,00	-56,01	-2,08	721,00	-17,77	100
	2,00	-2,38	-15,73	-34,52				68,50	2,00	-53,46	-2,51	361,00	-14,10	
	3,00	-2,61	-17,50	-36,09				46,00	3,00	-48,92	-2,72	241,00	-11,42	
	5,00	-3,01	-19,59	-39,38				28,00	5,00	-41,52	-3,08	145,00	-7,79	
	7,00	-3,24	-21,30	-43,47				20,29	7,00	-35,80	-3,28	103,86	-5,39	
	10,00	-3,43	-23,46	-48,73				14,50	10,00	-25,01	-4,10	73,00	-2,95	
	15,00	-3,81	-26,80	-56,41				10,00	15,00	-18,25	-6,71	49,00	-1,29	
	20,00	-7,41	-27,42					7,75	20,00	-11,10	-9,56	37,00	-0,91	
	30,00	-9,75	-29,50					5,50	30,00	-2,80	-11,91	25,00	-0,85	
	40,00	-10,64	-30,36					4,38	40,00	-0,32	-12,98	19,00	-0,82	
	50,00	-10,89	-31,04					3,70	50,00	-0,21	-13,68	15,40	-0,79	
	60,00	-11,05	-31,90					3,25	60,00	-0,20	-14,24	13,00	-0,77	
	90,00							2,50	90,00	-0,16	-14,90	9,00	-0,74	
	120,00							2,13	120,00	-0,14	-15,65	7,00	-0,70	
	150,00							1,90	150,00	-0,12	-17,46	5,80	-0,65	
	180,00							1,75	180,00	-0,10	-17,81	5,00	-0,61	
	210,00								210,00		-18,14	4,43	-0,56	
	240,00								240,00		-18,75	4,00	-0,52	
									300,00		-19,23	3,40	-0,48	
									360,00		-20,11	3,00	-0,43	
									420,00		-20,46	2,71	-0,39	
									480,00		-20,10	2,50	-0,35	
									540,00		-21,35	2,33	-0,31	
									600,00		-23,54	2,20	-0,28	
									720,00		-23,60	2,00	-0,25	

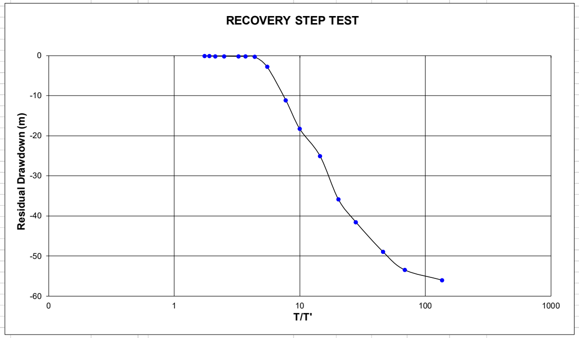
EXISTING EQUIPMENT

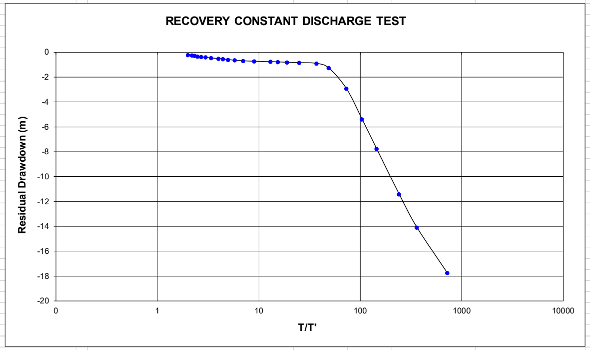
MOTOR :
PUMP :
CONDITION :
COLUMN SIZE :
No OF COLUMNS :

