# EVALUATION OF GROUNDWATER QUALITY AND GEOPHYSICAL SURVEY OF THE BOREHOLES IN GA-RAMASWIKANA (SIMSON) VILLAGE, LIMPOPO PROVINCE, SOUTH AFRICA

**BY**

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**A master's dissertation submitted to the University of Venda, Department of Earth Sciences in fulfilment of the requirements of a Master's of Earth Science degree in Hydrology and Water Resources**

**June 2025**

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## DECLARATION

I, Sethokga Sekgopo Paul, student number 17023127, declare that this dissertation for a master's degree in hydrology and water resources at the University of Venda is my work and has not been previously submitted for any degree to any other institution.



20/06/2025

Signature: ……  Date: …….



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## DEDICATION

This work project is dedicated to Almighty God, my daughter Dineo Mashudu Sethokga.



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## ACKNOWLEDGEMENT

I want to express my deepest gratitude to my supervisors, Prof. J.R Gumbo, Dr. O.S Durowoju, and Prof. R. Makungo for encouraging and pushing me to complete this master's research project. From them, I have learnt the most, hardworking spirit and how to solve scientific problems. My promoters have taught me that nothing comes easy.

I would also like to express my sincere gratitude to the National Research Foundation (NRF) for Infinite financial support, the Council of Geoscience for providing me with geological maps of my study area, and the South African Weather Service for the rainfall data provided.

To my wonderful family, I would love to express my deepest thanks and appreciation to my lovely Mother (Miss Sethokga T.D) who has been there for me in so many ways till now, may Almighty Lord continue to flourish her with blessings. To my father Andries Masebe big up. To my child Dineo Mashudu Sethokga, and her mother Thakhani Pearl Mphatha, I appreciate the inspiration that kept me going.

Let me also thank Mr Abraham Sepaela, a community leader, for allowing and aiding me to conduct a study in Ga-Ramaswikana. Blouberg Local Municipality for allowing me to do the research.

Infinite support from the University of Venda Earth Science department for allowing me to use their laboratories (Miss Ndamu Lulimu, Mrs Tshivhase Ele, and Dr. Mudzielwana Rabe).

Nevertheless, I would love to thank Almighty God.



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## ABSTRACT

Geochemical processes and the type of rock in which the aquifer is formed are, in most cases, responsible for natural groundwater deterioration. Therefore, groundwater deterioration is associated with various health risks to persons consuming the water, thus, it would vary from adults to children. Ga-Ramaswikana and surrounding communities depend on groundwater for household uses due to the lack of municipal water supply systems. This study focused on investigating the groundwater quality, geological formation, and geo-profile of boreholes in Ga-Ramaswikana village. The water samples and geophysical survey data were collected four times, once a season (autumn, winter, spring, and summer). The methods of water quality analysis and borehole profiling using PQWTS500 groundwater detector were adopted. The following water quality parameters were evaluated, physicochemical parameters such as Total Dissolve Solid (TDS), Turbidity, Salinity, Temperature, pH, and Electrical Conductivity (EC); The major anions and cations ($HCO_{3-}$ , $SO_4^{2-}$ , $NO_{3-}$ , $Cl^-$ , $F^-$ , $K^+$ , $Mg^{2+}$, $Ca^{2+}$, $Na^+$ ), and Trace metals such as (Aluminium (Al), Arsenic (As), Chromium (Cr), Copper (Cu), Iron (Fe), and Silicon (Si)). Fluoride concentrations were above the SANS limit (1.5) during the three seasons and is likely responsible for teeth discoloration. This makes the water unsuitable for drinking use. The average fluoride ($F^-$) levels for all weather seasons were 1.73, 2.1, 2.6, 2.9, and 1.9 mg/l for the following boreholes respectively, Sepaela, Mashabela, Public borehole, Mahladisa, and Rampa. The public and Rampa boreholes had the highest turbidity which exceeded the limit of 5 NTU for World Health Organisation, and South African National Standards. The community borehole had turbidity of 101.6, and 32.4 NTU in spring and summer respectively. For Rampa household, the water had a turbidity of 22 NTU and 9.7 NTU in winter and summer respectively. For trace metals, higher concentrations of aluminium were recorded in the following boreholes (P2, P4, P8, P12, P14, P15, P16, P18). 100 % of water samples in the study were prone to Silicon which affected the taste of water. Arsenic was present in high concentration in the following boreholes P12, P13, P14, P15, and P18 of different seasons. The P12 to P18 boreholes had arsenic concentrations of 1.69, 4.48, 3.01, 4.5, and 6.17 mg/l, except for P16 which was for Mogalakwena river water sample. The major cations ($Ca^{2+}$, $Na^+$, $Mg^{2+}$, and $K^+$) were plotted against major anions ($HCO_{3-}$ , $SO_4^{2}$-, and $Cl^-$) on a piper diagram to understand the water type dominant in the groundwater of Ga-Ramaswikana Village. The geochemistry of groundwater in Ga-Ramaswikana Village is dominated by calcium chloride ($CaCl_2$) water type in most boreholes. $CaCl_2$ is a type of hard water that gives a salty water taste of groundwater within Ramaswikana Village. The



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groundwater chemistry of a public borehole is $CaCl_2$ throughout all seasons. This tells that the public borehole is drilled on a calcium chloride rock formation. The decrease in annual rainfall trend has impacted the seasonal groundwater recharge.

Geophysical surveys were conducted to investigate the subsurface profile of boreholes and geological formations in Ramaswikana village. Therefore, the PQWTS500 groundwater detector machine revealed that some boreholes in the study were wrongly sited. This area is associated with the Gneiss formation and the groundwater in this area is salty. This may be due to geochemical processes such as weathering, rock-water interaction, dissolution of minerals, and ion exchange, which alter the water quality in the ground.

An integrated approach involving the geophysical survey and groundwater quality has been studied. Therefore, it has contributed to a better understanding of groundwater, geologic formation, its quality, and health risks of groundwater within Ga-Ramaswikana. The findings will be shared with relevant stakeholders in the water sector and community leaders for sustainable mitigation strategies and development.

**Keywords:** Groundwater quality, Geophysical survey, PQWTS500, Geological formation, Borehole profiling.



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# Table of Contents

DECLARATION ..... i
DEDICATION ..... ii
ACKNOWLEDGEMENT ..... iii
ABSTRACT ..... iv
Table of Contents ..... vi
List of Figures ..... x
List of Tables ..... xv
List of abbreviation ..... xvi
CHAPTER 1: INTRODUCTION ..... 1
1.1 Background of the study ..... 1
1.2 Problem Statement ..... 2
1.3 Motivation of the study ..... 4
1.4 Objectives ..... 5
1.4.1 Main objectives ..... 5
1.4.2 Specific objectives ..... 5
1.5 Research Questions ..... 5
1.6 Hypothesis ..... 6
1.7 Study Area ..... 6
1.8 Geology ..... 7
1.9 Outline of the Research ..... 8
CHAPTER 2: LITERATURE REVIEW ..... 9
2.1 Preamble ..... 9
2.2 Review of Groundwater Resources ..... 9
2.3 Groundwater Contamination ..... 10
2.4 Geochemistry of Groundwater ..... 11
2.5 Water Quality Parameters ..... 13
2.5.1 Physical Parameters of Water ..... 13
The pH ..... 13
Temperature ..... 13
Turbidity ..... 14
Electrical Conductivity (EC) ..... 14
Total Dissolved Solids (TDS) ..... 14
2.6 Major Anions and Cations ..... 14
Bicarbonate ($HCO_3$-) ..... 14
Chloride ($Cl^-$) ..... 15



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Sulphate ($SO_4^{2-}$) ..... 15
Fluoride ($F^-$) ..... 15
Nitrate ($NO_3$) ..... 16
Calcium ($Ca^{2+}$) ..... 16
Magnesium ($Mg^{2+}$) ..... 16
Sodium ($Na^+$) ..... 16
Potassium ($K^+$) ..... 17
Arsenic (As) ..... 17
Chromium (Cr) ..... 17
Copper (Cu) ..... 18
Iron (Fe) ..... 18
2.7 Fluoride abundance in rock-forming minerals ..... 19
2.8 Geology of the Alldays Gneiss Suite ..... 21
2.9 Health effects linked with contaminated groundwater ..... 22
2.10 Geophysical studies of groundwater ..... 24
2.11 Electromagnetic Groundwater Detector PQWT ..... 25
2.12 Overview of groundwater defluoridation technologies ..... 26
2.13 Summary of Literature Review ..... 27
CHAPTER 3: METHODOLOGY ..... 28
3.1 Preamble ..... 28
3.2 Data and Sample Collections ..... 29
3.2.1 Water Sampling ..... 29
3.2.2 Water sampling procedure ..... 30
3.2.3 Geophysical Survey ..... 31
3.3 Experimental Analysis ..... 32
3.3.1 Digestion of Water Samples ..... 32
3.3.2 Physicochemical Parameters ..... 33
3.3.3 Fluoride ($F^-$) ..... 33
3.3.4 Trace Metals and Cations ..... 34
3.3.5 Major Anions ..... 35
3.3.6 Borehole geophysical analysis (Borehole Profiling) ..... 36
3.4 Data analysis ..... 37
CHAPTER 4: RESULTS AND DISCUSSION ..... 39
4.1 Preamble ..... 39
4.2 Physicochemical Parameters of Groundwater ..... 39
4.2.1 Electrical Conductivity (EC) ..... 39



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4.2.2 Total Dissolved Solid (TDS) ..... 40
4.2.3 Salinity ..... 41
4.2.4 Potential Hydrogen (pH) ..... 42
4.2.5 Temperature ..... 42
4.2.6 Turbidity ..... 43
4.2.7. Turbidity of Mogalakwena River in Ga-Ramaswikana village ..... 44
4.3 Trace Metals in Groundwater ..... 45
4.3.1 Aluminium (Al) ..... 45
4.3.2 Arsenic (As) ..... 46
4.3.3 Calcium (Ca) and Magnesium (Mg) ..... 46
4.3.4 Chromium (Cr) ..... 47
4.3.5 Copper (Cu) ..... 47
4.3.6 Iron (Fe) ..... 47
4.3.7 Potassium ($K^+$) ..... 48
4.3.8 Sodium ($Na^+$) ..... 48
4.3.9 Silicon (Si) ..... 48
4.3.10 Titanium (Ti) ..... 49
4.4 Major Anions ..... 49
4.4.1 Bicarbonate ($HCO_3^-$) ..... 50
4.4.2 Chloride $Cl^-$ ..... 50
4.4.3 Sulphate $SO_4^{2-}$ ..... 51
4.4.4 Nitrate ($NO_3^-$) ..... 52
4.4.5 Fluoride in Groundwater ($F^-$) ..... 52
4.5 Groundwater Hydrochemistry ..... 53
4.6 PQWT Electromagnetic Borehole Profiles for autumn ..... 58
4.6.1 Sepaela Homestead Subsurface Profile ..... 58
4.6.2 Boloka Homestead Subsurface Profiles ..... 60
4.6.3 Mahaladisa Homestead Subsurface Profile ..... 61
4.6.4 Community Borehole Geo-Profile ..... 63
4.6.5 Mashabela Homestead Subsurface Profile ..... 64
4.7 Winter PQWT Electromagnetic Borehole Profiles ..... 66
4.7.1 L99 Sepaela Winter Borehole Profile ..... 66
4.7.2 L101 Rampa Winter Borehole Profile ..... 68
4.7.3 L102 Mashabela Winter Borehole Profile ..... 69
4.7.4 L103 Surveyed proposed site next to Mogalakwena River, raw profile for winter ..... 71
4.7.5 L04 Mahladisa Winter Borehole Profile ..... 72



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4.7.6 L105 Community Borehole Profile for Winter ..... 73
4.8 PQWT Electromagnetic Borehole Profiles for Spring ..... 75
4.8.1 L120 Sepaela Spring Borehole Profiles ..... 75
4.8.2 L121 Rampa Spring Borehole Profiles ..... 75
4.8.3 L122 Mashabela Homestead Borehole Profile ..... 76
4.8.4 L123 Proposed borehole site near Mogalakwena River ..... 77
4.8.5 L124 Public Borehole Profiles ..... 77
4.8.6 L125 Mahladisa Borehole Profiles ..... 78
4.9 Rainfall Data of Ga-Ramaswikana Village ..... 79
CHAPTER 5: CONCLUSION AND RECOMMENDATIONS ..... 80
5.1 Preamble ..... 81
5.2 Conclusions ..... 81
5.3 Recommendations ..... 82
5.4 Future Avenues for Further Research ..... 85
References ..... 85
Appendices ..... 99
Appendix 1: Autumn Physicochemical Water Quality Parameters ..... 100
Appendix 2: Winter Physicochemical Water Quality Parameters ..... 101
Appendix 3: Spring Physicochemical Water Quality Parameters ..... 101
Appendix 4: Summer Physicochemical Water Quality Parameters ..... 1023
Appendix 5: Major anions results (IC) ..... 103
Appendix 6: Ion Chromatography (IC) Sample codes ..... 104
Appendix 7: ICP-OES Sample Codes ..... 105
Appendix 8: SAWS monthly rainfall data of Ga-Ramaswikana village, station (07631496), Tolwe-Pol 22.98 50 28.57 50 1993 – 2023 08:00 (Extracted 2024/02/27 10:46). ..... 106



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## List of Figures

**Figure 1.1:** Public borehole of Ga-Ramaswikana (Simson) village……4

**Figure 1.2:** Study area map……...7

**Figure 1.3:** Geology map of the study area……..8

**Figure 2.1:** Piper diagram showing water type (Piper, 1944)……19

**Figure 2.2:** Durov diagram (Ravikumar et al., 2015)……..19

**Figure 2.3:** Alldays gneiss showing various sets of granitoid veins (Brandl, 2002)……...22

**Figure 3.1:** Community Borehole 1 storage tank ……..…….29

**Figure 3.2** M N equidistance is 10m and both move 1 meter……..30

**Figure 3.3** Geophysical survey at public borehole 2……...31

**Figure 3.4:** Digestion of water samples with Microwave digester…….31

**Figure 3.5:** Field measurements by Extech-EC500 multi-meter and turbidity meter Model TB400 Instruments……..32

**Figure 3.6:** Preparation of fluoride analysis with Orion Star 214 Thermos Scientific instrument…….33

**Figure 3.7:** Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), used for determination of trace metals and cations…..…….34

**Figure 3.8:** Ion Chromatography (IC) used for Major Ions analysis in water samples……..34

**Figure 3.9:** Geophysical groundwater survey at Ga-Ramaswikana (Simson) village…….....35

**Figure 3.10:** Borehole points/ Coordinates within Simson village…….36

**Figure 4.1:** EC of groundwater in autumn, winter, spring, and summer…….39

**Figure 4.2:** TDS of groundwater in autumn, winter, spring, and summer…….....40

**Figure 4.3:** Salinity of groundwater in autumn, winter, spring, and summer…….....40

**Figure 4.4:** pH of groundwater in autumn, winter, spring, and summer…….....41



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**Figure 4.5:** Groundwater temperature in autumn, winter, spring, and summer……..42

**Figure 4.6:** Turbidity of groundwater in autumn, winter, spring, and summer in Simson village……...43

**Figure 4.7:** High turbidity in public borehole water sample for drinking in Simpson village……...43

**Figure 4.8:** Turbidity of Mogalakwena River in autumn, winter, spring, and summer……..44

**Figure 4.9:** Calcium concentration in groundwater samples…….....46

**Figure 4.10:** Si concentration in groundwater samples……..……....48

**Figure 4.11:** Bicarbonate in groundwater……....49

**Figure 4.12:** Chloride levels in groundwater……...50

**Figure 4.13:** Sulphate concentrations in groundwater sources……50

**Figure 4.14:** Average Fluoride Concentration in Groundwater……..52

**Figure 4.15:** Trilinear Piper diagram showing major cations and anions in groundwater for all seasons…….53

**Figure 4.16:** Durov diagram showing the hydrochemical process of groundwater in Simson village……..…….55

**Figure 4.17:** Geological Map of Ga-Ramaswikana Villag…….……56

**Figure 4.18:** Sepaela household raw subsurface profile for autumn with drilled borehole at point 4, 70m deep…….57

**Figure 4.19:** Sepaela household processed and curve subsurface profile for autumn with drilled borehole at point 4……....58

**Figure 4.20:** Boloka household raw subsurface profile for autumn with drilled borehole at point 3, 30m deep…….59

**Figure 4.21:** Boloka household processed subsurface profile for autumn with drilled borehole at point 3, 30m deep…….60

**Figure 4.22:** Mahladisa household raw subsurface profile for autumn with drilled borehole at point 8……...61



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**Figure 4.23:** Mahladisa household processed subsurface profile for autumn with drilled bore-hole at point 8……61

**Figure 4.24:** Mahladisa household curve subsurface profile for autumn with drilled borehole at point 8……...61

**Figure 4.25:** Ga-Ramaswikna community borehole, raw profile for autumn. Borehole drilled at point 5, 125m deep……...62

**Figure 4.26:** Ga-Ramaswikna community borehole, processed profile for autumn. Borehole drilled at point 5, 125m deep……62

**Figure 4.27:** Ga-Ramaswikna community borehole, curve profile for autumn. Borehole drilled at point 5, 125m deep……63

**Figure 4.28:** Mashabela autumn, raw subsurface profile. Borehole drilled at point 3, 30m deep……..63

**Figure 4.29:** Mashabela autumn, processed subsurface profile. Borehole drilled at point 3, 30m deep…….64

**Figure 4.30:** Mashabela autumn, curve subsurface profile. Borehole drilled at point 3, 30m deep…….64

**Figure 4.31:** Sepaela winter, Raw and processed subsurface profile. Borehole drilled at point 4, 70m deep……66

**Figure 4.32:** Sepaela winter, curve subsurface profile. Borehole drilled at point 4, 70m deep……66

**Figure 4.33:** Rampa winter raw subsurface profile. Borehole drilled at point 3, 50m deep...67

**Figure 4.34:** Rampa winter processed subsurface profile. Borehole drilled at point 3, 50m deep……..67

**Figure 4.35:** Rampa winter curve subsurface profile. Borehole drilled at point 3, 50m deep……..68

**Figure 4.36:** Mashabela winter raw subsurface profile. Borehole drilled at point 3, 30m deep……69



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**Figure 4.37:** Mashabela winter processed subsurface profile. Borehole drilled at point 3, 30m deep…….69

**Figure 4.38:** Mashabela winter curve subsurface profile. Borehole drilled at point 3, 30m deep……..70

**Figure 4.39:** Mogalakwena raw subsurface profile. The proposed borehole was surveyed at point 2 beyond 50m deep…….70

**Figure 4.40:** Mogalakwena processed subsurface profile. The proposed borehole was surveyed at point 2 beyond 50m deep……...71

**Figure 4.41:** Mahladisa winter raw subsurface profile. Borehole drilled at point 2, 35m deep……..71

**Figure 4.42:** Mahladisa winter processed and curve subsurface profiles. Borehole drilled at point 2, 35m deep…….72

**Figure 4.43:** Community original borehole subsurface profile. Borehole drilled at point 5, 100m deep……73

**Figure 4.44:** Community processed and curve borehole subsurface profiles. Borehole drilled at point 5, 100m deep……...73

**Figure 4.45:** Sepaela spring processed and curve subsurface profiles. Borehole drilled at point 4, 70m deep…….74

**Figure 4.46:** Rampa spring processed and curve subsurface profiles. Borehole drilled at point 3, 50m deep……..75

**Figure 4.47:** Mashabela spring subsurface processed and curve profiles. Borehole drilled at point 2, 30m deep…….76

**Figure 4.48:** Spring public borehole subsurface profile processed and curve profiles. Borehole drilled at point 3, 100m deep……77

**Figure 4.49:** Mahladisa homestead subsurface profile for spring (processed and curved). Borehole drilled at point 3, 35m deep……..78

**Figure 4.50:** Annual rainfall timeline of Ramaswikana village (SWS, 2024)…….79

**Figure 5.1:** Surveyed proposed site next to Mogalakwena River, raw profile……83



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**Figure 5.2:** Surveyed proposed site next to Mogalakwena River, processed profile……..83

**Figure 5.3:** Surveyed proposed site next to Mogalakwena River, curve profile…….83

**Figure 5.4.** Borehole drilling in Zimbabwe Harare, 2024……...84



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## List of Tables

**Table 2.1**: Fluoride concentration classification and its risks. Revised after Keshavarz et al., (2015), Onipe et al., (2021), and Durowoju et al. (2015) ……20

**Table 3.1:** Summary of sample names and GPS coordinates of sampling points……...37

**Table 4.1**: Trace Metals Present in Groundwater Samples of Ga-Ramaswikana Village……49

**Table 4.2**: Groundwater Types…….54



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## List of abbreviation

$Ca^{2+}$ Calcium

$Cl^-$ Chloride

DO Dissolved Oxygen

DWAF Department of Water Affairs and Forestry

DWS Department of Water and Sanitation

EC Electrical conductivity

$F^-$ Fluoride

GWB Geochemistry Work Bench

HPGEEI Hunan Puqi Geologic Exploration Equipment Institute

HPWEI Hunan Puqi Water Environmental Institute

IAEA International Atomic Energy Agency

IC Ion Chromatography

ICP-OES Inductively coupled plasma - Optical emission spectrometer

ISE Ion Selective Electrode

$K^+$ Potassium

$Mg^{2+}$ Magnesium

$Na^+$ Sodium

$NO_3^-$ Nitrate

$PO_4^{3-}$ Phosphate

PQWT Proton Quantity Wave Technology

SABS South African Bureau of Standards

SANS South African National Standards



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$SO_4^{2-}$ Sulphate

TDS Total dissolved solids

USEPA United States Environmental Protection Agency

USGS United States Geological Survey

WHO World Health Organisation



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# CHAPTER 1: INTRODUCTION

## 1.1 Background of the study

Water is crucial for human existence; however, its quality should be prioritized (DWAF, 1995). Geochemical processes often help in the deterioration of water quality, which results from rock-water interactions (Greggio et al., 2020). The availability of freshwater is threatened by the contamination of water resources (Adimalla and Qian, 2019; Sajil Kumar and James, 2019; Subba Rao et al., 2019). The geological formation of an area may also influence the quality of subsurface water, which may be intensive during the weathering process. The groundwater flow, recharge, fluid mixing, and water-rock interaction processes that impact water quality can all be traced with the help of geochemical and isotopic data. According to Ntanganedzeni et al. (2018), natural processes like salinity, evaporation, marine aerosols, and rock–water interactions are frequently to blame for the widespread worldwide issue of groundwater contamination in coastal aquifers. The quality of groundwater should be assessed for health reasons because it is a major supply of water in South Africa and other countries (DWAF, 2004; Lapworth et al., 2017; Rohde et al., 2017; Kawo and Karuppannan, 2018). Therefore, these valuable sources must be managed and protected from pollution to ensure suitable water quality.

The pollution of groundwater resources by natural processes can be due to the climatic and geological conditions of the area (Mahlknecht et al., 2017; Wen-Geng et al., 2018; Vhonani et al., 2019). A broad understanding of rock-water interactions (geochemical processes) is crucial for identifying appropriate management measures for geogenic pollutants (Paul et al., 2019). Groundwater salinization is mostly caused by the accumulation of ions and is a major challenge in most semi-arid countries (Liu et al., 2018). Geophysical studies are crucial for showing the Earth's subsurface because they primarily serve to identify areas where water is present and aid in identifying groundwater recharge and discharge zones. For the analysis of subsurface topography, a variety of geophysical study methods are available, including electric, electromagnetic, gravity, magnetics, ground penetrating radar (GPR), and seismic methods. The choice of the geophysical approach is influenced by local logistical support and physical property differentiation. For groundwater applications, electrical and seismic techniques are frequently used. The electrical resistivity approach has become popular for groundwater investigation due to its ease of use and practical use (Gugulothu et al., 2020).



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Consumption of water associated with geogenic matters without any treatment may result in severe health effects depending on the amount of concentration present in that water (Kumar and Singh 2020). High fluoride concentration in drinking water may lead to dental or skeletal fluorosis, depending on the amount of the concentration in water which exceeds the limits of 1.5mg/l recommended by WHO and DWAF guidelines. Various studies in South Africa have shown that the existence of dental fluorosis is associated with drinking groundwater with high fluoride content, exceeding the limit of 1.5mg/l and this mainly occurs in rural areas (Odiyo and Makungo, 2018; Onipe, 2018). Globally, the intake of water with a high fluoride ($F^-$) concentration result in dental abnormalities, such as mottling of teeth (tooth decay), dental fluorosis, and skeletal and bone deformation (Malago et al., 2017; Odiyo and Makungo, 2018). The acceptable limit of fluoride content is significant in drinking water, thus for the protection of tooth decay and healthy development of bones (DWAF, 1995). The release of arsenic (As) through geochemical processes in the groundwater resources, will cause dissolution in the bloodstream, leading to diseases of bones, skin, kidney, lung, cancer of the liver, gall bladder, and intestines health problems (Raju, 2021).

Groundwater is perceived to be more potable source of water than surface water, and it is largely used without any treatment. The occurrence of inorganic pollutants like fluoride ($F^-$), nitrate ($NO_3^-$), arsenic (As), and other heavy metals have acute and chronic health effects (Singh et al., 2017; Adimalla et al., 2018), whereas human activities such as excessive use of biocides, poor construction, urbanization, sewage leakage, and untreated industrial discharge have the potential to change the groundwater quality (Burri et al., 2019). Groundwater is also an imperceptible natural resource that cannot be seen. It is accessible in diverse proportions, at various depths, and in various types of rocks on the surface layer and underneath of the earth. However, geophysical studies of groundwater are done to evaluate the potential groundwater recharge zones, for the purposes of borehole drilling, thus, to see the depth and the amount of water in the aquifers at the drilling site (Hassan et al., 2021). This study focuses on the geophysical assessment of groundwater and its quality, also the health risks amongst children and adults. The previous study by Sethokga (2021), has revealed high fluoride content in most borehole waters in Ga-Ramaswikana village.

### 1.2 Problem Statement

The key factors that contribute to groundwater contamination and reduction in groundwater table are acidification, salinization, and agriculture (application of biocides) (Kopittke et al.,



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2019). The geological formations also have a significant impact on groundwater quality, the process of weathering and dissolving of various geologic materials such as minerals containing salts among others (Adimalla et al., 2018; Vetrimurugan, 2018; Nolakana et al., 2016; Kumar and Singh 2020; Onipe et al., 2021). Several studies around the globe have discovered health implications associated with the intake of water contaminated by geogenic matters. The release of trace elements such as arsenic (As) through geochemical processes in the groundwater resources, will cause dissolution in the bloodstream leading to diseases of bones, skin, kidney, lung, cancer of the liver, gall bladder, and intestines health problems (Raju, 2021). A high fluoride concentration of over 1.5 mg/l in drinking water may cause skeletal or dental fluorosis depending on the exposure or amount present in that water (DWAF, 1996; WHO, 2006).

In South Africa, the occurrence of dental fluorosis is mostly associated with the intake of groundwater with high fluoride content, exceeding the limit of 1.5 mg/l and this mainly occurs in rural areas (Onipe et al., 2021). However, residents from Ga-Ramaswikana village, Nzhelele Siloam, and Matoks in Limpopo Province are exposed to dental fluorosis (mottled teeth) (Odiyo and Makungo, 2018; Sethokga, 2021). Drilling boreholes at any site, without a proper survey, could lead to obtaining inadequate water which is not sustainable.

From the field survey, it was observed that the groundwater in Ga-Ramaswikana (Simon) Village is salty, which might be due to geological formations underneath, type of rock, dissolving of various minerals, and geochemistry of water, leading to a high content of salt and other chemicals in water. The residents of Ga-Ramaswikana Village depend on groundwater for domestic uses and other various uses. The residents are exposed to water supply challenges, salty groundwater, and dental fluorosis, which is due to high fluoride ($F^-$) levels detected in the groundwater exceeding the limit of 1.5 mg/l (Sethokga, 2021). Hence, the groundwater in this village is regarded as not safe for human consumption. Due to inadequate water supply, the residents sorely depend on untreated borehole water (unknown groundwater quality) (Figure 1.1). Water scarcity has become a serious problem in the community. However, the assessment of potential groundwater recharge zones using a geophysical exploration of groundwater before drilling boreholes is vital. Boreholes drilled on shallow and perched aquifers, results in inadequate groundwater discharge. Some homestead in this Village have more than two drilled boreholes, this was due to drying of boreholes and lack of geophysical surveying before drilling.



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The availability of freshwater is one of the biggest challenges facing mankind nowadays, because issues related to it affect the lives of millions of people (Angelakis et al., 2021). However, due to rapid population growth, it becomes more difficult to find enough water of reasonable quality for potable usage in many world places. Geophysical approaches can solve these issues (Oyegoke, 2020; Collier, 1993). Geophysical methods are used in groundwater exploration to learn more about the underlying environment (Alabi et al., 2020). There is a widespread misperception that borehole water, even from very deep holes, is safe to drink, since the microbiological burden is minimal, and treatment is not often necessary required. However, the geological formation that the aquifer is covered by plays a significant role in the deterioration of groundwater (Ajiboye and Okafor, 2019).



**Figure 1.1:** Public borehole of Ga-Ramaswikana (Simson) village

### 1.3 Motivation of the study

The inadequate water supply has become a crisis in most rural communities, groundwater is used as a major primary source of drinking water globally and it is perceived to be more potable than surface waters, but the geological formations make it a concern (Vetrimurugan, 2018). The residents of Ga-Ramaswikana Village are exposed to dental fluorosis (Brown teeth), which was revealed to be due to high fluoride concentration found in groundwater (Sethokga, 2021). From the previous study, 95% of boreholes in the study had high fluoride ($F^-$) concentration that exceeded the limit, and it was also discovered that most borehole water samples contained high calcium and magnesium concentrations which represent the hardness of water. Using



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physical tasting of water, most borehole water were salty, which was due to high sodium and chloride in that water. Most boreholes in the study were not containing freshwater (Sethokga, 2021). However, the current study will review the geological formation associated with aquifers in the area, major anions and cations, geo-profiling of existing boreholes and health risks which may occur. The geophysical instrument will help in locating the proper sites to drill borehole of adequate water. This study is aimed at finding more on health risks associated with groundwater quality and profile the subsurface of selected boreholes that have low fluoride and salinity. This study will also investigate more on the current physiochemical, heavy metals and review geology of the area. This study would also be useful in the case of implementation of water projects, whereby they're drilling boreholes in the community, the methods used in the study will enable the drillers obtaining adequate freshwater for the community. The geophysical survey of boreholes was conducted to understand the hydrogeological conditions of the boreholes, since borehole water is scarce in this area.

## 1.4 Objectives

### 1.4.1 Main objectives

The study's main objective was to evaluate the groundwater quality and geo-profile the selected boreholes in Ga-Ramaswikana Village.

### 1.4.2 Specific objectives

- To determine the physical and chemical water quality parameters and their seasonal variation, significant anions and cations, and trace metals present in groundwater for all weather seasons to see the variation.
- To determine hydro-geochemistry of groundwater in Ga-Ramaswikana Village.
- To geo-profile the selected boreholes to understand the hydrogeological conditions of boreholes and the seasonal variation in groundwater levels.

## 1.5 Research Questions

- What are the seasonal variations of concentration of physical and chemical water quality parameters, Trace metals, and major ions?
- What is the geochemistry of groundwater in the study area?



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- What are the hydrogeological conditions of the selected boreholes in Ga-Ramaswikana?

## 1.6 Hypothesis

- The groundwater quality in Ga-Ramaswikana (Simson) Village is significantly affected by the area's geological formation, resulting in higher fluoride concentrations leading to dental fluorosis among residents.
- According to the data obtained from the groundwater detector machine (PQWTS500), most boreholes in the study were wrongly sited.

## 1.7 Study Area

Ga-Ramaswikana Village is located in Bochum, Blouberg Municipality, Limpopo Province, South Africa. It is 83.2 kilometers (by R521 and Tolwe Rd) from Vivo, a tiny farming community, and 37 kilometers from Alldays. Ga-Ramaswikana Village, also known as Simson Village, is located at coordinates 22.7492º S and 28.7912º E. Ga-Ramaswikana Village is a dry area with a limited water supply. This hamlet still uses traditional methods of water collection. For example, water from community boreholes is collected using 200 L water barrels, a hippo water roller, and buckets. The Mogalakwena River also passes at Ga-Ramaswikana Village, flowing from north of a border between South Africa and Botswana, to Limpokwena nature reserve. The Mogalakwena River is a tributary from the Limpopo River at coordinates of 22º27’24" S, 28º55’25" E. Figure 1.2 shows the location of the study area (Ga-Ramaswikina Village).



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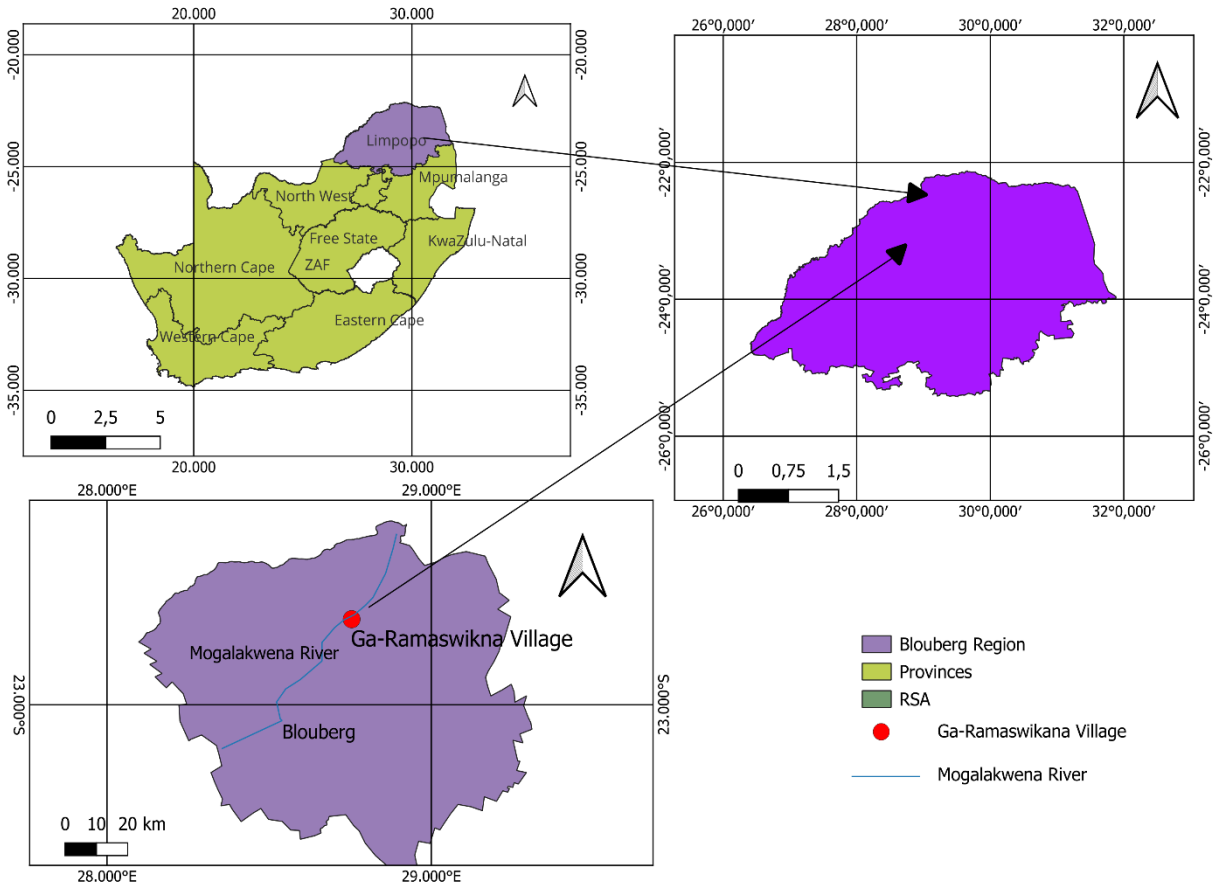



**Figure 1.2:** Study area map

## 1.8 Geology

According to Orpen et al. (1982), the grey biotite-gneiss of tonalitic composition is known as gneiss, and it was discovered to be intrusive. Granite and sedimentary rocks dominate the study region, which includes the majority of adjacent villages and certain areas of Blouberg municipality (Figure 1.3). The geological formations of Ga-Ramaswikana Village are associated with igneous (Granitic) and sedimentary rocks and the rocks containing minerals such as fluorite, biotite, cryolite, muscovite, fluorspar, topaz, apatite, and minerals containing sodium-chloride (Onipe et al., 2020). The Ga-Ramaswikana Village is associated with Alldays gneiss formation, as shown in Figure 1.3 of the geological map of the study area (Brandl, 2002).



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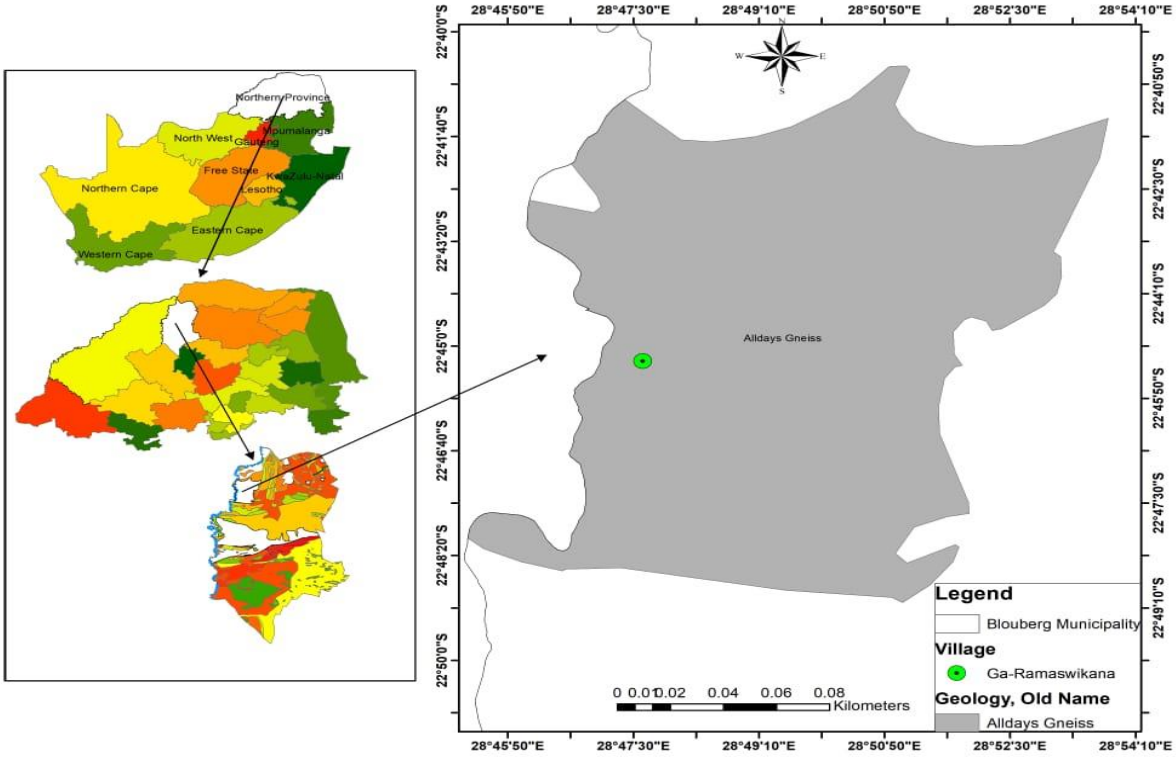



**Figure 1.3:** Geology map of the study area

## 1.9 Outline of the Research

This dissertation is structured into 5 chapters. Chapter 1 contains background of the study, problem statement, motivation, objectives, research questions, hypothesis, study area and geology. Chapter 2 consist of literature review. Chapter 3 is methodology which include material and methods. Chapter 4 is results discussion, whereas chapter 5 is conclusion and recommendation.



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# CHAPTER 2: LITERATURE REVIEW

## 2.1 Preamble

This chapter reviewed the literature on geophysical studies of groundwater, geochemical processes, and health risks associated with water quality for groundwater. Moreover, groundwater contamination, and the causes and effects of geochemical processes on water quality. In this case, various kinds of literature were reviewed on geochemical processes affecting groundwater quality, groundwater geophysical surveys, and water geochemistry. Literature on studies done in Limpopo Province, Bochum, within Blouberg Municipality were also reviewed to understand better groundwater quality and the geological formation within areas around Bochum.

## 2.2 Review of Groundwater Resources

Groundwater is one of the most important sources of drinking water for both developing and developed countries (DWAF, 2004). As a result, it must be kept, controlled, and safeguarded against various forms of contamination. The dependence on groundwater resources is much higher than the surface waters, this might be due to inadequate water supply from Municipality. Potable groundwater should be adequate to meet industrial, agricultural, and domestic demands to enhance the livelihood of people or the standard of living. Globally, water pollution is becoming a threat to our water resources, because if most water resources are polluted, this will lead to freshwater scarcity (US News, 2018; McPhillips, 2019; Akinola et al., 2018; Buba and Maina, 2020). Hence, this simply means that the poor quality of water affects the availability or quantity of freshwater.

Groundwater comes from precipitation that enters the ground and passes down to the aquifer through various processes such as infiltration and percolation. In some cases, rainwater is slightly acidic pH; therefore, it tends to dissolve solid minerals in the soil and the aquifer (Patil et al., 2020). The geochemistry of groundwater is influenced by the passing of water through various rocks such as granite, limestone, sandstone, basalt, and numerous minerals. Therefore, this will give groundwater different composition, particularly the geochemical processes in groundwater (Patil et al., 2020; Akinbile and Yusoff, 2011). Although groundwater is perceived to be more potable and safer than surface water, there are natural processes such as geochemical processes that affect our groundwater resources naturally (Tomasek et al., 2022).



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Excessive pumping, lack of rainfall, overpopulation, and water contamination can lead to massive depletion of groundwater resources (USGS, 2018; Bilal et al., 2021). The geophysical approach can help mitigate subsurface water scarcity (Oyegoke et al., 2020, Gumbo et al., 2023).

The global dilemma of groundwater over-abstraction and contamination is believed to encompass Sub-Saharan Africa, where groundwater resources are typically underutilized (Cobbing, 2020). This crisis adds to a discourse of shortage, disregarding the potential role of groundwater in irrigation, water security, and economic growth. In southern Africa, groundwater development is hindered by a lack of essential services such as energy, survey, drilling and pumping equipment, infrastructure, physical access, finance, credit, and institutional support (Cobbing, 2020). Global groundwater abstraction has tripled since the 1940s, reaching over 1,000 km3/year (Margat and van der Gun, 2013; Fienen and Arshad, 2016).

### 2.3 Groundwater Contamination

Due to geochemical processes occurring in the subsurface, an area's rock type or geology has a substantial impact on the quality of groundwater. Greggio et al. (2020), discovered geochemical processes occurring in the low-lying coastal aquifer of Ravenna, Italy, including organic matter degradation in salinized and anoxic conditions, sediment-water interactions, adsorption, redox reactions, ion exchange, precipitation, and mineral dissolution. Geochemical processes play a huge role in deteriorating our groundwater resources. However, such geochemical processes must be identified for potable and safe water consumption. Granitic rocks are mostly associated with high fluoride concentrations in groundwater (Fayazi, 1994; Onipe, 2018). Brinda and Elango (2011) found that fluoride contamination in groundwater originates from natural sources, specifically host rock. A geochemical approach (the use of multiple tracers) was utilized to discover the sources of salinization in groundwater of Bou-Areg (Morocco) (Bahir et al., 2018; Elmeknassi et al., 2022). The hydro-chemical data obtained from the aquifer demonstrate that high salinity is primarily produced by the presence of dissolving processes of evaporative rocks and carbonates from Miocene substrata, as well as rock-water interaction (Bradai et al., 2022; Selman et al., 2022).

Many groundwater systems use adsorption to control arsenic levels. The concentration of arsenic in groundwater is a global problem, high levels of arsenic in groundwater have been



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reported to be a major health issue around the world (Sanjrani et al., 2019; Shahid et al., 2020; Shaji et al., 2021). Although groundwater is perceived to be safe, if the concentration of heavy metals such as arsenic (As) is high, it could pose a potential human health threat (Shaji et al., 2021; Shahid et al. 2018; Yanez et al. 2018). A great increase has been revealed in the worldwide situation of arsenic contamination in groundwaters. Almost 108 countries across the globe are affected by arsenic contamination in groundwater with concentrations exceeding the acceptable limit of 10 ppb recommended by the World Health Organization (WHO) (Shaji et al., 2021). Hence, the highest among these are from the following regions Asia, Europe, Africa, North America and South America, and Australia. A study by Shaji et al., (2021), has revealed that more than 230 million people across the globe are at risk of arsenic poisoning. However, countries in Southeast Asia like Burma, Thailand, India, Cambodia, Pakistan, Nepal, Bangladesh, Vietnam, and China, are the most affected by arsenic (As) contamination in groundwater resources (Shahid et al., 2020).

Groundwater contamination can occur through geological formations, as evidenced by high levels of microbiological microorganisms and excessive concentrations of calcium, magnesium, phosphate, and nitrates at some schools in Vhuronga, Limpopo Province, South Africa (Odiyo et al., 2020). A study by Mepaiyeda et al. (2020), in Eastern Cape, has indicated that heavy metal concentrations in water samples are above the general permissible limits. However, the likely source of these heavy metals is toxic and hazardous waste put on the landfill in violation of the landfill design and classification; thus, adequate trash categorisation and inspection of waste thrown at the landfill are required. The geophysical investigation indicates pollution by leachate to a depth of about 10 meters across three profiles and a depth to the bedrock of around 20 meters. The existence of structural features such as cracks in the Hardrock may significantly disposed to the percolation of contaminants into the groundwater underneath overtime (Mepaiyeda et al., 2020).

### 2.4 Groundwater Geochemistry

In Southeast Asia, arsenic contamination has been a threat to groundwater resources. It was found naturally in groundwater sources in parts of Cambodia, Vietnam, and Lao People's Democratic Republic, except for Thailand which was mainly due to tin mining activities (Shahid et al., 2020). It has been reported that over 19 million people are at arsenic poisoning threat particularly in groundwater in rural areas (Sanjrani et al., 2019). Mostafa et al. (2017) discovered that all groundwater samples from Rajshahi City, Bangladesh, had bicarbonate and



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calcium contents that above WHO standards, and the water was extremely hard. Furthermore, the quantities of calcium, manganese, iron, lead, and arsenic were found to be higher than the permitted level in the majority of groundwater samples. The study also found significant amounts of metals in groundwater, including iron (Fe), manganese (Mn), lead (Pb), and arsenic (As), which pose a threat to human health. Therefore, the groundwater of Rajshahi City in Bangladesh is not suitable for human consumption, unless treated. The interaction of Rock and water was the primary geochemical process influencing groundwater chemistry in Rajshahi City, Bangladesh (Mostafa et al., 2017).