MUNYAI FD UNIVEN STUDY — **BOREHOLE NO :** BH 1 NEW BOREHOLE









INTERPRETATION

BOREHOLE DATA		RECOMMENDATIONS	gal/hr	m3/hr	l/s	hrs/day
DEPTH :	108 m	PUMPING RATE	gal/hr	m3/hr	l/s	hrs/day
S W L :	32,84 m	MAXIMUM :				
STRIKE :	68 m	RECOMMENDED :	7929,52	36,00	0,50	12
TEST PUMP TYPE :	WA23-3	MAX ABSTRACTION PER DAY :			**21,6**	m^3/day
PUMP DEPTH :	98,5 m	PUMP SETTING (m) :				44,5
DATE TESTED :	30/01/2022	PERMISSIBLE DRAWDOWN (m) :				65,66

GENERAL COMMENTS		HYDRAULIC PARAMETERS			EXISTING PUMPING EQUIPMENT	
GEOLOGY :	Quartzite	T (STEP 1) :	3,80	m^3/day/m	MOTOR :	New Borehole
AQUIFER TYPE :	FRACTURED	T (RECOVERY STEPS) :	29,16	m^3/day/m	PUMP :	New Borehole
DRILL TARGET :	Geological Structure	T (CONSTANT DISCHARGE) :	1,58	m^3/day/m	COLUMN SIZE :	New Borehole
RECOVERY :	99 %	T (RECOVERY CONSTANT DISCHARGE) :	14,06	m^3/day/m	No of COLUMNS:	New Borehole
WATER QUALITY :	Class 0	STORAGE COEFFICIENT :	N/A		OUTLET SIZE :	New Borehole
PROBLEM SPECIES :	NONE	SPECIFIC CAPACITY (after 2 hrs pumping) :	0,05	l/s per m	CONDITION :	New Borehole

APPENDIX E: Water Quality Laboratory Results

MURATHO
LABORATORY SERVICES AND CONSULTING

sanas
Testing Laboratory
T0807

Tel: 015 291 2265 Email: info@muratholab.co.za 85 Jorissen Street Moregloed Polokwane 0713 P O BOX 415 Bendor Park

LABORATORY TEST REPORT

Report No.: 2021/08/934

Customer ID: Duncan Munyai

Physical Address: 29 Tshokwane Street
Ivy Park Ext 19
Polokwane

Date of Report: 06/09/2021

Sample Origin: Borehole

Contact Person: Duncan Munyai
Tell: N/A
Mobile: 078 800 4106
Email: fdmunyai@gmail.com

Samples information

Date of sampling: 22/08/2021

Sample type: Ground water

Time sample(s) received: 09h41

No. of samples: 2

Date samples received: 25/08/2021

Date test performed: 25/08/2021-06/09/2021

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Laboratory does not offer statement of conformity
Uncertainty of measurement for all methods included in the SANAS Schedule of Accreditation is available on request

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T0807

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Results

Parameter		Unit	Method ID	Sample ID Dzamba Village (2021/08/934/1)	Sample ID Mabulo Village (2021/08/934/2)
pH @ 25°C		pH value	CH01	7.62	7.26
Conductivity		mS/m	CH02	11.51	16.59
Total Dissolved Solids	*	mg/l	CH02	74.82	107.84
Turbidity		NTU	CH03	88.40	0.59
Total Alkalinity as $CaCO_3$		mg/l	CH04	10.00	13.00
Fluoride as F		mg/l	CH017	0.68	ND
Sulphate as SO_4		mg/l	CH017	0.18	0.58
Nitrate as N		mg/l	CH017	0.70	10.58
Chloride as Cl		mg/l	CH017	8.27	13.24
Total Hardness	*	mg/l	CH05	49.19	66.71
Calcium Hardness	*	mg/l	CH06	21.30	34.58
Magnesium hardness	*	mg/l	CH07	27.89	32.13
Potassium as K	*	mg/l	CH013	0.08	1.01
Calcium as Ca	*	mg/l	CH06	8.52	13.83
Magnesium as Mg	*	mg/l	CH07	6.80	7.84
Sodium as Na	*	mg/l	CH013	6.44	10.01
Zinc as Zn	*	mg/l	CH013	0.26	0.04
Iron as Fe	*	mg/l	CH013	ND	ND
Manganese as Mn	*	mg/l	CH013	0.03	0.01
Copper as Cu	*	mg/l	CH013	ND	ND