Groundwater in the Limpopo, Free State, Western Cape, KwaZulu-Natal, Northwest, and Northern Cape provinces of South Africa has been shown to contain high levels of fluoride (Onipe et al., 2021). Nzhelele, Ga-Ramaswikana, Matoks, and Waterberg Villages in Limpopo Province have significant fluoride concentrations in their groundwater (Odiyo and Makungo, 2012; Onipe et al., 2021; Sethokga, 2021; Abiye et al., 2018).

In South Africa, groundwater in Karoo aquifers, Namaqualand, and some parts of Johannesburg West contains high content of arsenic like 500 µg/l (Abiye and Bhattacharya, 2019). The hydrochemistry of Giyani groundwater is primarily controlled by water-rock interaction, carbonates, and silicate minerals. The arsenic (As) concentration was found to be 10 µg/L exceeding the acceptable limit of WHO for drinking water (Mudzielwana et al., 2020). The hydrogeochemical properties of groundwater in Greater Giyani Municipality and their link to arsenic levels were successfully assessed. A study by Mudzielwana et al. (2020), in Greater Giyani Municipality, Limpopo, the pH of groundwater was found to range from neutral to weakly alkaline. The primary anions and cations were discovered to be in the following order: $HCO_{3-} > Cl^{-} > SO_4^{2-} > NO_{3-}$ and $Na^{+} > Mg^{2+} > Ca^{2+} > K^{+} > Si^{4+}$, respectively. The study discovered that water-rock interaction mostly controls the hydrochemistry of groundwater in Giyani, with carbonates and silicate minerals serving as ion sources. The arsenic levels exceeded the WHO's recommended limit of 10 µg/L in drinking water.

According to a case study conducted in Namwon, Korea, water chemistry is primarily measured by the combination of three processes: the input of Cl/SO4 salts; the weathering of minerals such as silicates, carbonates, and lime; and the generation of nitrates via aerobic breakdown of organic matter and nitrification. However, according to reaction stoichiometry mass balance study, mineral weathering was discovered to be the primary factor influencing groundwater chemistry (Vinnarasi et al., 2020). Several studies on hydro-geochemical



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processes impacting groundwater have been conducted to assess and understand various aquifers and improve water resource management (Tarawneh et al., 2020; Abiye et al., 2018; Durowoju et al., 2019; Malaza, 2017).

Groundwater from dewatering boreholes in the Triassic and Pliocene strata is made up of a variety of water bodies with different chemical compositions. It was recently recharged and transformed, mostly by interaction with carbonate minerals (Kanduc et al., 2019). Kanduc et al. (2019) confirm that the Pliocene aquifer's groundwater has existed for many years, impacted by silicate mineral dissolution and inhibited by redox reactions such as microbial methanogenesis and bacterial sulfate reduction.

Geochemical processes occur naturally underground, and they interact with groundwater. The aquifer's rock type, mineral dissolution, surface and groundwater interaction, and geological processes all have an impact on groundwater contamination (Patil, 2020; Akinbile and Yusoff, 2011). Pearson correlations, bivariate plots, saturation indexes, and Gibbs diagrams suggested that rock dominance processes, such as carbonate and halite mineral dissolution, ion exchange, and silicate weathering, were the key hydrogeochemical processes influencing groundwater quality in Limpopo Province's Soutpansberg region (Lalumbe and Kanyerere, 2022).

## 2.5 Water Quality Parameters

### 2.5.1 Physical Parameters of Water

- **The pH**

  The pH is the degree of how acidic or basic the water is. It ranges from 0 to 14, with 7 being neutral. If the pH of water is less than 7, thus an indication of acidity, while a pH of greater than 7 indicates a base (Natalie Butler, 2018; USGS, 2019). Measurement of the pH of water is significant; thus, it will reveal if the water is basic, acidic, or neutral. The pH of groundwater in most cases arose from chemicals, minerals composition, and the geologic formation of an area. The suitable pH range for drinking water should be from 6.5 to 8.5 (WHO guidelines).

- **Temperature**

  Water temperature is crucial since it influences water chemistry. At higher temperatures, the rate of chemical reactions increases. In most cases, groundwater with high temperatures can dissolve more minerals from the rock underground and will then have a higher electrical conductivity (USGS, 2018). The oxygen solubility decreases when the



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temperature of water is high and this may result in the presence of some toxic chemicals (Mammarella, et al., 2018).

- **Turbidity**

Turbidity is a measure of the relative clarity of water or light scattering ability of water (USGS, 2018). Therefore, it is caused by particles suspended or dissolved in water that scatter light making the water appear murky or cloudy. The aesthetic quality of water could be reduced extensively due to the high concentration of turbidity in water. The turbidity of water is also correlated to a measure of the transparency or clearness of water and TDS or TSS (DWAF, 1996). Turbidity is measured in nephelometric turbidity units (NTU), turbidity of above 5 NTU could have an aesthetic effect on persons consuming the water (DWAF, 1996).

- **Electrical Conductivity (EC)**

The Electrical conductivity is a measure of the ability of water to conduct an electrical current. This ability is due to the presence of ions in water like bicarbonate, carbonate, nitrate, sodium, magnesium, potassium, calcium, chloride, and sulphate that carry an electrical charge (DWAF, 1996).

- **Total Dissolved Solids (TDS)**

The TDS is a measure of the quantity of various inorganic salts dissolved in water. The concentration of total dissolved solids is directly proportional to the electrical conductivity of water. Total dissolved solids consist of inorganic salts, calcium, sulphates potassium, sodium, bicarbonates, chlorides, magnesium, and some small amounts of organic matter that are dissolved in water. Water with high TDS often has a bad taste and could result in a laxative effect. The TDS concentration should not exceed the limit of 1200 mg/l. Therefore, if such water is used for drinking for a long period may lead to some health effects (DWAF, 1996).

## 2.6 Major Anions and Cations

- **Bicarbonate ($HCO_3$-)**

This is a mixture of water and carbon dioxide from carbonate rocks like dolomite and limestone, and it produces a basic environment. The acceptable limit of Bicarbonate is 600



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mg/l (WHO guidelines). Since sodium and bicarbonate ions are present in most water types (primarily in the granite gneiss formation), they have the potential to raise fluoride concentration in groundwater by dissolving fluoride from fluoride-bearing minerals (Raju, 2017).

- **Chloride ($Cl^-$)**

Chloride ion occurs naturally and is common in most natural waters and therefore, most often found as a component of salt (sodium chloride) or in some cases in combination with potassium or calcium. Chloride has become a concern in national water supplies due to increased concentrations imparting a salty taste to water and accelerating the corrosion rate of metals (DWAF, 1996).

- **Sulphate ($SO_4^{2-}$)**

Sulphate is a common basic of water and results from the dissolution of mineral sulphates in rock and soil, mostly calcium sulphate minerals and other moderately soluble sulphate minerals (DWAF, 1996). Sulphate with high concentration in drinking water led to acute health effects like diarrhea in human. However, these become temporal and reversible since sulphate is usually released in the urine. The sulphate limit in drinking water should be less than 200 mg/l, more than this will result in water tasting salty or bitter and might as well cause diarrhea to some individuals (DWAF, 1996). According to WHO, (2006), the permissible limit for sulphate is 400 mg/l.

- **Fluoride ($F^-$)**

Fluoride is a relatively stable anion that is difficult to remove from water to the required acceptable concentration range. Although calcium fluoride is relatively insoluble, its solubility is an order of magnitude higher than the levels which need to be achieved by treatment. Fluoride is crucial in drinking water only at suitable limit. It protects tooth decay and the harmful bacteria inside the mouth (DWAF, 1996). The concentration of fluoride exceeding 1.5 mg/l in drinking will probably lead to dental fluorosis (mottling of teeth), whereas the concentration in long-term drinking water is greater than 3.5 mg/l, the water is not safe for consumption as it may lead to skeletal fluorosis (DWAF, 1996; WHO, 2006). In most of Sub-Saharan Africa, especially Eastern countries like Sudan and South Africa high fluoride levels in groundwater sources have been reported intensively (Onipe et al., 2020). Hence, fluoride has been reported to be a common pollutant in groundwater.



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- **Nitrate ($NO_3^-$)**

Nitrate can act as an indicator of pollution resulting from the usage of fertilizers in the field and sewage disposal. In some environments, nitrates occur naturally with high levels and the concentration can further increase due to runoff from agricultural fields (WHO, 2011). The nitrate in our drinking water sources surface and groundwater across the world has increased intensively due to agricultural practices (use of organic manures and inorganic fertilizers) (Ward, et al., 2018). In drinking water, nitrate levels exceeding 11 mg/l may pose a health impact on people dri nking that water for a long period and in infants may cause blue baby syndrome (DWAF, 1996; SANS, 2015). Long-term drinking water with high nitrate content may enhance the risk of an individual getting colorectal cancer (Schullehner, et al., 2018). 2.7 million People were estimated to be exposed to nitrate due to drinking water quality between 1978 and 2011 years nationwide (Schullehner, et al., 2018).

- **Calcium ($Ca^{2+}$)**

Calcium is naturally present in water resources, which could be due to the geological formation of an area. The presence of Calcium and magnesium in a specified quantity in water is responsible for the hardness of the water (DWAF, 1996). According to DWAF (1996) standards, <32 mg/l is the permitted level of calcium in drinking water, larger than that may constitute a concern to water quality. In Sri Lanka, 41% of groundwaters were found to be hard, with calcium carbonate levels exceeding DWAF guidelines (Udeshani et al., 2020). Low calcium levels in drinking water are critical for bone strength (DWAF, 1996).

- **Magnesium ($Mg^{2+}$)**

Magnesium is a basic geological metal that interacts with oxygen and water to form magnesium oxide and magnesium hydroxide. Magnesium is a common constituent of water and occurs as a double positive charged magnesium ion (DWAF, 1996). High concentrations of magnesium in water may result in health and aesthetic effect. A concentration of greater than 70 mg/l in drinking water will not be allowed for consumption due to potential aesthetic and health impacts (DWAF, 1996).

- **Sodium ($Na^+$)**

$Na^+$ is a base metal that reacts with water to form highly soluble, positively charged $Na^+$. $Na^+$ is abundant in the environment and usually occurs as sodium chloride, but sometimes



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as bicarbonate, sodium sulphate, or even nitrate. $Na^+$ is found as a rock salt (solid sodium chloride) in areas where geological deposits occur (DWAF, 1996). In our drinking water sources, sodium occurs naturally and is vital if not exceeding the limit of WHO and DWAF guidelines. In South-eastern New York Township, due to road salt contamination, the sodium and chloride concentrations of groundwater were found to be high, which resulted in salty groundwater (Kelly et al., 2018).

- **Potassium ($K^+$)**

Potassium is a base metal that reacts cruelly with water to form positively charged ions. Potassium in association with anions always occurs in water, especially chloride, but can also occur with sulphate, nitrate, or bicarbonate (DWAF, 1996). If potassium ($K^+$) levels in water exceed 50 mg/l, it has an aesthetic and health effect, lends a bitter taste to water, and ingestion may induce nausea and vomiting (DWAF, 1998; 1996).

- **Arsenic (As)**

Arsenic is the most common cause of severe heavy metal poisoning in adults. The consumption of water with high arsenic content can cause hyperkeratosis, cancer, malignant melanoma, peripheral nervous system problems, and cardiovascular diseases (Saleh et al., 2018). The World Health Organization recommended the acceptable limit for arsenic in drinking water to be less than 10 µg/l (Radfard et al., 2017; Varol and Subul, 2018). Studies across the globe have revealed that potentially toxic element like arsenic is found naturally in groundwater resources (Bundschuh et al., 2017; Nwankwo et al., 2020). China is one of the most affected countries facing health issues because of arsenic contamination in groundwater that is often greater than established limits for human health. Although arsenic is present in several geographical regions in mainland China, Northern China has been identified as a high-risk area (Sanjarani et al., 2019).

- **Chromium (Cr)**

Chromium is a potentially toxic metal (PTM) occurring in water and groundwater due to natural and anthropogenic sources (Tumolo et al., 2020). This metal is very harmful to human health, and it can be harmful to the kidneys and lungs. The permissible limit for chromium in drinking water should not exceed 10 µg/L (Saleh et al., 2018; Mishra et al. 2018; Ke et al., 2017). Metals like lead, nickel, arsenic, mercury, cadmium, zinc, chromium, selenium, and cobalt are exceedingly unsafe even in little amounts (Ahmad et al., 2020; Zheng et al., 2020; Anastopoulos et al., 2019). These are also known as potential



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toxic elements (PTEs), which are dangerous and exist naturally in water resources via geochemical processes (Singh et al., 2022).

- **Copper (Cu)**

Copper is toxic at a higher concentration and can cause severe health problems such as diarrhea, vomiting, cirrhosis of the liver, and weakness feeling (Saleh et al., 2018).

- **Iron (Fe)**

This is another concern of heavy metals, mainly because consumption of water with high levels of Fe, may pose a serious threat to young children. Fe may cause a metallic taste in drinking water, and exposure to high levels of Iron (Fe) applies to adverse effects on the liver, kidney, and cardiovascular system (Saleh et al., 2018).

**Hydrochemistry of groundwater**

Groundwater hydrochemistry is the study of the natural chemistry of subterranean water with an emphasis on how it interacts with its environment and is impacted by both natural and man-made processes. This area of study looks at the chemical makeup of groundwater, including the levels of different dissolved compounds and the mechanisms affecting these levels. To evaluate the quality of groundwater, forecast its suitability for use, and control any pollution, an understanding of hydrochemistry is essential (Piper, 1944; Al Farraj et al, 2012). A hydrogeological technique for depicting the dominating principal ions governing the chemistry of an area's surface and groundwater is the Piper trilinear diagram. The water's evolution and the connection between rock types and water composition are assessed by the Piper trilinear diagram as shown in (Figure 2.1) (Piper, 1944; Ravikumar et al., 2015). Although the Durov diagram and piper plot are comparable, the former is superior since it can indicate certain geochemical processes that may have an impact on groundwater genesis (Ravikumar et al., 2015). Cations and anions in relation to TDS and pH are depicted in this plot.



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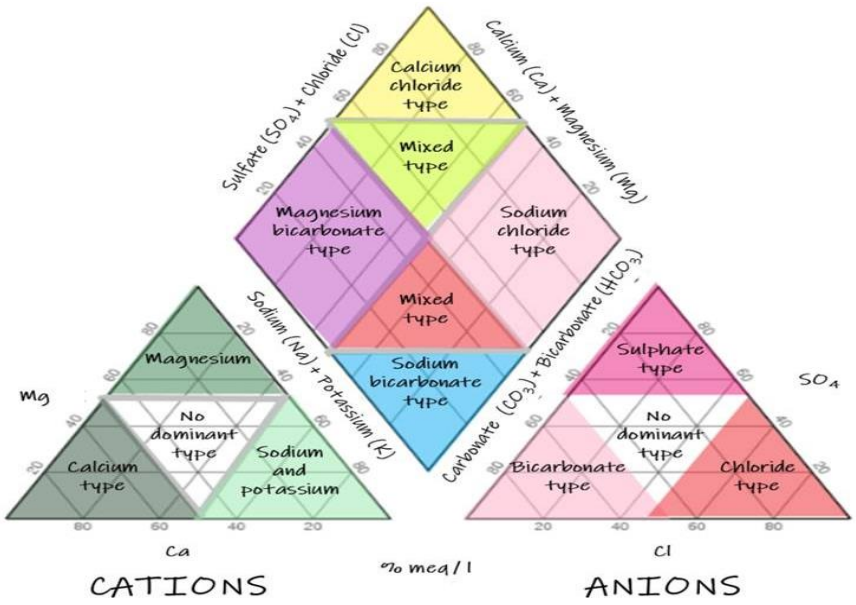



**Figure 2.1**: Piper diagram showing water type (Piper, 1944).

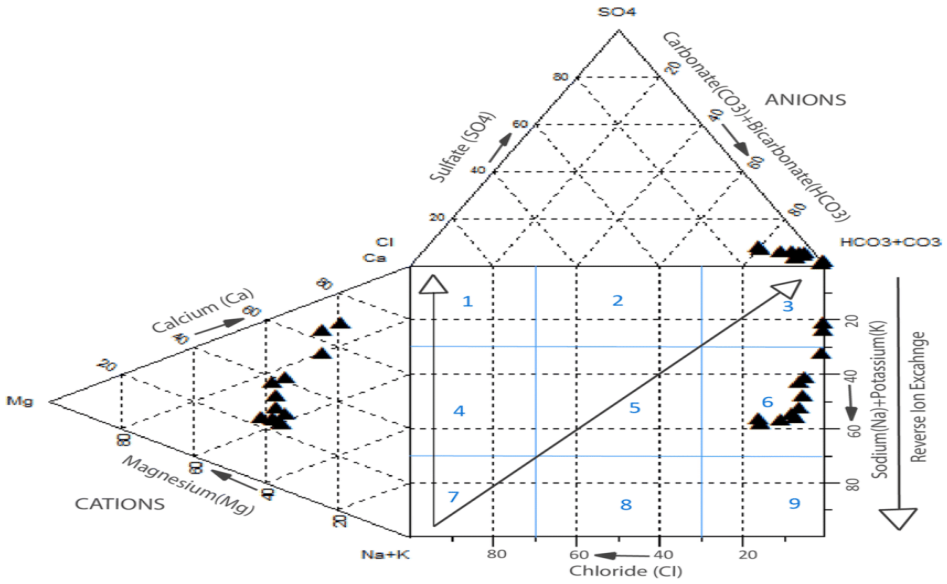



**Figure 2.2:** Durov diagram (Ravikumar et al., 2015).

## 2.7 Fluoride abundance in rock-forming minerals

Fluoride-rich aquifers arise primarily in geologic environments where fluoride-rich minerals are prevalent, such as volcanic rocks, granitic rocks, and sedimentary rocks (Onipe et al., 2020; Jayawardana et al., 2012). Fluoride content is released into groundwater in these environments due to mineral weathering, which occurs when water combines with minerals in soils and rocks. Acidic water can also drain fluoride from minerals containing fluoride. Fluorite ($CaF_2$), which is usually linked with granitic rocks, is the most common fluoride-rich mineral discovered in



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aquifers. Fluorite can dissolve in water, releasing fluoride ions that are then absorbed by groundwater. A study by Raju (2017), in the Eastern India, has revealed that high weathering of fluoride-bearing minerals (i.e., biotite and apatite) in granite gneiss contains abundant fluoride, alkaline hydrogeological environment, low rainfall, high temperature, evapotranspiration, and ion exchange primarily govern fluoride concentration in groundwater.

The geogenic sources that consist of the following minerals fluorite, cryolite, muscovite, fluorspar, topaz, apatite, biotite, and amphibole are likely to be the cause of fluoride in groundwater resources (Onipe et al., 2020; Brandl, 2007). Areas that are associated with a geological formation like igneous and sedimentary rocks are also associated with fluoride concentrations in groundwater (Onipe et al., 2020; Abiye et al., 2018). The concentration of fluoride in groundwater increases because of geochemical processes such as dissolution of fluoride-containing minerals like fluorite in water, rock-water interaction, and other processes. Ga-Ramaswikana village is one of the areas that is formed within the igneous and sedimentary rocks consisting of fluoride and salt content in the aquifers. The salinity in most groundwater resources is due to high sodium and chloride ion concentrations in groundwater (USGS, 2019). However, this is because of weathering of rocks and minerals that contains salt content (sodium and chloride minerals). Extreme total dissolved solids (TDS) indicate that groundwater moves quicker in the deep zone, ideally through fractures, whereas groundwater flow is slower in the shallow zone than in the deep (Annadasankar et al., 2020).

**Table 2.1:** Fluoride concentration classification and its risks. Revised after Keshavarz et al., (2015), Onipe et al., (2021), and Durowoju et al. (2015).

| **Fluoride concentration (mg/L)** | **Health risk** |
|---|---|
| < 0.5 mg/L | Dental cavity |
| 0.5 – 1.5 mg/L | Promotes dental health |
| 1.5 – 4 mg/L | Dental fluorosis |
| 4 – 10 mg/L | Dental, Hip fracture, and Skeletal fluorosis |
| > 10 mg/L | Crippling fluorosis |
| > 200 mg/L | Death risk |



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## 2.8 Geology of the Alldays Gneiss Suite

The geology of Simson area in Limpopo is associated with Alldays gneiss suite, shown in (Figure 1.3) of the geological map of the study area. The Alldays gneiss is a medium to coarse-grained rock that can be leucocratic, light to dark grey, or pinkish grey, with a gneissose structure characterized by ferromagnesium mineral orientation. The granulite facies metamorphism of the gneiss protolith resulted in the formation of mostly stromatic migmatite with varied proportions of leucotomy and melanosome (Brandl, 2002; Orpen et al. 1982). Alldays gneiss refers to all grey, biotite-bearing gneiss (Brandl, 1990). The sand river gneiss, which creates a prominent closed fracture near the map's eastern margin, is the sole exception. As a result, some Alldays Gneiss was previously known as Mogalakwena Gneiss (Pienaar, 1985). The mineralogy of Alldays gneiss includes plagioclase, K-feldspar, biotite, quartz, hornblende, and opaque phase, as well as locally occurring cummingtonite, garnet, and pyroxene (Brandl, 2007; Van Reenen and Van Wyk, 1982). The Alldays gneiss is also made up of minerals that are resistant to weathering, dissolution, and erosion such as feldspar, quartz, mica, and hornblende. The stripy appearance of the rock is due to the deformation and recrystallization processes that occurred during its creation (Jaekel et al., 1997). The Alldays Gneiss suite's geology has a major effect on the quality and availability of groundwater or aquifers in the area. Water cannot easily pass through the rock since it is highly impervious (Van Reenen and Van Wyk, 1982; Brandl, 2007; Brandl, 1993; Orpen et al. 1982). However, cracks or joints in the rock allow water to flow through and form underground aquifers.

The mineral composition of the Alldays Gneiss influences groundwater quality because groundwater can dissolve minerals in the rock as it flows through. For example, the presence of minerals like feldspar and quartz can make groundwater alkaline, but the presence of minerals like hornblende can make it acidic. Furthermore, the permeability of the rock can influence the pace at which groundwater recharge as well as the amount of water that can be stored in subsurface aquifers. In general, the Alldays gneiss suite's geological properties have a significant impact on the quality and amount of groundwater or aquifers in the area (Brandl, 1993; Brandl, 2002; Brandl, 2007; Van Reenen and Van Wyk, 1982). Understanding the geology of the area is critical for the proper management and protection of these natural resources for future generations. The figure 2.1 below is the part of Alldays gneiss formation showing various sets of granitoid veins (Brandl, 2002).



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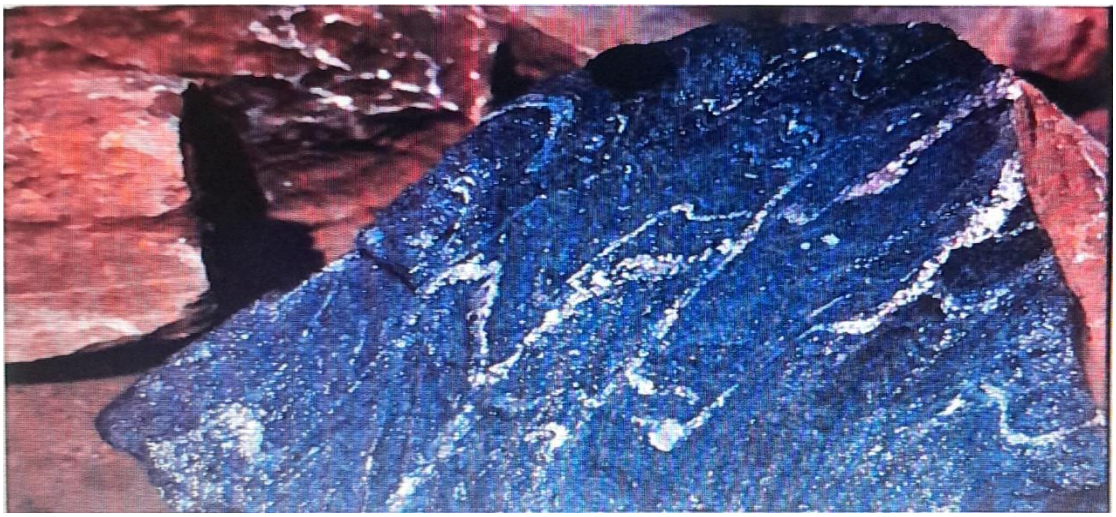


**Figure 2.3:** Alldays gneiss showing various sets of granitoid veins (Brandl, 2002)

## 2.9 Health effects linked with contaminated groundwater

Chronic exposure to geochemically contaminated groundwater has resulted in major health issues to billions of people globally (Wang et al., 2020). Cases of dental fluorosis and diarrheal diseases due to high fluoride and coliform levels in drinking water for residents of these villages in Limpopo Province mostly dependent on untreated drinking water from rivers, springs, boreholes, and rainwater (Odiyo and Makungo, 2018). Skeletal and dental fluorosis (mottling of teeth) is because of drinking water with high fluoride levels (WHO, 2011). Globally, various studies indicated that health risks such as dental and skeletal fluorosis are associated with the consumption of water with high fluoride content, moreover, this usually occurs in rural areas where groundwater acts as a primary source of drinking (Odiyo and Makungo, 2018; Malago et al., 2017; Durowoju et al., 2015). According to the assessment of hydro-geochemical properties, carbonate, dissolution, silicate weathering, and reverse ion exchange influence the hydrochemistry of groundwater. Various research conducted across the world have identified potential harmful elements such as arsenic, vanadium, molybdenum, copper, zinc, nickel, and cadmium that are naturally present in groundwater resources and are responsible for groundwater contamination (Bundschuh et al., 2017; Mitchell et al., 2011; Nwankwo et al., 2020).

Particularly, excess or lack of some crucial elements in drinking water, like fluoride ($F^-$), selenium (Se), and iodine (I) can lead to serious health issues such as dental or skeletal fluorosis and thyroid enlargement or a goiter (Gevera et al., 2019). The release of arsenic (As) through the geochemical process is the most significant factor in alluvial aquifers causing arsenic



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contamination than sources of arsenic (As) (Raju, 2022). Arsenic is a pollutant that dissolves in the bloodstream, which may result in diseases like cancer of the liver, skin disease, bone and kidney diseases, the intestines, and gall bladder (Raju, 2022).

Consuming magnesium-rich water may cause diarrhea in humans (Sengupta, 2013). Magnesium deficiency in human anatomy may raise the risk of hypertension, atherosclerosis, vasoconstriction, cardiac arrhythmia, acute myocardial infarction, eclampsia in pregnant women, vascular disease, type 2 diabetes, and osteoporosis (Rishi et al., 2019). Consuming water with $Na^+$ ion levels below WHO guidelines is essential for human health, but exceeding 200 mg/l can lead to health issues such as congenital diseases, hypertension, nervous problems, and kidney disease (WHO 2011; Rao et al. 2012; Rishi et al. 2019).

The high salt content in drinking water contributes to hypertension and disease related to people consuming the water, particularly pregnant women (Rosinger and Young, 2020; Shammi et al., 2019). In children, consumption of water with high salinity may result in cognitive performance amongst children, hence it was found to be negatively associated with children's educational ability in coastal Bangladesh (Akter, 2019). Salt content exceeding the guideline limits for drinking water may lead to kidney problems directly through excessive pressure, for example, the high workload for the sodium and other cellular pumps in the nephron, or indirectly through its hypertensive effects (Qian, 2018; Kitada et al., 2017).

Limpopo Province, South Africa, uses groundwater as one of its drinking water sources. A study by Mutileni et al. (2023), examined the quality of groundwater in the Vybong region, analysing 17 boreholes. The data indicate that the water quality is suitable for residential purposes, except for drinking. During the wet season, nearly 50% of the samples were contaminated with E. coli and Total coliform bacteria. Except for nitrate, the anion concentrations met the SANS and WHO requirements. Aluminium levels in boreholes were above permissible limits, posing a health concern to people. The trace metal levels measured met legal criteria but calculating the possible health risk based on lifetime intake of the water revealed both non-carcinogenic and carcinogenic risks, particularly for children (Mitileni et al., 2023).

In Vhuronga, Limpopo Province, South Africa, most of the water quality metrics were within the acceptable range for household usage. Some groundwater tests included calcium, magnesium, and nitrate levels were slightly above the standards. Microbial contamination of groundwater posed a significant hazard to schoolchildren's health (Odiyo et al., 2020).



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## 2.10 Geophysical studies of groundwater

The geophysical survey of groundwater is of great importance in the provision of potable, adequate water (Alab et al., 2020; Olateju et al., 2017; Hunan Puqi Water Environmental Institute). The various geophysical instruments of different depths are used in detecting groundwater recharge zones and to identify the site water can be found.

In South Africa, water scarcity has become a national phenomenon. It was reported by DWS that by 2030 South Africa will be water scarce. However, groundwater is the most reliable source of water (Rohde et al., 2017; DWAF, 2004). The geophysical survey of borehole drilling and estimation of the groundwater is very significant in most rural and urban communities, thus, easing the shortage of water, drying up of aquifers, and improving water supply (Mpofu et al., 2020; Muchingami et al., 2019). The EM method was used at Afe Babalola University to assess the correct location of boreholes for groundwater recharge zone purposes, and it was observed that some boreholes were wrongly located at the locations of low groundwater yield zone and recharge zone (Oyegoke et al., 2020). Various geophysical methods have been used for groundwater searching. Nevertheless, electrical resistivity (ER) is the most widely used method. It has been used in groundwater investigation and contaminant delineation in many countries (Khalil et al., 2013; Metwaly et al., 2014; Uhlemann et al., 2017). In some environments, especially granitic environments, the method has produced good borehole drilling results (Bon et al., 2022).

The Electromagnetic (E.M) method for groundwater investigation should get recognition and be used as an option in the geophysical exploration of groundwater because it simplifies the usage and requires little or no field experience for interpretation. Furthermore, the electromagnetic method can produce a 2D image of the subsurface at once (Oyegoke et al., 2020). Mokoena et al. (2020), investigated groundwater salinity with the use of geophysical (E.R) and geochemical methods. The readings of the electrical resistivity (ER) model discovered three resistivity zones. The first zone has low resistivity of 1 to 3Ω.m, which characterizes an aquifer filled with saline water. The second resistivity zone had values ranging from 3 to 30Ω.m, which denotes a saline-saturated formation. The third resistivity zone represents a sandy layer (sandstone) consisting of freshwater having high resistivity values exceeding 30Ω.m (Mokoena et al., 2020).

The Electrical Resistivity method (ER) is the most widely used method for studying the subsurface of the earth (Song et al., 2011; Chen et al., 2022). The Electrical Resistivity (ER)



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approach is predicated on the idea that the electrical resistivities of the subsurface materials and their spatial changes determine how electrical potential is distributed in the ground surrounding a current-carrying electrode (Alabi et al., 2016). This makes it possible to map the geological structures and characteristics below the surface. An electrical current is injected into the ground as part of the ER technique, which measures the voltage variations at the surface. Subsurface materials such as rocks, soils, and water have varying resistivities, which affect the voltage distribution around the current electrodes (Wightman et al., 2003; Environmental Geophysics, 2016). The distinctive resistivity of each material indicates how well it can withstand the flow of electrical current. Low resistivity materials, such as water or conductive soil, conduct current more readily than high resistivity materials, such as dry sand or rock, which provide greater resistance (Environmental Geophysics, 2016).

### 2.11 Electromagnetic Groundwater Detector PQWT

The Proton Quantity Wave Technology (PQWT) refers to a class of electromagnetic groundwater detectors used for exploring subsurface water. It produces a magnetic field that interacts with beneath water to alter electric currents, which the instrument can pick up on. The PQWT groundwater detector can also determine the depth and quantity of groundwater before drilling, therefore, this is more significant than other invasive methods of groundwater detection (Hunan Puqi Water Environmental Institute). The PQWT groundwater detector uses resistivity geophysical methods, which measure the electrical resistance of subsurface materials. Different geological formations have characteristic resistivity values depending on their composition, porosity, saturation, and fluid content (Isah et al., 2023).

The PQWT instrument is often used in the detection of potential sites for drilling groundwater, therefore, it can profile the subsurface with the use of electromagnetic radiation that enters the ground from the surface to the subsurface, depending on how deep the instrument can go. The electromagnetic PQWT groundwater detector was used in a study in Ede North, Southwestern Nigeria in the Olubunku dumpsite and vicinity; as a result, six out of eight PQWT profiles indicate a shallow level of groundwater at a depth of about 30m, which is vulnerable to contamination because the majority of the water in the study area is obtained from hand-dug wells that are less than 20m deep (Isah et al., 2023). The PQWT electromagnetic groundwater detector has demonstrated its effectiveness in determining the subsurface rock resistivity, classifying rocks primarily into sedimentary and igneous/metamorphic types, identifying structures (such as fractures), determining lateral extent and thickness, and determining rock



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distribution. Furthermore, it aids in the identification of aquifers and aquifer species. Identifying the aquifer and its types, groundwater depth, groundwater prospects zones, groundwater levels, and subsurface flow direction (Isah et al., 2023; Harinath Vukkisala, 2017).

**Electrical resistivity of PQWT**

The PQWT groundwater detector's resistivity values can vary based on the geological characteristics of the area being measured. Higher resistivity readings, on the other hand, are often associated with reduced water content or the lack of groundwater (Song et al., 2011; Chen et al., 2022; Hunan Puqi Water Environmental Institute). While exact numbers vary, resistivity readings in the thousands of ohmmeters (m) or greater are frequently indicative of drier or less water-bearing strata. These higher resistivity results imply that the subsurface material has lower conductivity, resulting in less water content.

Geophysical techniques have become effective tools to identify and distinguish contamination both laterally and vertically. The method of electromagnetic survey was used to investigate the groundwater within the University of Afe Babalola University in Ado-Ekiti, Nigeria. The efficient and abandoned boreholes were randomly selected, and it was found that some boreholes were wrongly sited on a low groundwater-yielding zone, whereas some were correctly sited on vertical cracks and weathered formations (Oyegoke et al., 2020).

## 2.12 Overview of groundwater defluoridation technologies

There are a variety of documented techniques for removing fluoride from water. These can be divided into three groups: those based on the addition of chemicals to cause precipitation during coagulation (Turner et al., 2005; Mekonen, 2001; Beneberu, 2006); those based on ion exchange and adsorption (Jamode et al., 2004; Agarwal et al., 2003; Coetzee et al., 2003); and those based on membrane separation technologies (Menkouchi et al., 2007; Schoeman and Steyn, 2000; Sordo et al., 1998; Tahaikt et al., 2006). Defluoridation methods include contact precipitation, bone charcoal, Algona, activated alumina, clay, nanofiltration, membrane filtration, and ion exchange technology. Reverse osmosis, electrodialysis, and distillation are advanced treatment technologies.

A borehole water supply in a rural region (Madibeng Local Municipality, Northwest Province, South Africa) has a fluoride concentration of 5 to 6 mg/l (Schoeman, 2009). Due to high fluoride concentration, this water is not acceptable for drinking, because it may induce mottling of dental enamel in youngsters and fluorosis in adults. As a result, the fluoride content should



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be lowered to less than 1.5 mg/l to make the water consumable. Both the activated alumina and reverse osmosis techniques can be used quite efficiently for water defluoridation. The activated alumina technique, on the other hand, is seen to be a simpler and more robust method of water defluoridation, particularly in rural areas. As a result, the activated alumina technique was chosen for water defluoridation. The activated alumina plant was planned, built, and commissioned. Fluoride levels in feed water were reduced from 6 to 8 mg/l to less than 1.5 mg/l. The plant output ranged between 940 and 1 296 $m^3$, with a fluoride breakthrough of about 2.0 mg/l. It was proved that first-world technology may be efficiently deployed in a rural region with sufficient operator training and supervision (Schoeman, 2009).

## 2.13 Summary of Literature Review

In the literature review, the combination approach of geophysical survey and physicochemical investigation of groundwater resources has been reviewed, it has contributed to a better understanding of groundwater, geologic formation, its quality, and health risks associated with the groundwater.

### Groundwater quality evaluation

The research shows that groundwater serves as a crucial source of drinking water, mostly in rural areas of South Africa, where surface water may be scarce (DWAF, 2004). Various studies on assessment of groundwater quality were reviewed. Water quality parameters like physicochemical (Temperature, pH, EC, TDS, Turbidity), and concentrations of major Ions and trace elements were reviewed.

### Factors affecting groundwater quality

Numerous studies have identified anthropogenic and natural factors that influence groundwater quality in rural settings. Geological formations of aquifer, industrial discharges, agricultural runoff, and poor sanitation contribute significantly to groundwater contamination. In Ga-Ramaswikana, the local geology, and climate inconsistency are key factors that impact both the quality and availability of groundwater resources (Council of Geoscience; SAWS).

### Health implications

The health effects of inadequate groundwater quality are well-documented. Publics depending on borehole water for drinking, contaminants such as fluoride, nitrates, and heavy metals pose



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a serious threat to human health. Various research highlights the need for regular monitoring and management strategies to mitigate risks associated with groundwater contamination (Wang et al., 2020; DWAF, 1995). The groundwater is perceived to be potable. However, it is crucial to monitor the groundwater quality for safe drinking water (Ajiboye, and Okafor, 2019).

### Geo-profile studies

Geo-profile studies provide understanding of the geological composition and hydrological features of aquifers. Understanding the geological background of boreholes in Ga-Ramaswikana is vital for assessing groundwater availability and quality. Studies have discovered the relationship between geological formations and groundwater characteristics, confirming that local geology impacts aquifer recharge and contaminant mobility significantly (Isah et al., 2023; Harinath Vukkisala, 2017). Various studies have revealed the importance of geophysical survey before borehole drilling to obtain good water zone (Alab et al., 2020; Olateju et al., 2017; Oyegoke et al., 2020; Mokoena et al., 2020; Isiah et al., 2023; Hunan Puqi Water Environmental Institute).

### Conclusion

The existing literature highlights the importance of integrated evaluation of groundwater quality and its geological profile. By investigative the specific context of Ga-Ramaswikana Village, this thesis aims to contribute valuable insights into local groundwater issues, informing sustainable management practices and public health interventions.

## CHAPTER 3: METHODOLOGY

### 3.1 Preamble



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This section presents the methods used to collect and analyse data in the investigation of groundwater quality, and geophysical survey of boreholes in Ga-Ramaswikana Village. This section highlights the overview of the methods that were used to achieve the objectives in the study.

## 3.2 Data and Sample Collections

### 3.2.1 Water Sampling

**Sample preparation**

Sample preparation is a crucial factor for quality assurance and control. The equipment used for sample collections were sterilized with distilled before sample collection, to improve the quality control and assurance (WHO, 1985; USGS, 2009).

Water samples were collected in 300ml sterilized bottles. As suggested by Sethokga, (2021), the samples were collected from six selected boreholes within Ga-Ramaswikana village for a period of all four seasons, once a season (autumn, winter, spring, and summer). The groundwater sources were selected based on the outcomes of the previous study (Sethokga, 2021). Six borehole sites were selected, three having low fluoride and the other three with high fluoride concentration. Hence, these sites were also surveyed with PQWTS500, for geo-profiling. Understanding the spatial distribution, causes, and governing variables of fluoride contamination in groundwater is the foundation for the decision to choose three boreholes with low fluoride concentrations and three with high fluoride concentrations for water sampling and geophysical surveying. The groundwater potential recharge zones will also be assessed on these 6 sites. Therefore, this will give a clear subsurface image or profile for a better interpretation and understanding of where boreholes of adequate water should be drilled within the area.



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**Figure 3.1:** Community borehole 1 storage tank

### 3.2.2 Water sampling procedure

The equipment used for sample collections were sterilized before sample collection, to avoid unnecessary pollutants which might lead to inaccurate results of water quality to the sampler (WHO, 1985; USGS, 2009). 500 ml sterilized bottles were used to collect water samples from each of the selected borehole sites. The samples were collected from 6 boreholes, in summer, autumn, winter, and spring. Therefore, the geochemical properties like temperature, pH, TDS, EC, and Turbidity and geophysical identification of groundwater recharge zones were measured in the field with multi-meter and geophysical instruments (PQWT-TC500) respectively. Other parameters like heavy metals and major anions and cations were assessed at the University of Venda Laboratory. These water parameters were measured in duplicate for quality control. The samples were kept in a cooler box with ice during transit from the field to the University of Venda Laboratory to prevent results from being altered and to increase quality control and assurance.



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### 3.2.3 Geophysical Survey

The electromagnetic groundwater detector (PQWTS500) was used to geo-profile the boreholes in the study. The instrument uses two copper rods and a 50 m tape measure. To calibrate the instrument, both magnetic electrodes were inserted into the soil, connected one-to-one with copper electrodes, the “Line Test " button was pressed in the equipment for 2-3 seconds, and the instrument indicator light turned green. A 10-meter tape was used, starting point was marked at 0 metres. The M N two electrode bar equidistance was 10 metres; after finishing measure point 1, both M N were moved to 1 metre. The M N Electrode equidistance wiring is shown below in Figure 3.2. Figure 3.3 shows the geophysical survey at the public borehole.

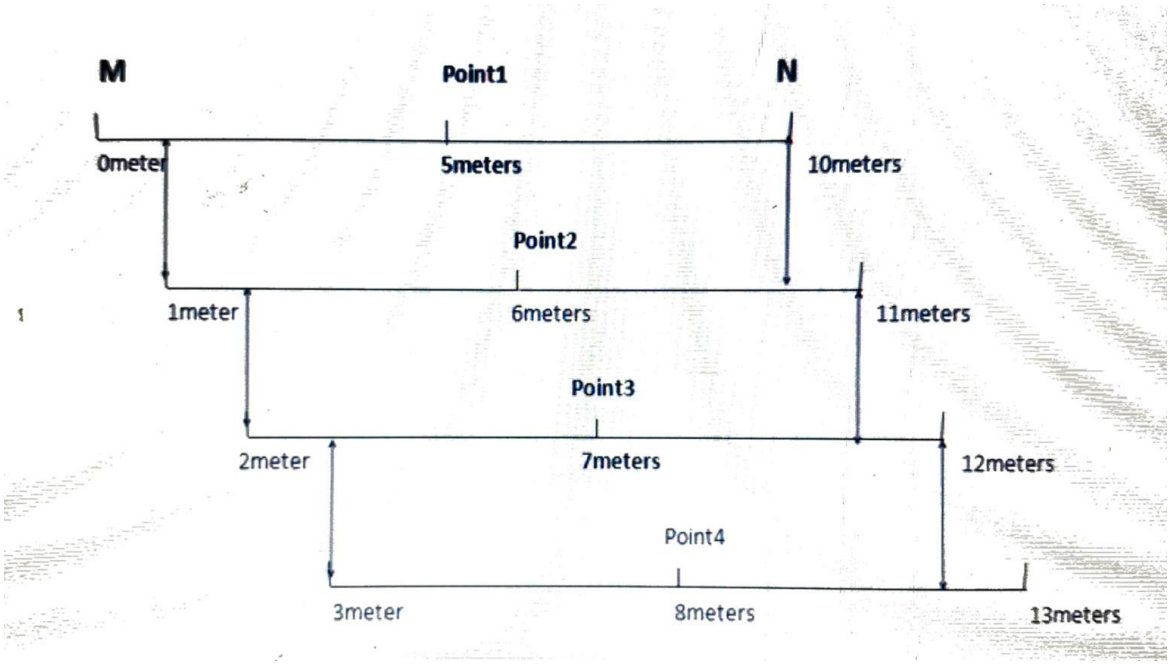



**Figure 3.2:** M N equidistance for geophysical survey.



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**Figure 3.3:** Geophysical survey at public borehole 2

## 3.3 Experimental Analysis

### 3.3.1 Digestion of Water Samples

The water samples were filtered before digestion process. This was done using Simple-Pure water filters with pore size of 0.45 µm. The 45 ml of water sample was mixed with 5ml of nitric acid in a vessel. Therefore, the solution in vessels were placed in a microwave digester for digestion. (Figure 3.4) The digestion process took 1 hour to heat (heat up to 187 degrees Celsius) and cool (cool to room temperature).




**Figure 3.4:** Digestion of water samples with Microwave digester



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### 3.3.2 Physicochemical Parameters

The pH, temperature, TDS, EC, and salinity were measured by Extech-EC500 multi-meter, and turbidity was measured by Model TB400 turbidity meter. (Figure 3.5) The field measurements were done in triplicates, and an average of the results was computed, thus for accuracy purposes (Durowoju, 2015; APHA, 1998). The salinity of the water was also derived from EC measurements.



**Figure 3.5:** Field measurements by Extech-EC500 multi-meter and turbidity meter Model TB400 Instruments

### 3.3.3 Fluoride ($F^-$)

The Orion Star 214 Fluoride meter (Figure 3.6) was used to measure the fluoride ($F^-$) concentration of groundwater samples of Ga-Ramswikana Village. The instrument was calibrated with fluoride with TISAB II standard 1, 2, and 10 ppm before use and set to a 1:1 ratio. The TISAB II solution was used as a buffer to prevent interaction and the occurrence of other ions. The sample of 10 ml was mixed with the same equal amount of 10 ml TISAB II (Thermo Scientific Orion meters; Onipe et al., 2021).



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**Figure 3.6:** Preparation of fluoride analysis with Orion Star 214 Thermos Scientific instrument.

### 3.3.4 Trace Metals and Cations

The concentration of heavy metals which are (Cr, Pb, Cd, As, Fe, and Cu), and trace metals including cations ($K^+$, $Mg^{2+}$, $Ca^{2+}$, $Na^+$, As, Cr, Cu, Al, Fe, Si, and Ti), were determined using atomic inductively coupled plasma optical emission spectroscopy (ICP-OES) at the University of Venda Mining and Geology Laboratory. Before the analysis, the water samples were filtered with 0.45 µm, and the process of water digestion was taken. This is when a drop of 5 ml of nitric acid was mixed with a 45 ml of water sample and the solution was then moved into vessels in a microwave digester. The solution was poured into labelled ICP-OES test tubes for analysis.



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**Figure 3.7:** Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), used for determination of heavy metals and cation.

### 3.3.5 Major Anions

The Ion Chromatography (IC) (Figure 3.8) was used for analysing the major anions ($HCO_3$- , $SO_4^{2-}$ , $NO_3$- , $Cl^-$, $F^-$) in water samples. This was done at University of Venda, ERM Lab. The water samples were filtered with 0.22 µm water filters. The Metrohm 850 Professional Ion Chromatography instrument was calibrated before the analysis (Mulaudzi et al., 2024). Therefore, water samples were placed in IC test tubes for analysis and one sample ran for at most 20 minutes.



**Figure 3.8:** Ion Chromatography (IC) used for Major Ions analysis in water samples.



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### 3.3.6 Borehole geophysical analysis (Borehole Profiling)

The identification of proper sites to drill boreholes with more water of great quality was done using the geophysical instrument (PQWT-S500m) with the electrical resistivity method. The PQWT-TC500M geophysical instrument detected water underground to the depth of 500 m from the ground's surface. The two electrical rods were inserted into the ground for readings to take place, and the instrument showed the amount of water underground and the depth where the water can be obtainable (Alabi et al., 2020; Mokoena et al., 202; Hassan et al., 2021)., see the example below in Figure 3.9.