Key:
ND: Not detected
*: Not SANAS Accredited. Tests marked "Not SANAS Accredited" are not included in the SANAS Schedule of Accreditation for this Laboratory

Name: Mukhethwa Nepfumbada **Signature:** Date: 06/09/2021
(Technical Signatory)

END OF REPORT

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Tel: 015 291 2265 Email: info@muratholab.co.za 85 Jorissen Street Moregloed Polokwane 0713 P O BOX 415 Bendor Park

LABORATORY TEST REPORT

Report No.: 2021/10/1120

Customer ID: Duncan Munyai

Physical Address: 29 Tshokwane Street
Ivy Park Ext 19
Polokwane

Date of Report: 29/10/2021

Sample Origin: Borehole

Contact Person: Duncan Munyai
Tell: N/A
Mobile: 078 800 4106
Email: fdmunyai@gmail.com

Samples information

Date of sampling: 20/10/2021

Time sample(s) received: 15h14

Date samples received: 20/10/2021

Date test performed: 20/10/2021-28/10/2021

Sample type: Ground water

No. of samples: 2

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Results

Parameter		Unit	Method ID	Sample ID	Sample ID
				Dzamba Village	
				New BH S30.3224128 E22.8115054 (2021/10/1120/1)	**Old BH S30.3236876 E22.8129333 (2021/10/1120/2)**
pH @ 25°C		pH value	CH01	7.27	7.48
Conductivity		mS/m	CH02	10.35	14.95
Total Dissolved Solids	*	mg/l	CH02	67.28	97.18
Turbidity		NTU	CH03	18.50	4.24
Total Alkalinity as $CaCO_3$		mg/l	CH04	105.00	145.00
Fluoride as F		mg/l	CH017	ND	ND
Sulphate as SO_4		mg/l	CH017	3.73	2.90
Nitrate as N		mg/l	CH017	0.10	2.58
Chloride as Cl		mg/l	CH017	9.72	12.18
Total Hardness	*	mg/l	CH05	37.67	151.52
Calcium Hardness	*	mg/l	CH06	17.58	81.00
Magnesium hardness	*	mg/l	CH07	20.09	70.52
Potassium as K	*	mg/l	CH013	0.35	0.62
Calcium as Ca	*	mg/l	CH06	7.03	32.40
Magnesium as Mg	*	mg/l	CH07	4.90	17.20
Sodium as Na	*	mg/l	CH013	5.06	10.70
Zinc as Zn	*	mg/l	CH013	0.28	0.10
Iron as Fe	*	mg/l	CH013	0.06	0.64
Manganese as Mn	*	mg/l	CH013	0.02	ND
Copper as Cu	*	mg/l	CH013	0.01	0.01

Key:
ND: Not detected
*: Not SANAS Accredited. Tests marked "Not SANAS Accredited" are not included in the SANAS Schedule of Accreditation for this Laboratory

Name: Mukhethwa Nepfumbada **Signature:** Date: 29/10/2021
(Technical Signatory)

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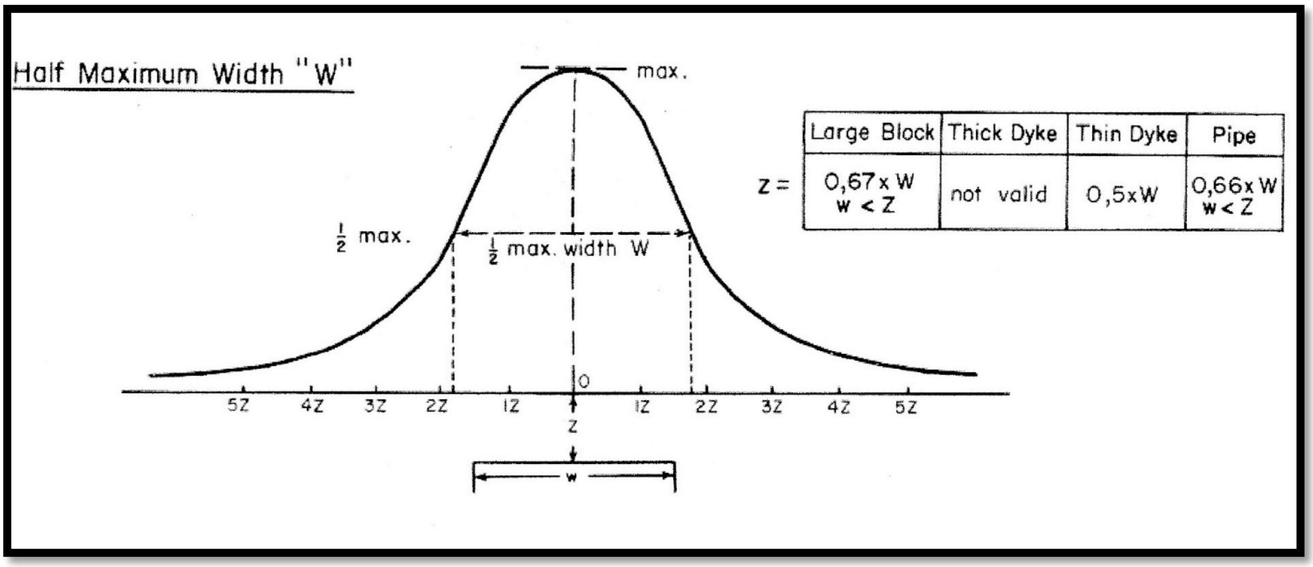
APPENDIX F: Width Estimates from Magnetic Anomaly Profiles (Roux, 1980)



APPENDIX G: "*Quality of Domestic Water Supplies – Volume I – Assessment Guide."* **- DWS, 1997**

SAMPLE ID	GUIDELINES	CLASS 0 *(Ideal_ quality)*	CLASS I *(good_ quality)*	CLASS II *(marginal_ quality)*	CLASS III *(poor_ quality)*	CLASS IV *(unacceptable quality)*
ANAL TYPE	***UNITS***					
pH		5.0– 9.5	>4, <10	<4, >10	<3.5, >10	<3, >11
Conductivity	mS/m	<70.0	70 - 150	150 - 370	370 - 520	>520
T.D.S.	mg/l	<450	450 -1000	1000 -2400	2400 -3400	>3400
Sulphate	mg/l	<200.0	200 - 400	400 - 600	600 - 1000	>1000
Nitrate: N	mg/l	<6.00	6.0 – 10.0	10.0 – 20.0	20.0 – 40.0	>40.0
Chloride	mg/l	<100.0	100-200	200-600	600-1200	>1200
Fluoride	mg/l	<0.70	<1.0	1.0 – 1.5	1.5 – 3.5	>3.5
P-Alkalinity	*	-	-	-	-	-
M-Alkalinity	*	-	-	-	-	-
Carbonate	*	-	-	-	-	-
Bicarbonate	*	-	-	-	-	-
Total Hardness	*	<100.0	100 – 200	200 - 300	300 – 600	>600
Calcium Hardness	*	-	-	-	-	-

Mg Hardness	*	-	-	-	-	-
Calcium	mg/l	32 - 80	80 - 150	150 - 300	>300	NC
Magnesium	mg/l	<30.0	30 - 70	70 - 200	200 - 400	>400
Potassium (dissolved)	mg/l	<25.0	25 - 50	50 - 100	100 - 500	>500
Iron (dissolved)	mg/l	<0.200	0.5 – 1.0	1.0 – 2.0	5.0 – 10.0	>10.0
Manganese (diss)	mg/l	<0.050	0.1 – 0.4	0.4 – 4.0	4.0 – 10.0	>10.0

Water Quality Classification, DWS, 1997

Class 0	**Ideal water quality-suitable for lifetime use.**
Class I	**Good water quality-suitable for use, rare instances of negative effects.**
Class II	**Marginal water quality-conditionally acceptable. Negative effects may occur in some sensitive groups.**
Class III	**Poor water quality-unsuitable for use without treatment. Chronic effects may occur.**
Class IV	**Dangerous water quality-totally unsuitable for use. Acute effects may occur.**