**Figure 3.9:** Geophysical groundwater survey at Ga-Ramaswikana (Simson) village



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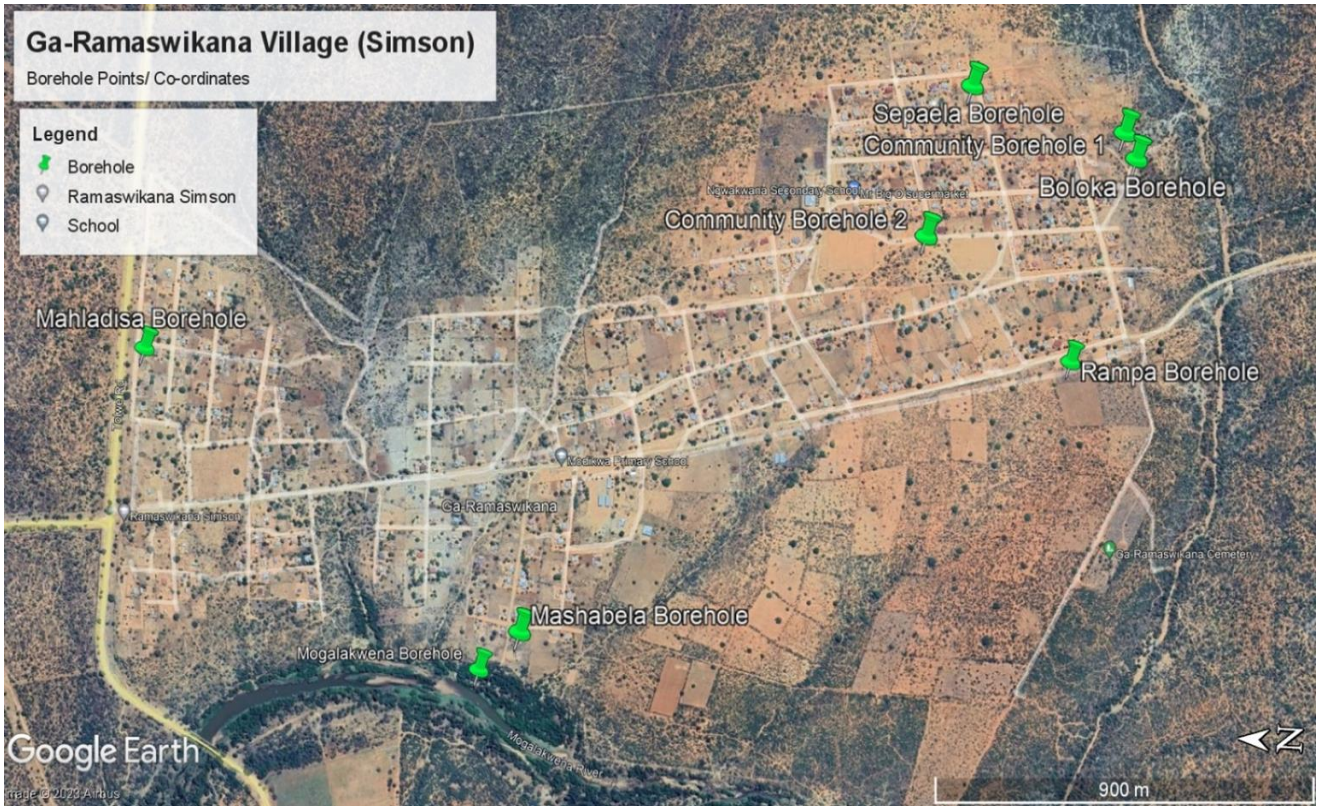



**Figure 3.10:** Borehole points/ Coordinates within Simson village

### 3.4 Data analysis

The data of the evaluation of the groundwater quality, geological formation, and borehole profiles in Ga-Ramaswikana Village were analysed using Microsoft Excel 2018, Arc GIS, Google Earth, and GWB software. The study's data or results are presented in the form of tables, graphs, and maps to ease interpretation and understanding of the groundwater quality linked with the subsurface profiles at the selected boreholes.



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**Table 3.1:** Summary of sample names and GPS coordinates of sampling points for geophysical survey and water samples.

| GPS Coordinates | Depth (m) | Borehole Name |
|---|---|---|
| 22 45 32S<br>28 48 02E | 70m current site 4<br>Potential<br>site 2 60 to 140m (best)<br>site 3 60 to 80m | Sepaela<br>082 641 0645 |
| 22 45 45S<br><br>28 47 57E | 30m<br>No water | Boloka Matlopela<br>Principal |
| 22 45 44S<br><br>28 47 59E | 120m<br>Site 5<br>No water<br>24 pipes*5 | Community borehole 1 (Not Functional) |
| 22 45 44S<br><br>28 47 59E | 30m<br>Site 6 and 7<br>No water | Community borehole 2 near borehole 1 (Not Functional) |
| 22 45 29S<br><br>28 47 50E | Site 5<br>125m (25 pipes*5m)<br>Little water | Community borehole No2<br>Concrete reservoir (Existing borehole) |
| 22 44 59S<br><br>28 47 17E | 30m<br>Site 3 | Mashabela |
| 22 44 29S<br><br>28 47 38E | 35m<br>Site 8 | Mahladisa |
| 22.761304S<br><br>28.7946977E | 60m | Rampa |



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# CHAPTER 4: RESULTS AND DISCUSSION

## 4.1 Preamble

This chapter includes the findings and discussion of experimental work on measuring groundwater quality and subsurface profile of boreholes in Ga-Ramaswikana village, Bochum.

## 4.2 Physicochemical Parameters of Groundwater

### 4.2.1 Electrical Conductivity (EC)

The EC values for all weather seasons for Sepaela, Rampa, Mashabela, Mahladisa, and public boreholes ranged from 810 to 1587.7, 853.7 to 1983.3, 863.7 to 2568, 834.3 to 2213.3, and 793 to 1214 µS/cm respectively. A high EC value indicates a significant amount of salinity and total dissolved solids. Thus, TDS and Salinity are directly proportional to the Electrical conductivity (DWAF, 1998). Summer had the lowest electrical conductivity values in all borehole water samples, compared to other seasons. Therefore, this ranged from 793 µS/cm to 863.7 µS/cm. According to SANS 241 (2015), in winter and spring, the groundwater samples of Rampa borehole exceeded the 1700 µS/cm guideline limit. Groundwater samples of the Mashabela borehole exceeded the limit of 1700 µS/cm in autumn, winter, and spring (2063.3, 2568, 2490 µS/cm), respectively, except for summer (863.7 µS/cm). The electrical conductivity of water sampled at the Mahladisa borehole had the highest EC in autumn, winter, and spring (2213.3, 1995.7, 2123.3 µS/cm) respectively, except for summer which had 834.3 µS/cm. Sepaela and Public boreholes had the EC values within the SANS, (2015) guideline. The electrical conductivity for summer in all boreholes was within the 1700 µS/cm limit of SANS (2015). This ranged from 793 to 863.7 µS/cm. During winter season, there was no collection of water sample from the public borehole as there was no water present, likely caused by a decrease in the groundwater table during dry conditions (Ekere et al., 2019; Xin et al., 2020). The measured concentrations of EC for groundwater in autumn, winter, spring, and summer were presented in the Figure 4.1.



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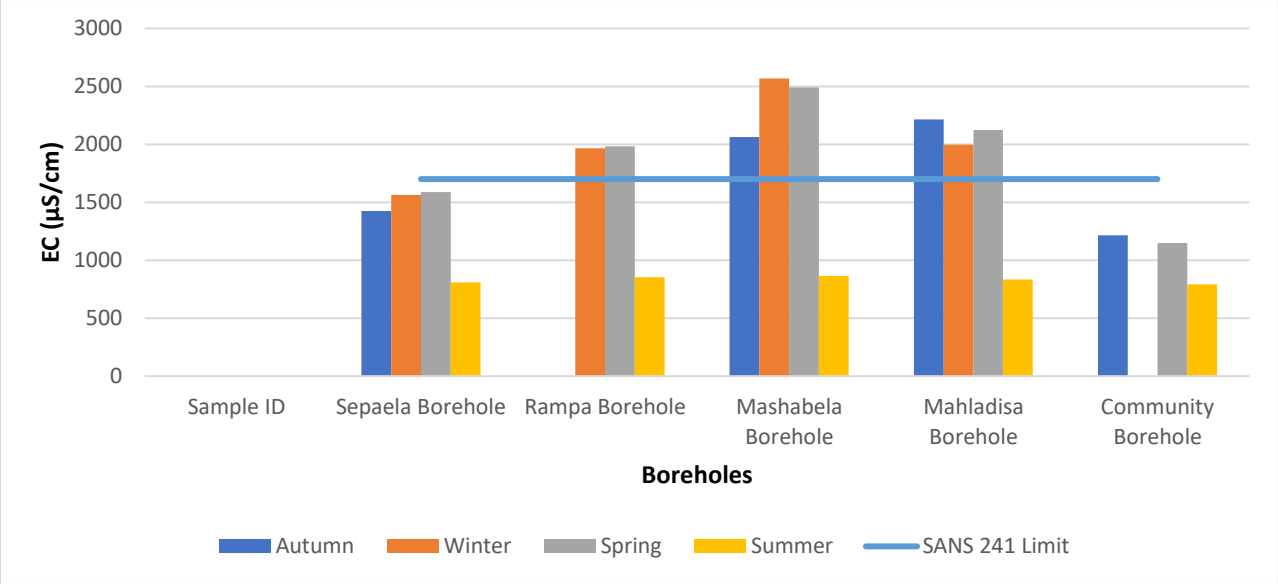



**Figure 4.1:** EC of groundwater in autumn, winter, spring, and summer

### 4.2.2 Total Dissolved Solid (TDS)

The TDS and EC have a relationship, their relationship is that they are directly proportional to each other, and when TDS increases the EC will also increase (DWAF, 1996). According to WHO (2022), TDS level of less than 600 mg/l is considered acceptable. However, TDS levels beyond 1000 mg/l become extremely disagreeable. All boreholes in summer had a drop in the level of TDS compared to other seasons, this may be due to seasonal variations. Hence, this also applies to the EC values in summer (Ekere et al., 2019; Xin et al., 2020). The TDS of groundwater in summer ranged from 547.7 mg/l in the community borehole to 604.3 mg/l in the Mashabela borehole, shown in (Figure 4.2). The boreholes that exceeded the limit of SANS of 1200 mg/l for all seasons except for summer are Mashabela and Mahladisa boreholes. Mashabela had 2063.3, 1743, and 1749.3 mg/l in autumn, winter, and spring, respectively. Mahladisa borehole had 1556.7, 1476.7, and 1404 mg/l for autumn, winter, and spring respectively. All boreholes exceeded the 1000 mg/l limit of WHO, except for the summer season and the Rampa borehole in spring, as shown in appendices.



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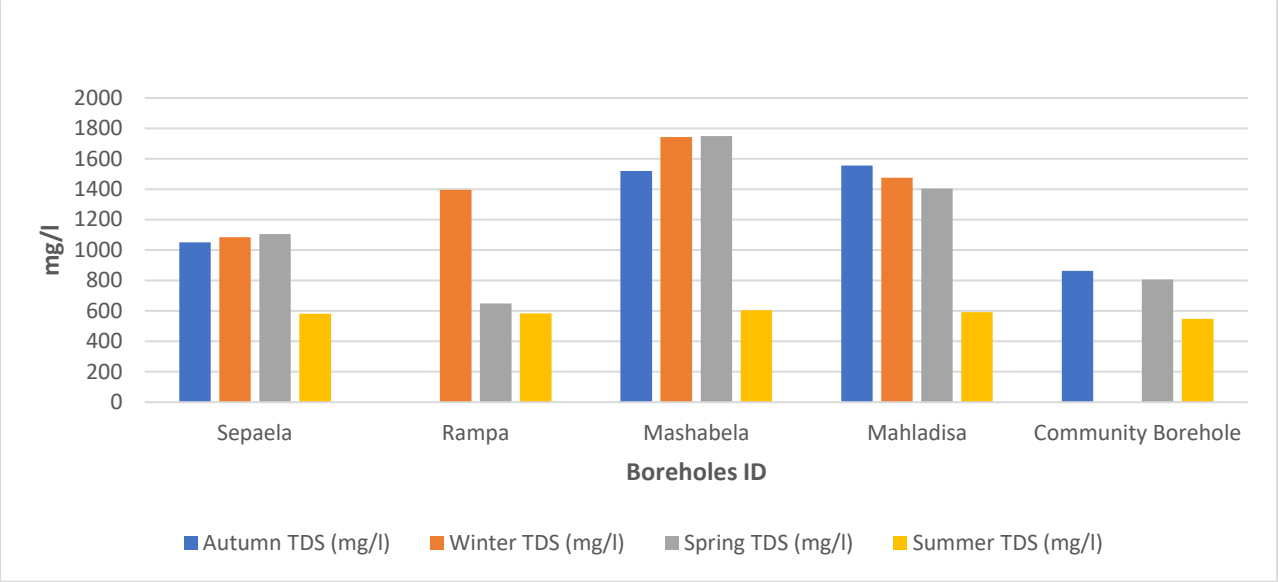



**Figure 4.2:** TDS of groundwater in autumn, winter, spring, and summer.

### 4.2.3 Salinity

The salinity, EC, and TDS always have a relationship. EC is a measure of salt content dissolved in water, hence the increase in EC favors the increase in Salinity (Shigut et al., 2016). Mashabela, Mahladisa, and Rampa groundwater samples tasted salty in all seasons, except for summer which was slightly low, but detectable. Figure 4.3 shows concentrations of salinity in groundwater for all weather seasons.

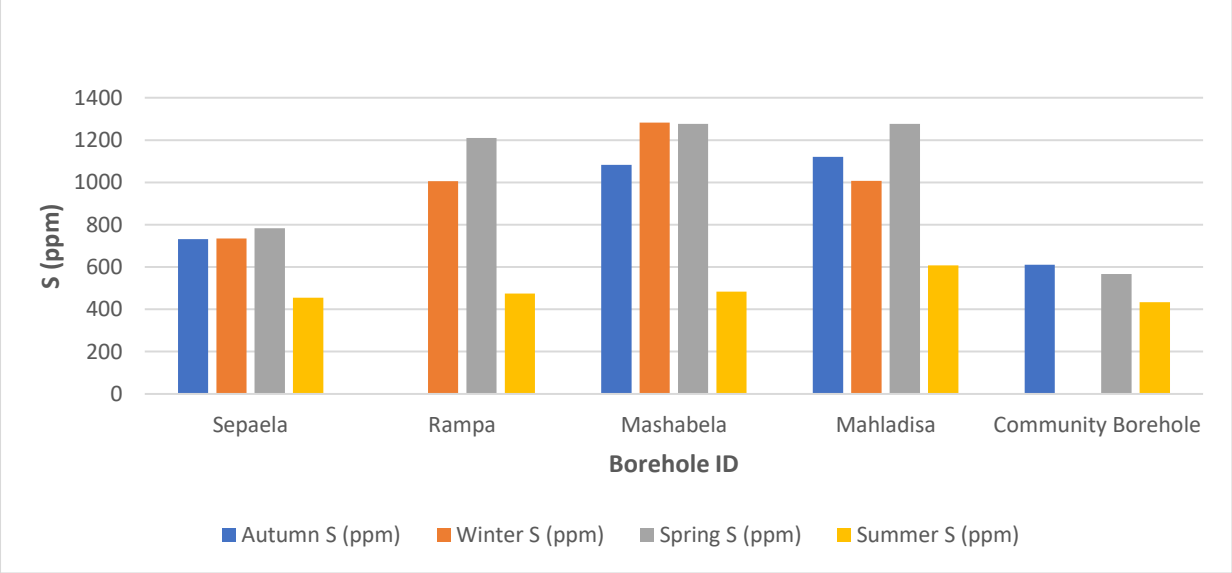



**Figure 4.3:** Salinity of groundwater in autumn, winter, spring, and summer.



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### 4.2.4 Potential Hydrogen (pH)

As shown in Figure 4.4 of the pH levels in groundwater samples of Ga-Ramaswikana village. According to the SANS and WHO guidelines, the pH levels in groundwater samples in all-weather seasons were within the permissible limits. The pH of groundwater samples was not acidic, but alkaline in Rampa in winter, Mashabela in spring and summer, and public boreholes in all seasons. The pH of the public borehole is basic ranging from 8 to 8.3, However, it does not pose any threat to human health, since it is within the 6.5 and 8.5 limits of WHO and SANS.

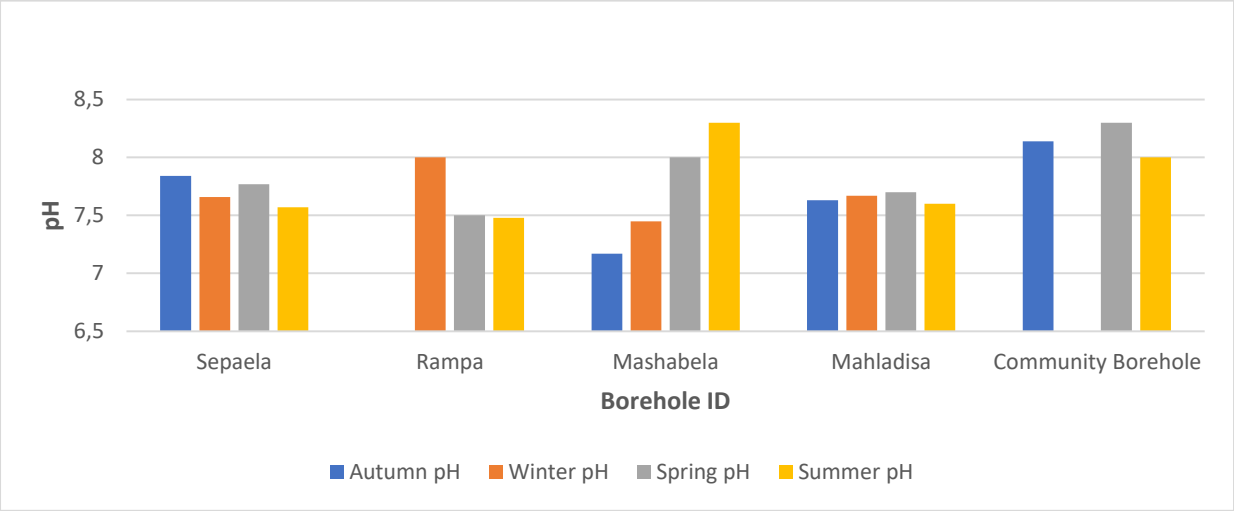



**Figure 4.4:** pH of groundwater in autumn, winter, spring, and summer.

### 4.2.5 Temperature

An increase in water temperature will decreases oxygen solubility and this may increase toxicity of certain chemicals (Mammarella, et al., 2018). High temperature in groundwater influences chemical reactions or water chemistry, thereby dissolving minerals from a rock in an aquifer. Therefore, this will lead to an increase in electrical conductivity (USGS, 2018). The overall temperature of groundwater samples in all-weather seasons ranged from 22.5 to 28.3 degrees Celsius.



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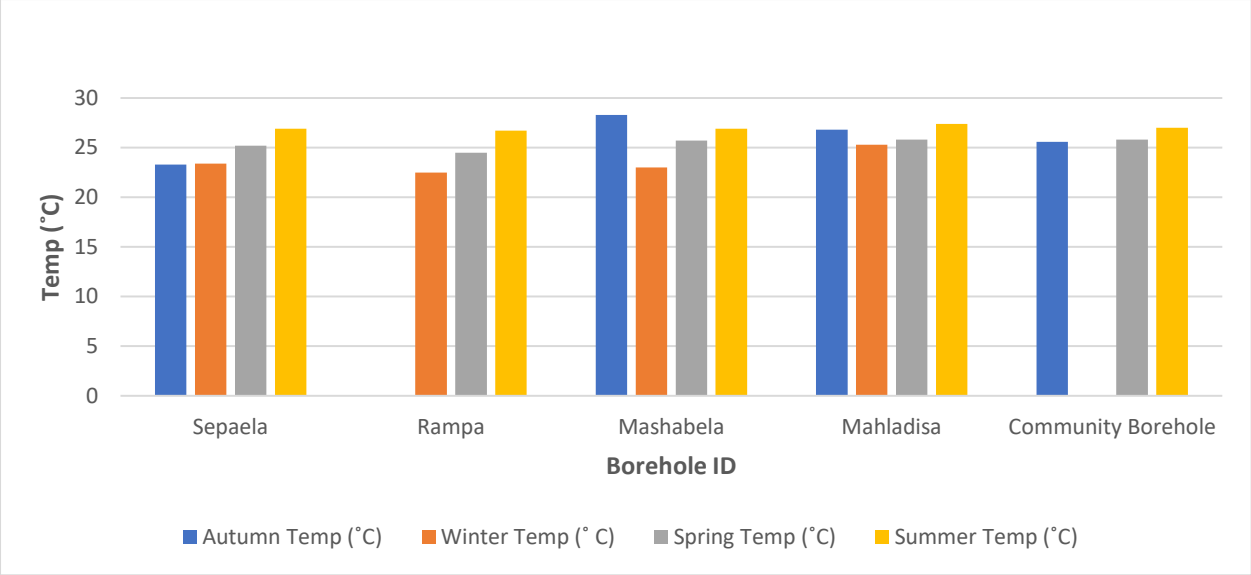



**Figure 4.5:** Groundwater temperature in autumn, winter, spring, and summer.

### 4.2.6 Turbidity

The turbidity of all boreholes was within the permissible limits of SANS, (2015) and WHO, except for Rampa and public borehole water samples. For the Rampa household, the water had a turbidity value of 22 and 9.7 NTU in winter and summer respectively (Figure 4.6). For public boreholes, water samples had the highest turbidity of 101.6 and 32.4 NTU in spring and summer respectively, exceeding the turbidity of Mogalakwena River and the limit of 5 NTU for drinking water (SANS, 2015; WHO). The water in the community borehole was brown during sampling, (See Figure 4.7).



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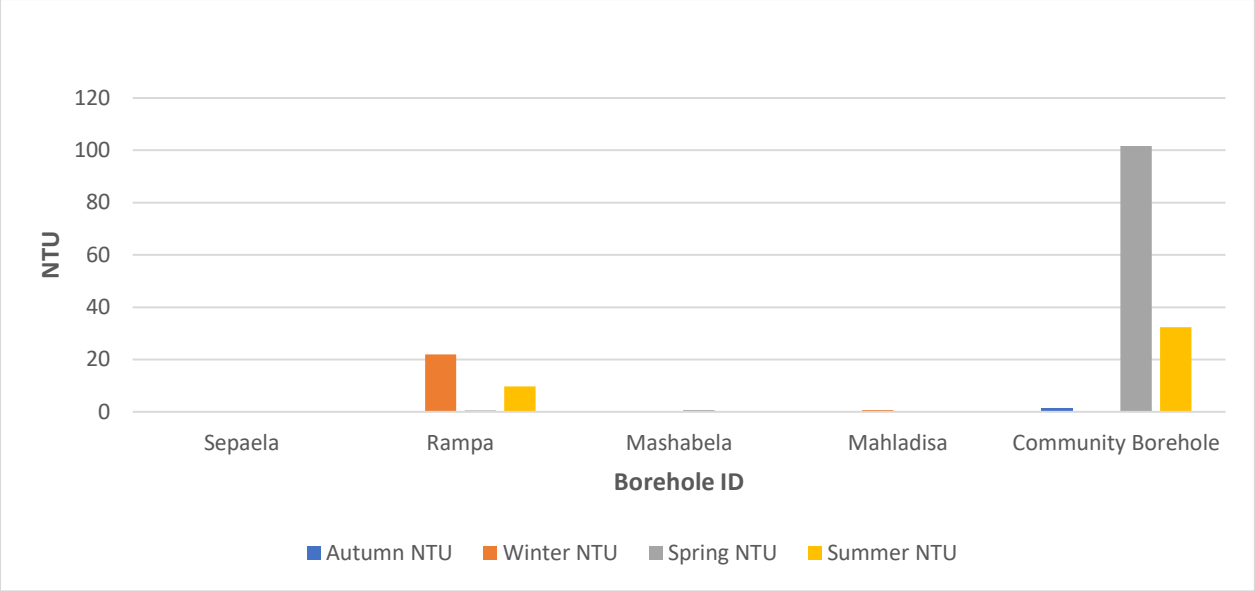



**Figure 4.6:** Turbidity of groundwater in autumn, winter, spring, and summer in Simson village.



**Figure 4.7:** High turbidity in public borehole water sample for drinking in Simpson village

### 4.2.7. Turbidity of Mogalakwena River in Ga-Ramaswikana village

The river water samples were collected twice in winter and summer. The river water was also analysed to compare the water quality in the river and Mashabela's borehole water located



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nearby the river shown in the (Figure 4.8) of borehole points, which may be influenced by factors such as surface and groundwater interaction. The turbidity of the river water sample was 2.7 in winter and 27.1 NTU in summer. The Mogalakwena River was sampled to see the variation of water quality results between the River and Mashabela's borehole which is located nearby the river, which may be influenced by surface and underground water interaction.

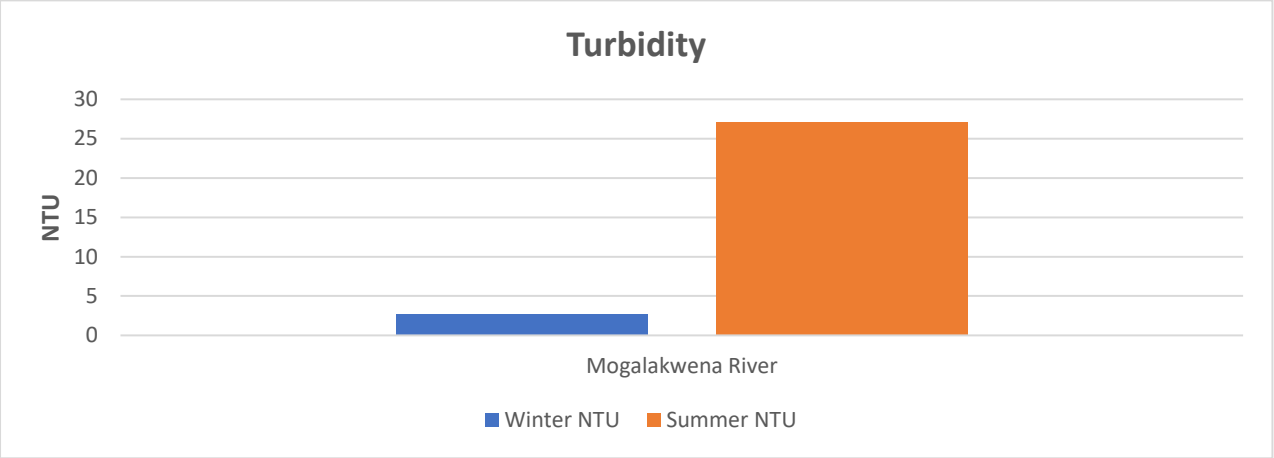



**Figure 4.8:** Turbidity of Mogalakwena River in autumn, winter, spring, and summer.

### 4.3 Trace Metals in Groundwater

#### 4.3.1 Aluminium (Al)

The aluminium permissible limit in drinking water for WHO and SANS are 0.2 mg/l and 0.3 mg/l respectively. However, as shown in Table 4.1, the following boreholes in the study have exceeded the limits of WHO and SANS guidelines, (P2, P4, P8, P12, P14, P15, P16, P18). The boreholes are (public borehole for autumn, Mashabela autumn, Mahladisa winter, Mahladisa spring, Rampa summer, public borehole summer, Mogalakwena river water sample, Rampa borehole water sample for spring), respectively. The highest Al was found in Mahladisa's borehole (P12) in spring with a value of 4.232 mg/l which could pose a serious health effect to human. The second highest aluminium in drinking water was also found in Mahladisa's borehole (P8) in winter, 1.69 mg/l, exceeding the limits of both SANS 241 and WHO guidelines. Mogalakwena River (P16) in winter, had a value of 1.324 mg/l in water, however, the water from the river is not used for consumption and it will not cause any harm to human health.



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### 4.3.2 Arsenic (As)

Seventy percent of the boreholes within the study in all seasons were found to be below detectable level, this includes (Sepaela, community, Mahladisa, and Mashabela's boreholes for Autumn; In winter, Sepaela, Rampa, Mashabela, and Mahladisa's boreholes; For spring, Sepaela, Community, and Mashabela's boreholes; For summer, Mahladisa, and Mashabela's borehole). The water from Rampa (P18) and Mahladisa's boreholes (P12) in spring exceeded the limit of 0.01 mg/l of WHO guidelines. Hence, this also includes the following boreholes in summer, Sepaela (P13), Rampa (P14), and Community boreholes (P15). The boreholes had arsenic concentrations of 1.69, 4.48, 3.01, 4.5, and 6.17 mg/l from P12 to P18, except for P16 which was for Mogalakwena river water sample. These groundwater sources have high arsenic concentration which exceeds the 0.01 mg/l limit of SANS 241 and WHO for drinking water. This could pose a serious threat such as cancer, hyperkeratosis, malignant melanoma, peripheral nervous system problems, and cardiovascular diseases to humans consuming the water in the long run (Saleh et al., 2018).

### 4.3.3 Calcium (Ca) and Magnesium (Mg)

The relationship between calcium and magnesium contributes to the hardness of the water and these two occur naturally in groundwater sources due to the geologic formation of an area (DWAF, 1996). 70% of calcium concentration was detectable in the water samples. The acceptable limit of calcium in drinking water for is 32 mg/l (DWAF, 1996). However, P2, P3, P5, P6, P7, P9, P12, P13, and P17 exceeded the limit of DWAF with 110.43 mg/l, 61.45 mg/l, 73.72, 62.77, 86.08, 53.86, 94.54, 69.92, and 89.28 mg/l respectively. Calcium was not detectable in the following water samples P4, P8, P11, P14, P18, and P20, shown in (figure 4.9). For Magnesium (Mg), the results were 5.18, 35.56, 0.74, 0.40, 44.48, and 10.56 mg/l for P1, P3, P10, P15, P16, and P19 respectively.



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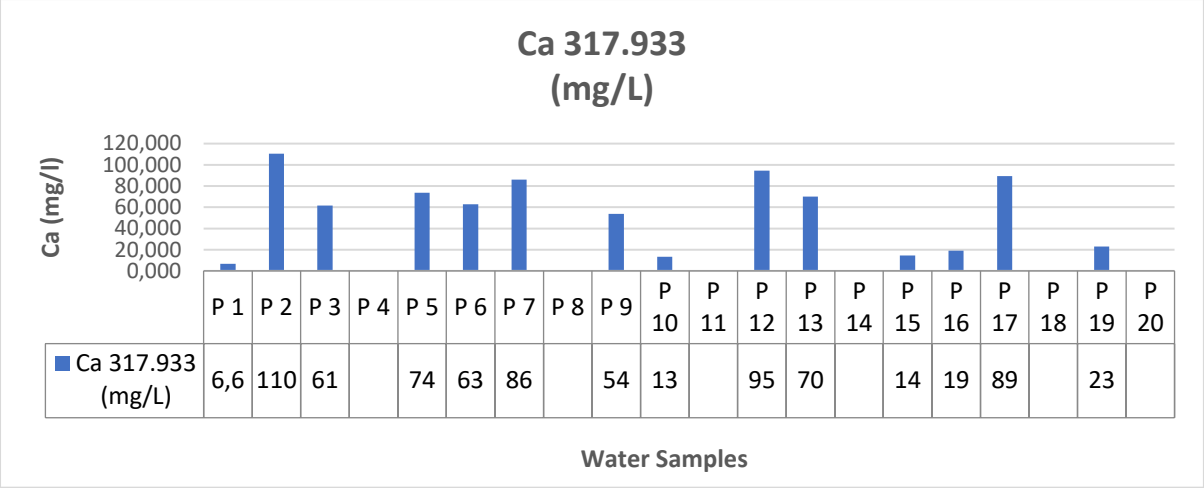



**Figure 4.9:** Calcium concentration in groundwater samples

### 4.3.4 Chromium (Cr)

The acceptable limit for chromium in drinking water is 0.05 mg/l (SANS, 2015; WHO guideline). Chromium in the groundwater sources in the study was detected but in low concentration. The concentration of chromium from P2 to P20 respectively were 0.03, 0.011, 0.003, 0.01, 0.01, 0.064, 0.01, 0.013, 0.016, 0.016, 0.019, 0.018, 0.019, 0.014, 0.025, 0.016, 0.016, 0.02, and 0.017 mg/l. Only P1 was undetectable (Table 4.1). Chromium concentration in the groundwater samples were below the SANS 241 and WHO limits (0.05 mg/l).

### 4.3.5 Copper (Cu)

According to South African National Standard 241 (2015), the acceptable copper limit in domestic water is 2 mg/l. However, the copper concentration in groundwater samples in the study was detected in an acceptable limit. The Cu concentration ranged from 0.001 to 0.073 mg/l.

### 4.3.6 Iron (Fe)

According to South African National Standard 241 (2015), the acceptable limit for Iron (Fe) in drinking water is 2 mg/l. The concentration exceeding 2 mg/l will lead to chronic health effects. The groundwater samples in the study were within the SANS 241 limit, except for a public borehole in summer (P15) which had the highest concentration of 3.47 mg/l. In summer, a community borehole (P15) is likely to be prone to high Fe concentration, as shown in Table 3.1. Therefore, this may lead to chronic health effects such as abdominal pain and diarrhoea.



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### 4.3.7 Potassium ($K^+$)

The allowable $K^+$ concentration in drinking water in South Africa is 20 mg/l (WHO; SANS, 2015; DWAF, 1996). The $K^+$ in groundwater samples in the study ranged from 0.764 to a maximum of 9.58 mg/l. However, the concentration of potassium in borehole waters in the study area complied with the recommended limits of DWAF (1996), SANS: 241 (2015), and WHO guidelines (Table 4.1).

### 4.3.8 Sodium ($Na^+$)

The $Na^+$ concentration in groundwater samples within the study was not detected, except for P1 with a concentration of 11.23 mg/l for the Sepaela borehole in autumn (Table 4.1). Although the $Na^+$ concentration in the study was below detection, sodium is crucial in permissible limits. Hence, this is for the human body which needs Na to maintain blood pressure, control fluid levels, and for normal nerve and muscle function (Arega, 2020).

### 4.3.9 Silicon (Si)

Silicon is a trace element mineral that occurs naturally in soil or rock, and it helps enhance the growth of bones (Kim et al., 2014). The Si of high content in reaction with water leads to water pollution. Various studies have supported that the presence of silica in drinking water may result in cognitive decline among individuals (Guyonnet and Vellas, 2007; Rondeau et al., 2008). 100 % of borehole water samples in the study exceeded the Si permissible limit of 30 mg/l in drinking (EPA). The Si of groundwater samples (Figure 4.10) ranged from 937.27 to a maximum of 27 531.39 mg/l, greater than the silicon limits of EPA, and WHO. The results shows that the groundwater in Ga-Ramaswikana village is prone to Si. High Si in drinking water does not pose a serious threat to human health, it is associated with a change in the taste of water and odour (Amu et al., 2022). SANS and WHO guidelines did not specify the acceptable limits of Si in drinking water.



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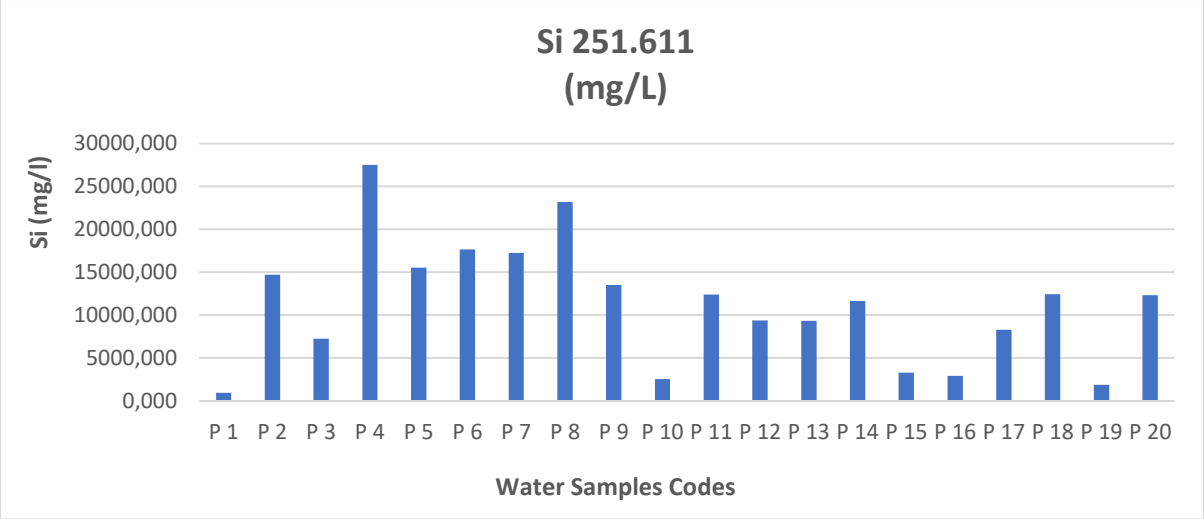



**Figure 4.10:** Si concentration in groundwater samples

### 4.3.10 Titanium (Ti)

Titanium was present in most groundwater samples, but in acceptable concentrations, as shown in Table 4.1. The SANS has set a maximum permissible limit for titanium in drinking water of 0.2 and 0.1 mg/l for WHO limit.

| Sample Id | Al 396.153 (mg/L) | As 193.696 (mg/L) | Ca 317.933 (mg/L) | Cr 267.716 (mg/L) | Cu 327.393 (mg/L) | Fe 238.204 (mg/L) | K 766.490 (mg/L) | Mg 285.213 (mg/L) | Na 589.592 (mg/L) | Si 251.611 (mg/L) | Ti 334.940 (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| P 1 | 0.002 | | 6.578 | | 0.001 | | 0.764 | 5.177 | 11.230 | 937.269 | |
| P 2 | 0.326 | | 110.473 | 0.029 | 0.053 | 0.555 | 9.580 | | | 14709.333 | 0.020 |
| P 3 | 0.000 | | 61.454 | 0.011 | 0.034 | 0.404 | | 35.556 | | 7251.662 | 0.003 |
| P 4 | 0.220 | | | 0.003 | 0.036 | 0.348 | | | | 27531.389 | |
| P 5 | 0.067 | | 73.715 | 0.008 | 0.016 | 0.079 | 9.202 | | | 15548.086 | 0.000 |
| P 6 | 0.027 | | 62.765 | 0.008 | 0.015 | 0.052 | 8.817 | | | 17684.292 | 0.000 |
| P 7 | 0.067 | | 86.082 | 0.064 | 0.073 | 0.110 | 11.577 | | | 17257.116 | 0.051 |
| P 8 | 1.690 | | | 0.008 | 0.016 | 0.388 | 6.277 | | | 23185.983 | 0.016 |
| P 9 | 0.076 | | 53.858 | 0.013 | 0.027 | 0.084 | 9.271 | | | 13519.296 | 0.000 |
| P 10 | 0.167 | | 13.460 | 0.016 | 0.048 | 1.154 | 1.075 | 0.737 | | 2566.353 | 0.005 |
| P 11 | 0.077 | | | 0.016 | 0.034 | 0.147 | 2.951 | | | 12415.585 | |
| P 12 | 4.232 | 1.686 | 94.536 | 0.019 | 0.036 | 0.913 | 3.208 | | | 9398.758 | 0.025 |
| P 13 | 0.127 | 4.475 | 69.923 | 0.018 | 0.037 | 0.178 | 5.671 | | | 9344.876 | 0.000 |
| P 14 | 0.332 | 3.007 | | 0.019 | 0.051 | 1.235 | 3.452 | | | 11640.383 | 0.002 |
| P 15 | 0.370 | 4.499 | 14.435 | 0.014 | 0.020 | 3.465 | 1.001 | 0.391 | | 3291.477 | 0.005 |
| P 16 | 1.324 | 4.725 | 19.050 | 0.025 | 0.066 | 1.951 | 4.096 | 11.481 | | 2924.418 | 0.047 |
| P 17 | -0.013 | | 89.281 | 0.016 | 0.060 | 0.122 | 3.595 | | | 8283.934 | |
| P 18 | 0.341 | 6.167 | | 0.016 | 0.041 | 0.675 | 3.846 | | | 12458.217 | 0.003 |
| P 19 | 0.109 | | 23.093 | 0.020 | 0.033 | 0.178 | 3.546 | 10.556 | | 1898.875 | 0.002 |
| P 20 | 0.087 | | | 0.017 | 0.024 | 0.186 | 2.227 | | | 12317.552 | |

**Table 4.1:** Trace Metals Present in Groundwater Samples of Ga-Ramaswikana Village

### 4.4 Major Anions



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### 4.4.1 Bicarbonate ($HCO_3^-$)

The hundred percent of $HCO_3^-$ concentration in all boreholes water samples were detected. Although there are no permissible SANS, WHO, and USEPA limits for bicarbonate, high levels of bicarbonate in drinking water may affect the taste of water and have an influence in excessive fluoride concentration in water (Bruvold & Gaffey, 1969). Figure 4.11 shows the concentrations of bicarbonate in borehole water samples of Ga-Ramaswikana village. The concentration ranged from 0.008 to 600.4 mg/l.

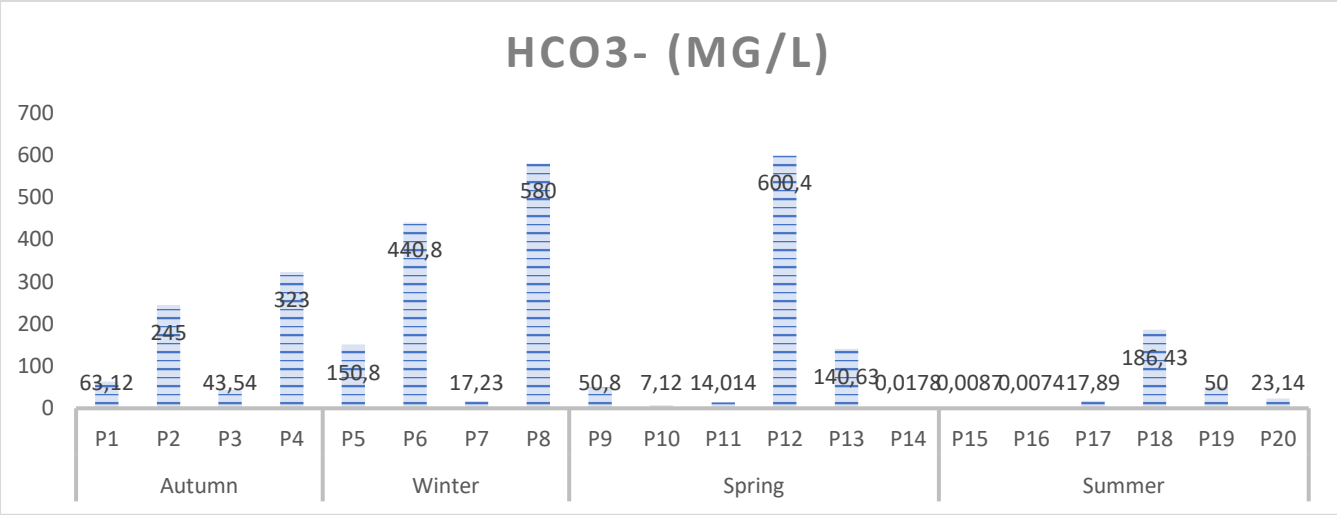



**Figure 4.11:** Bicarbonate on groundwater

### 4.4.2 Chloride $Cl^-$

The concentrations of $Cl^-$ in groundwater sources in Ramaswikana village were detectable and within the 300 mg/L (SANS limit). Mashabela borehole (P18) in summer, slightly exceeded the 300 mg/l limit of SANS with a concentration of 303.24 mg/l (Figure 4.12). The figure 4.12 shows the concentrations of Cl in borehole water samples of Ramaswikana Village. The detailed concentrations are illustrated in Appendix 5.



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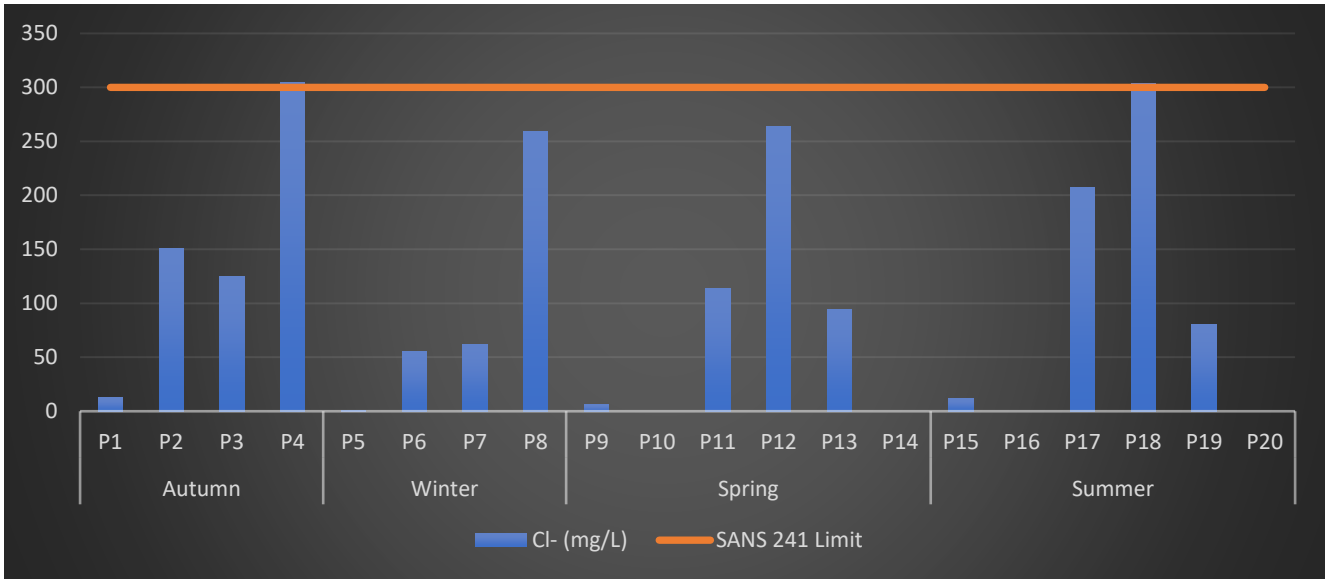



**Figure 4.12:** Chloride levels in groundwater

### 4.4.3 Sulphate $SO_4^{2-}$

According to the drinking water standard of SANS (2015), a $SO_4^{2-}$ concentration exceeding 500 mg/L may lead to acute health effects to humans consuming the water, and 250 mg/L to 500 mg/L will result in aesthetic problems. The $SO_4^{2-}$ concentration in borehole water samples from P1 to P20 ranged from 110.47 mg/L to 6.58 mg/L. The $SO_4^{2-}$ concentration of water samples in the study were within the limit the aesthetic and acute health limits of SANS and WHO (WHO, 2004; SANS, 2015). Figure 4.13 represents the concentrations of water samples in Ramaswikana village from P1 to P20. Appendix 5 shows a table of sulphate concentration results.

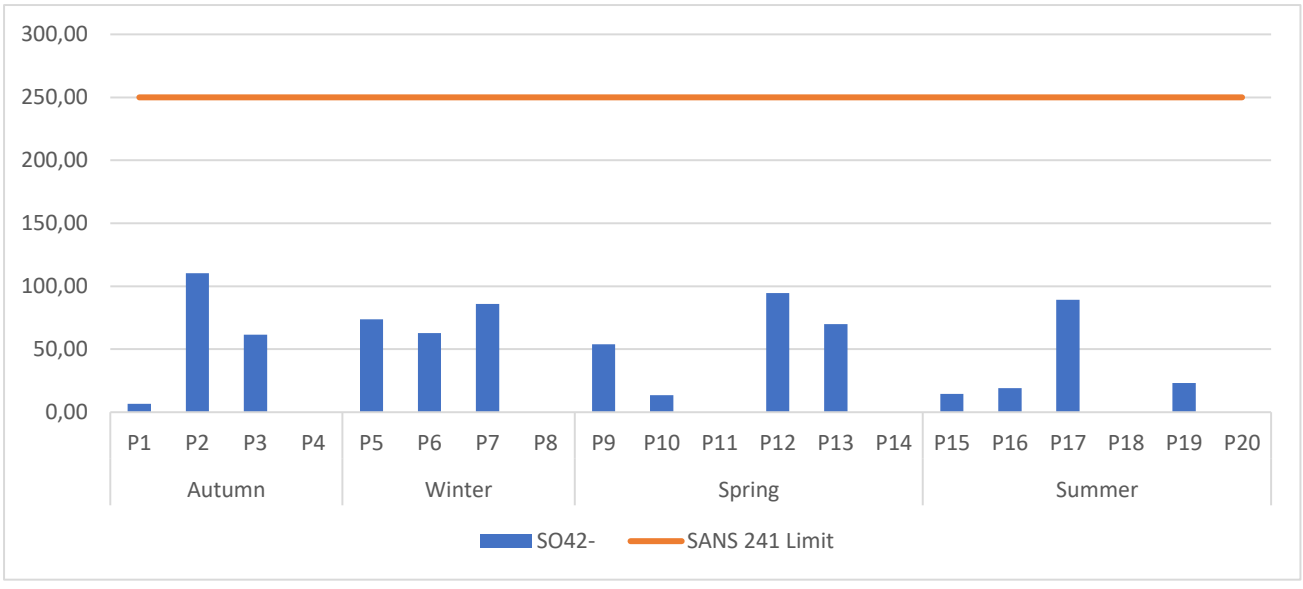



**Figure 4.13:** Sulphate concentrations in groundwater sources



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### 4.4.4 Nitrate ($NO_3^-$)

The $NO_3^-$ concentration exceeding the 11 mg/l in drinking water will result to serious health effect (SANS, 2015). Seventy five percent of water samples in the study were below detectable, except for P12, P14, P16, P18, and P20 which respectively belong to Mashabela spring, Mogalakwena River spring, Mogalakwena River summer, Mashabela summer, and Rampa for summer. The concentrations of this water quality parameter are shown in appendix 5 with sample codes. Nevertheless, all water samples in the study complied with the $NO_3^-$ limit of 11 mg/l (WHO, 2011; SANS, 2015). The nitrate is mostly caused by anthropogenic activities like application of biocides and agriculture, in the study area they don't practise such activities, the detectable nitrate concentration in Mashabela borehole in spring and summer may have been influenced by surface and ground water interaction (Mogalakwena River and Mashabela's borehole water interaction). Hence, the two sources are located close to each other.

### 4.4.5 Fluoride in Groundwater ($F^-$)

Figure 4.14 shows fluoride concentrations in groundwater sources within Ga-Ramaswikana Village. In Sepaela borehole the fluoride concentration exceeded the limit of the World Health Organization in spring and summer with concentrations of 2.1 and 2 mg/l respectively. Mashabela's borehole had fluoride concentrations of 1.88, 2, 1.84, and 2.5 mg/l in autumn, winter, spring, and summer respectively. The fluoride concentration in Mashabela's groundwater samples in all-weather seasons exceeded the limits of SANS 241 and WHO. Therefore, this put Mashabela's groundwater source at high fluoride risk. Hence, it is why people in Mashabela's household have mottled teeth. The water from Mashabela's borehole tastes more salty than other boreholes. The community borehole also had the most fluoride concentration exceeding the SANS and WHO limits. The fluoride concentrations of public water sources are 1.8 mg/l, 3 mg/l, and 2.82 mg/l for autumn, spring, and summer respectively. In winter, the public borehole was not producing any water. According to the PQWT electromagnetic groundwater survey, the water table in the public borehole had dropped in winter as shown in Figure 4.44 of the processed borehole profile, this was due to the area not receiving enough rainfall to recharge the groundwater resources, as shown in Appendix 8 of South African Weather Service report. Mahladisa's borehole had fluoride concentrations exceeding the guidelines of SANS and WHO, except for the autumn season, as shown in Figure 4.14 below. Rampa borehole had the lowest fluoride levels in groundwater, except for spring with a concentration of 3.7 mg/l. Spring season had the highest average fluoride concentration, compared to other weather seasons.



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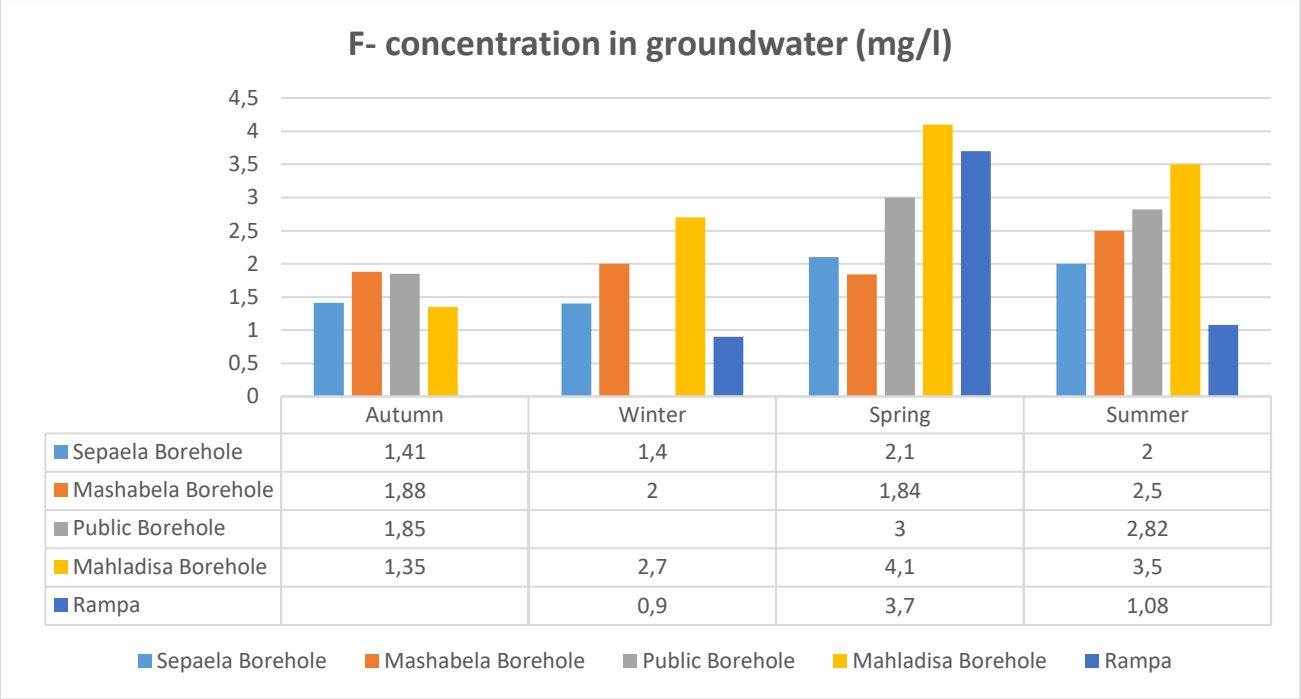



**Figure 4.14:** Average Fluoride Concentration in Groundwater

## 4.5 Groundwater Hydrochemistry

### Piper diagram

A Piper diagram was used to assess the hydrochemistry of groundwater and determine the possible sources of groundwater pollution in the area. Additionally, to classify groundwater into hydro-chemical facies. The concentrations of fluoride, phosphate and nitrate were excluded in piper diagram. The major cations ($Ca^{2+}$, $Na^{+}$, $Mg^{2+}$, and $K^{+}$) were plotted against major anions ($HCO_{3}^{-}$, $SO_4^{2-}$, and $Cl^{-}$) on a piper diagram to understand the water type dominant in the groundwater of Ga-Ramaswikana Village (Figure 4.15). The geochemistry of groundwater in Ga-Ramaswikana Village is dominated by calcium chloride ($CaCl_2$) water type in most boreholes. The most dominant cation and anion are calcium and chloride. The $CaCl_2$ is a type of hard water that influences a salty taste of water depending on the ratio of the concentrations (Kriger R.A, 1963). The groundwater chemistry of a public borehole is $CaCl_2$ throughout all weather seasons. This tells that the public borehole is drilled on a calcium chloride rock formation.



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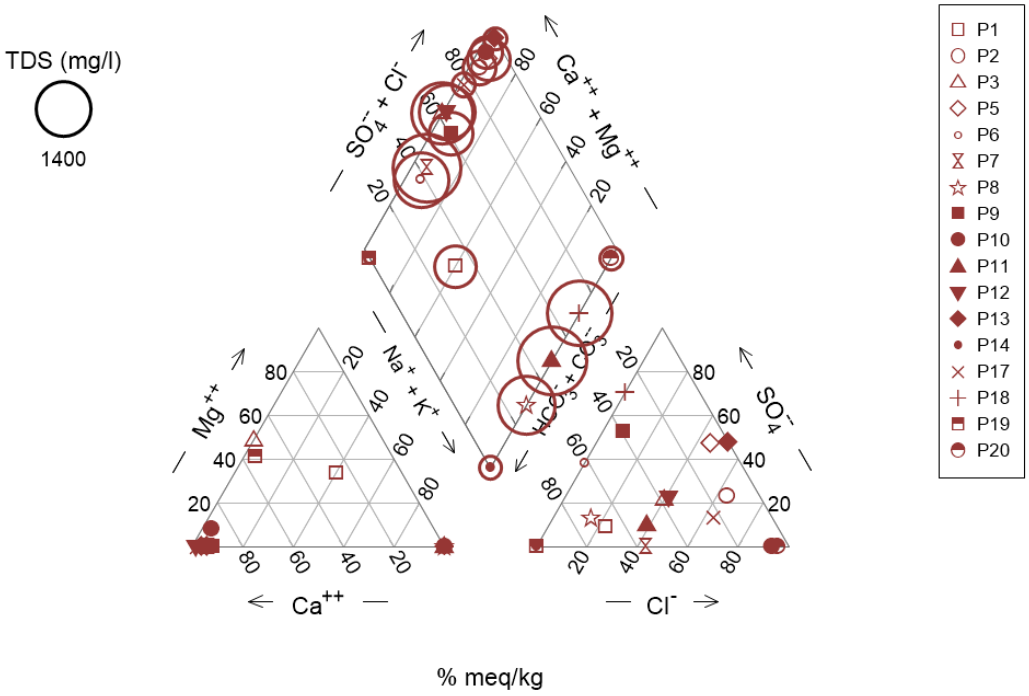



**Figure 4.15:** Trilinear Piper diagram showing major cations and anions in groundwater for all seasons.



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### Water types from piper diagram

**Table 4.2:** Groundwater types of Ga-Ramaswikana village

| Sample code | Water type |
|---|---|
| P1 | Na-HCO3 |
| P2 | Ca-Cl |
| P3 | Ca-Cl |
| P4 | H-Cl |
| P5 | Ca-Cl |
| P6 | Ca-HCO3 |
| P7 | Ca-HCO3 |
| P8 | K-HCO3 |
| P9 | Ca-SO4 |
| P10 | Ca-Cl |
| P11 | K-HCO3 |
| P12 | Ca-Cl |
| P13 | Ca-Cl |
| P14 | |
| P15 | Ca-Cl |
| P16 | |
| P17 | Ca-Cl |
| P18 | |
| P19 | |
| P20 | K-Cl |

### Durov diagram

The durov diagram differs from the Piper because of its ability to show geochemical processes that may affect groundwater. Therefore, it also shows TDS concentrations. Durov diagram and piper plot are comparable, the former is superior since it can indicate certain geochemical processes that may have an impact on groundwater genesis (Ravikumar et al., 2015). Cations and anions in relation to TDS and pH are depicted in this plot. In the durov diagram (Figure 4.16) there is a massive geochemical process taking place, leading to geochemical contamination of groundwater in Ga-Ramaswikana Village. The groundwater samples for different seasons in the study area have various chemical pollution, which may be due to chemical reaction from weathering of rocks underneath.



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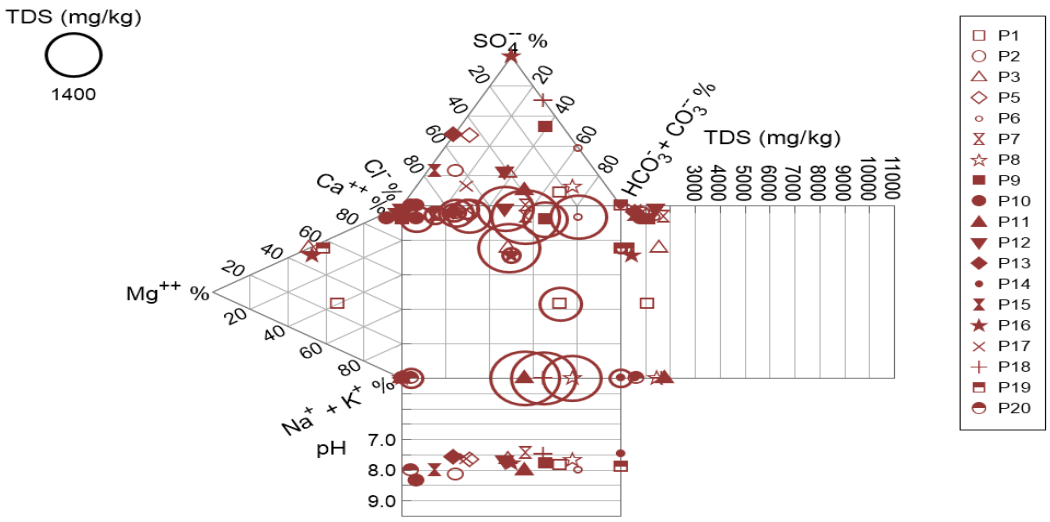



**Figure 4.16:** Durov diagram showing the hydrochemical process of groundwater in Simson village.

According to the geological maps provided by the Council for Geoscience, Ga-Ramaswikana Village is associated with Alldays gneiss suite which is made up of various minerals and rocks such as greyish biotite bearing gneiss, quartz-feldspar, amphibolite, ferromagnesium minerals, plagioclase, cummingtonite, k-feldspar, garnet, hornblende, pyroxene, and among others (Brandl, 1990; Brandl, 2007; Brandl, 2002). The association of amphibolite-carbonate is mostly prominently found in the Mogalakwena River area (Brandl, 2007). The water from the aquifer made up of those minerals will always pose a threat to water quality. Figure 4.17 is a geological map of Ga-Ramaswikana Village. However, the map is dominantly covered with sandy soil. The public and Mahladisa boreholes are covered by grey, medium-grained, migmatite, and tonalitic-trondhjemite gneiss. The groundwater in Ga-Ramswikana village in most boreholes is linked with high fluoride concentrations. Therefore, this is due to the presence of fluorite minerals in the aquifer.



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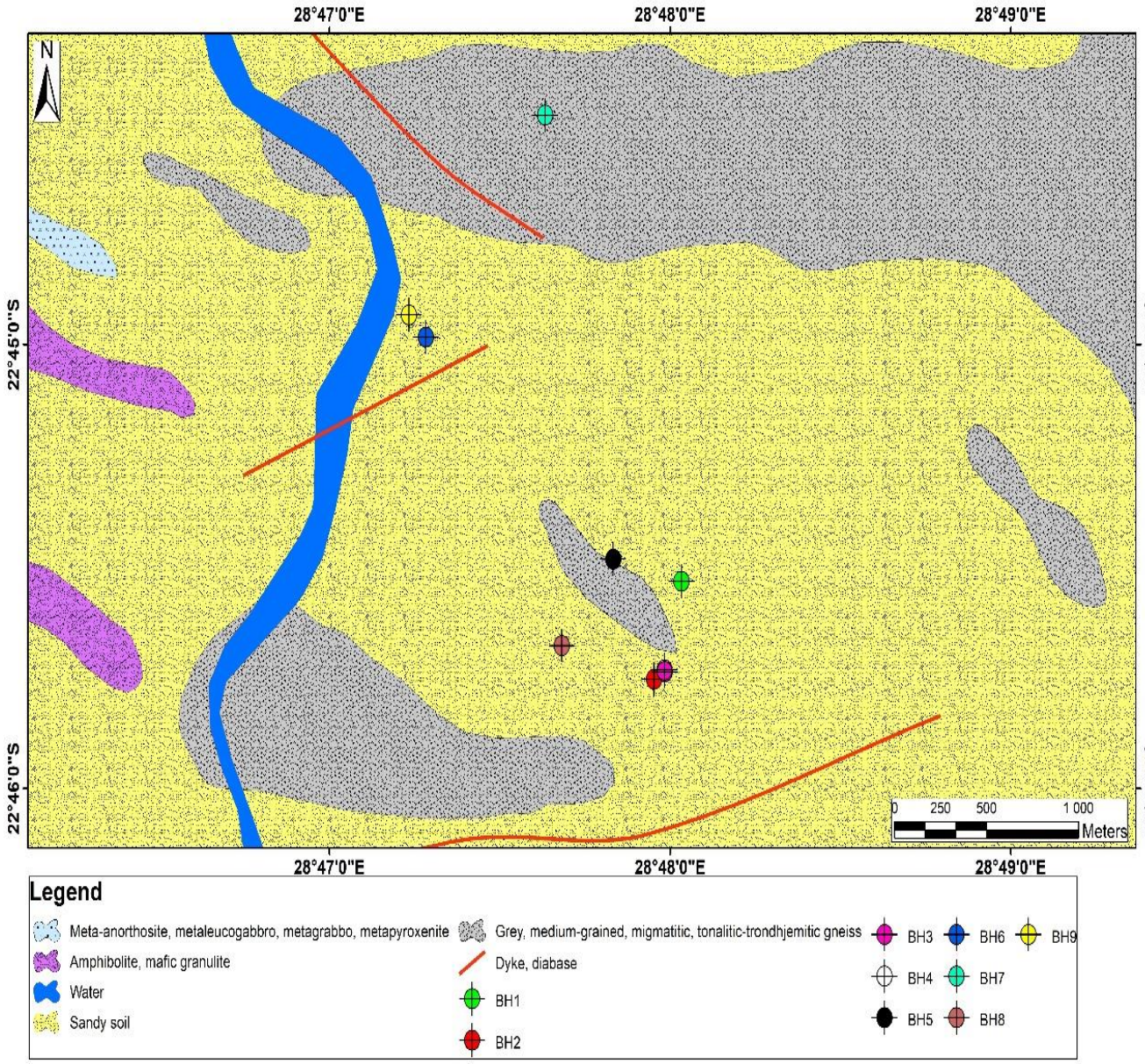



**Figure 4.17:** Geological formation of Ga-Ramaswikana village/ geological material characterization and borehole points.



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## 4.6 PQWT Electromagnetic Borehole Profiles for autumn

### 4.6.1 Sepaela Homestead Subsurface Profile

Figures (4.18 and 4.19) indicates the geo-profiles of Sepaela's borehole. A represents the original/ raw profile, B represents the processed profile, and C is a curve graph profile. The borehole profile comes in three different forms, i.e. original profile, processed profile, and curved profile. The resistivity values with different colours represent the possibility of finding water or rock strata. The Sepaela's borehole is drilled at point 4 70 m deep as shown in the Figure 4.18 below. Point 4 has low resistivity values from the surface to 70 m deep, medium resistivity values from 40 to 140 m, there is high resistivity from 150 to 450 m which shows a hardrock with no possibility of getting water. Therefore, the Sepaela borehole was wrongly sited at point 4 with no vertical rock fracture that yields water and has shallow water (Figures 4.18 and 4.19). Point 2 could have been the best point to drill borehole in Sepaela's homestead. The borehole drilled at point 4 dries, since the area experiences low annual rainfall (SAWS data). The best site or point for drilling a borehole in Sepaela's household is point 2 with low resistivity values and a V-curved shape (vertical rock fracture) shown in a processed and curved profiles. Point 2 from surface to 140 m deep represent conductive material (water). A V-shaped at points 2 and 3 represents areas of potential water zones, since there is a vertical rock fracture and blue zones associated with lower resistivity, which indicates high water probability (Madukwe and Talabi, 2020; Chen, 2022; Oyegoke et al., 2020).

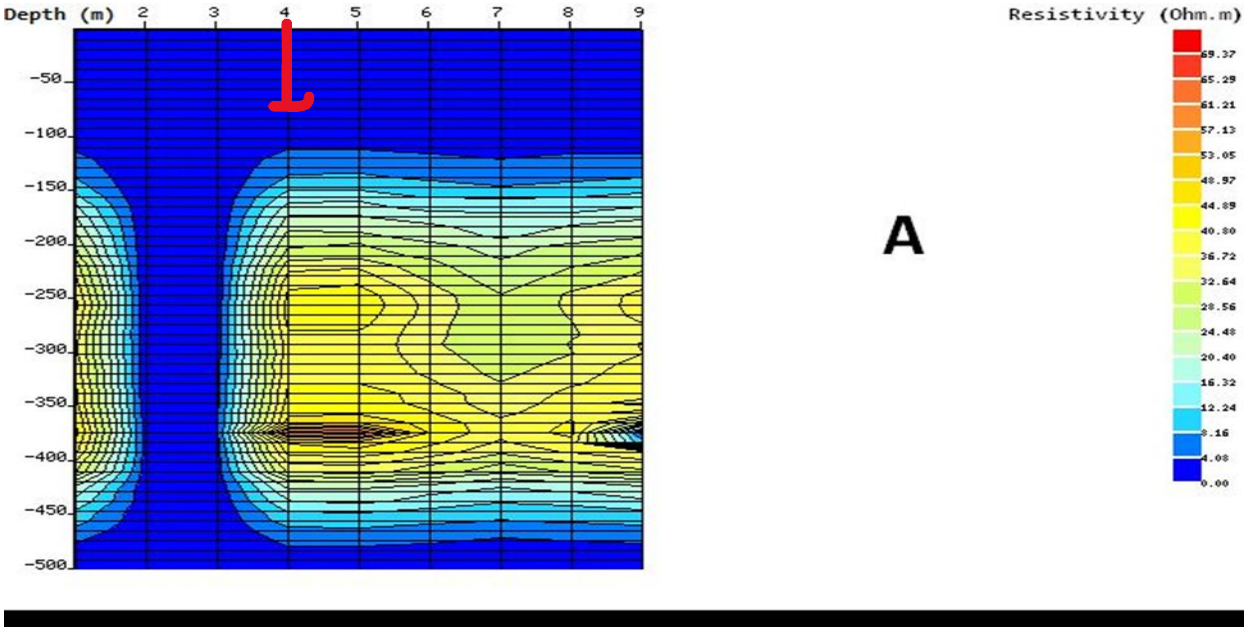



**Figure 4.18:** Sepaela household raw subsurface profile for autumn with drilled borehole at point 4, 70 m deep.



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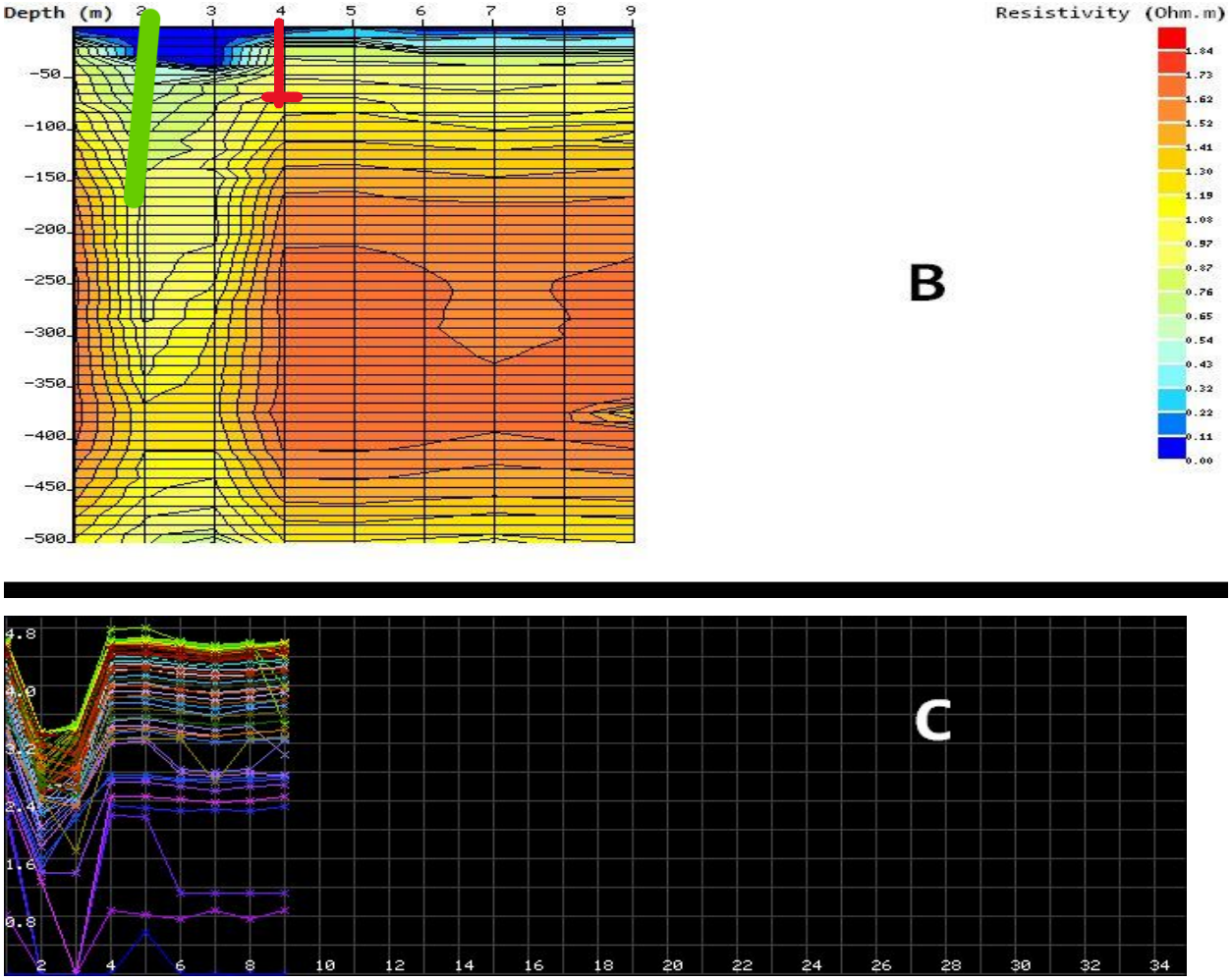



**Figure 4.19:** Sepaela household processed and curve subsurface profiles for autumn with drilled borehole at point 4, 70 m deep.



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### 4.6.2 Boloka Homestead Subsurface Profiles

The blue colour on a profile is mostly associated with low resistivity values, which represent the presence of conductive material (water) or the possibility of getting water in that zone (Oyegoke et al., 2020; Madukwe and Talabi, 2020). However, it is not in all cases where you may find water in a blue sport, particularly just a few meters from the surface. The blue zones at the top may represent saturated soil, which is just soil moisture (little water) (HPWE Institute). Sufficient groundwater is mostly found in fractured rocks/ cracked zones (Oyegoke et al., 2020; Lateef, 2012). Therefore, the reason why Boloka borehole is dry is because it was drilled 30m deep at point 3, shown in the Figure 4.20. Hence, the area does not experience much rainfall, leading to groundwater depletion, due to low groundwater recharge (SAWS Data). Shown in Figure 4.21 of a processed profile, from 50 to 120 m deep at point 3 there is low resistivity, which shows a high possibility of getting water. This borehole was surveyed only once in autumn because it was no longer supplying water. This borehole was drilled 30 m deep at point 4, and it should have been drilled beyond 50 to 100 m deep. The green illustration on the profiles shows the best site and red shows an existing drilled borehole.

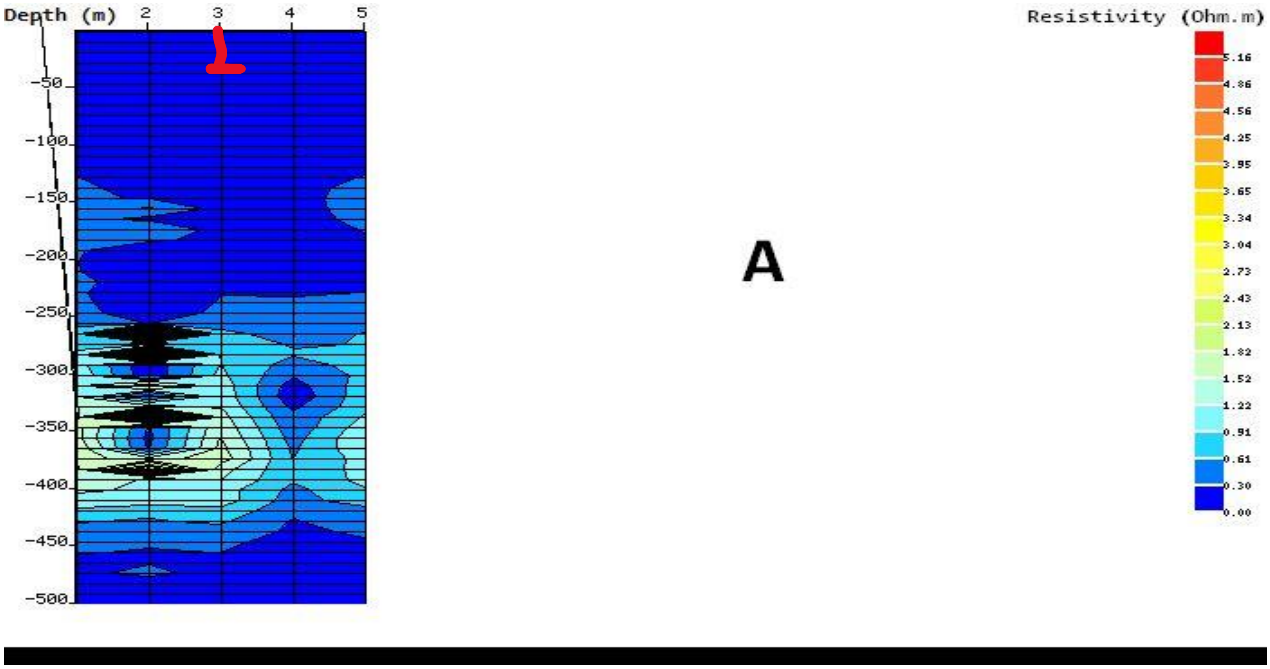



**Figure 4.20:** Boloka household raw subsurface profile for autumn with drilled borehole at point 3, 30 m deep.



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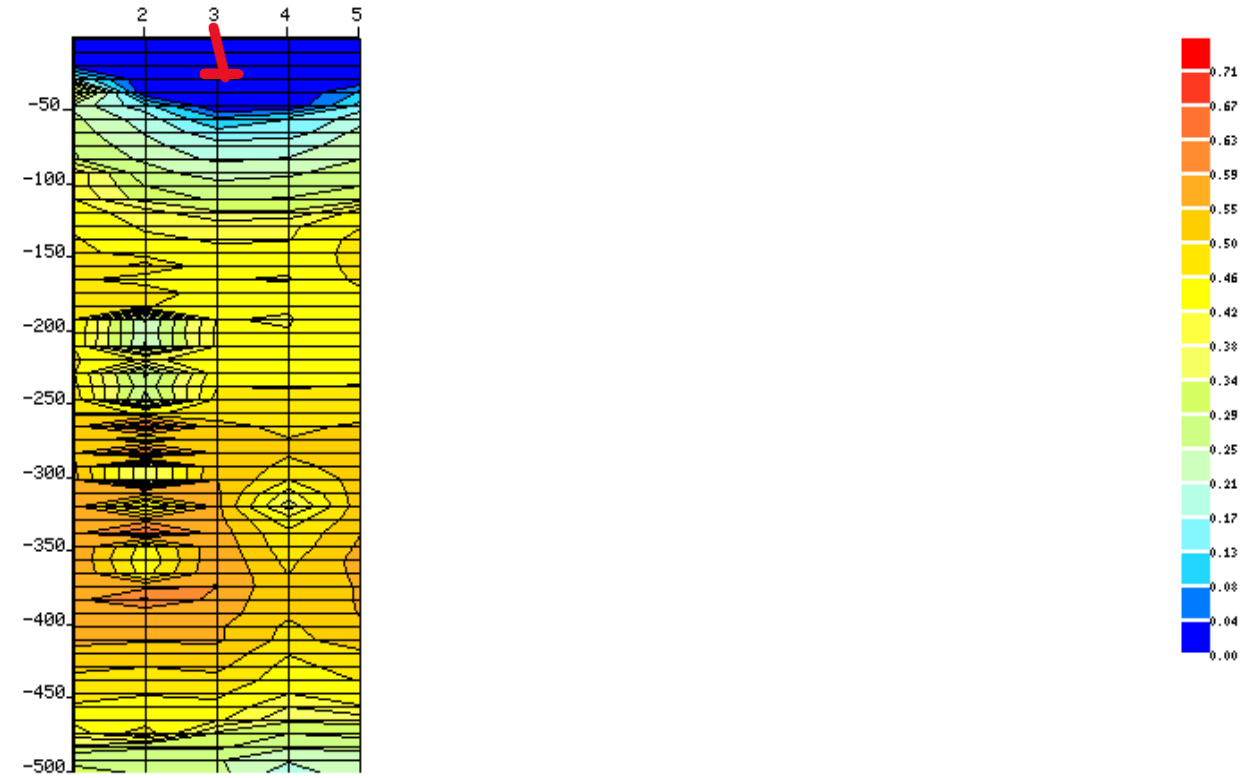



**Figure 4.21:** Boloka household processed subsurface profile for autumn with drilled borehole at point 3, 30 m deep.

### 4.6.3 Mahaladisa Homestead Subsurface Profile

The borehole profile of Mahladisa's household has low resistivity values and clear contour lines which indicate the pattern or flow of the water underground (Oyegoke et al., 2020; Chen, 2022). The curved profile shows a lot of V-green graphs. Hence, this indicates the presence of high groundwater zones. The borehole is drilled at point 8, 35 m deep (Resistivity is low at point 8). Nevertheless, At Point 7 the resistivity is also low from the saturated soil at the top to 440m downwards. This means that point 7 is also a good point for drilling sufficient water that can supply the whole community of Simson. Point 7 also recharges the existing borehole at point 8, this is the reason this borehole does not get dry throughout the year.



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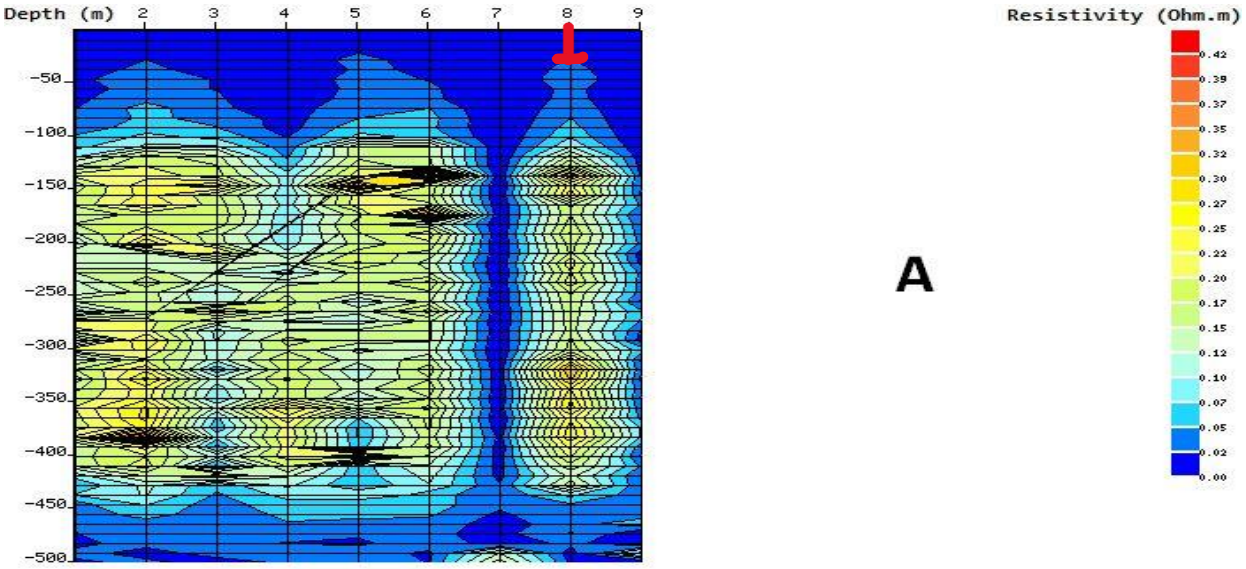



**Figure 4.22:** Mahladisa household raw subsurface profile for autumn with drilled borehole at point 8, 35 m deep.

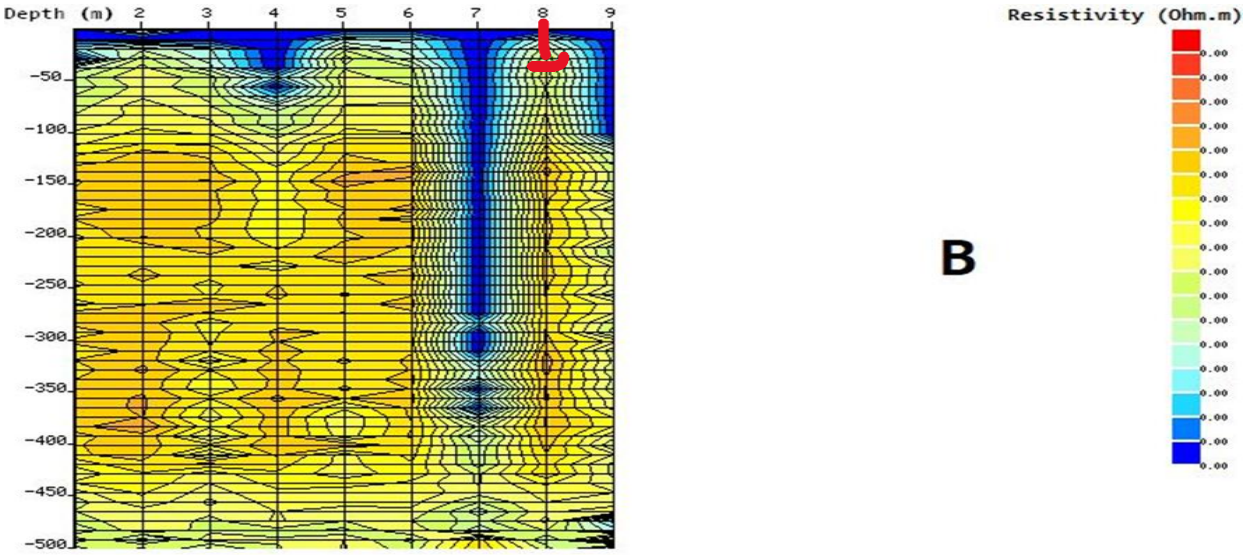



**Figure 4.23:** Mahladisa household processed subsurface profile for autumn with drilled borehole at point 8, 35 m deep.

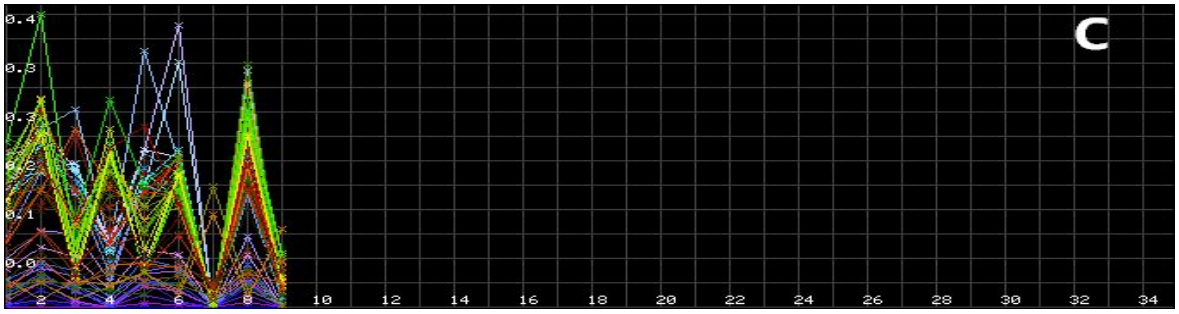



**Figure 4.24:** Mahladisa household curve subsurface profile for autumn with drilled borehole at point 8.



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### 4.6.4 Community Borehole Geo-Profile

The borehole is drilled 125 m deep at point 5. The area at point 5 is associated with low resistivity, representing a high probability of water. The red spot on the borehole profile is associated with a hard rock. In autumn, the borehole was pumping significant turbid water, possibly due to several factors such as Well construction, sediments, or natural mineral deposits (Oyegoke et al., 2020; Alabi et al., 2022).

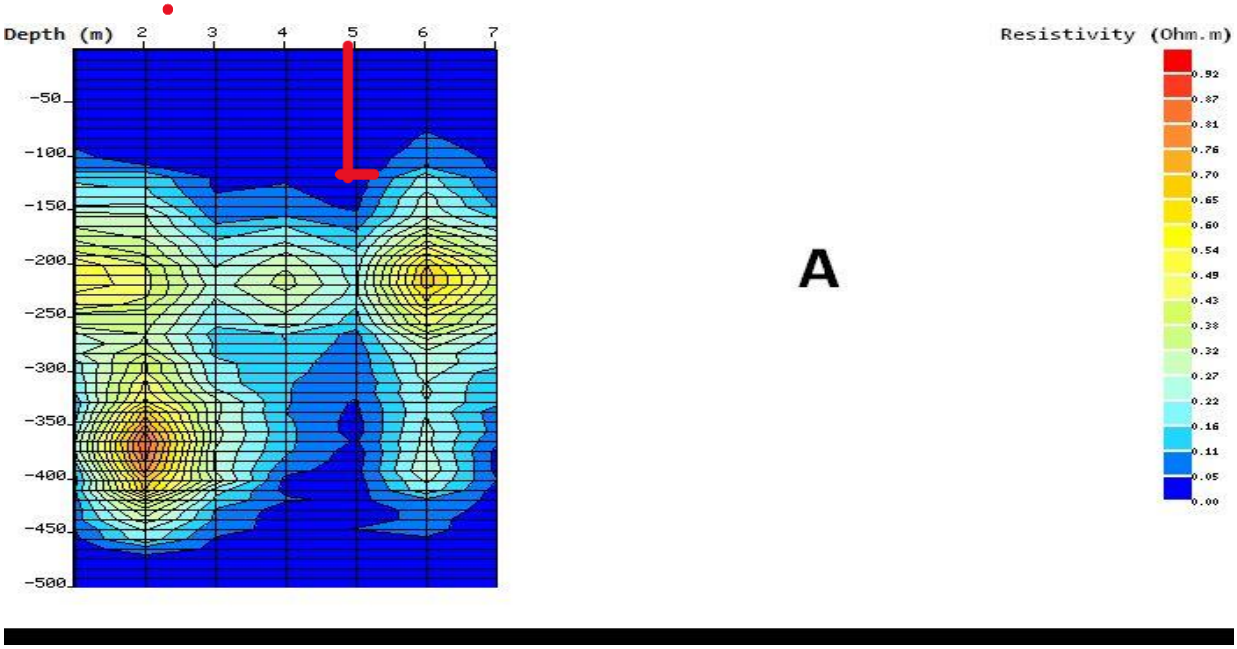



**Figure 4.25:** Ga-Ramaswikna community borehole, raw profile for autumn. Borehole drilled at point 5, 125 m deep.

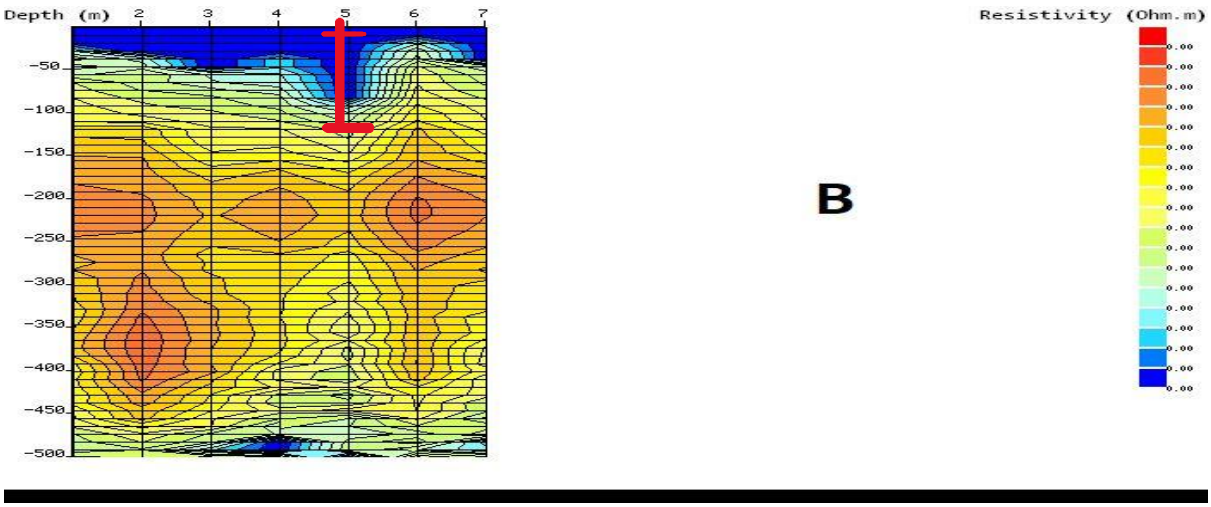



**Figure 4.26:** Ga-Ramaswikna community borehole, processed profile for autumn. Borehole drilled at point 5, 125 m deep.



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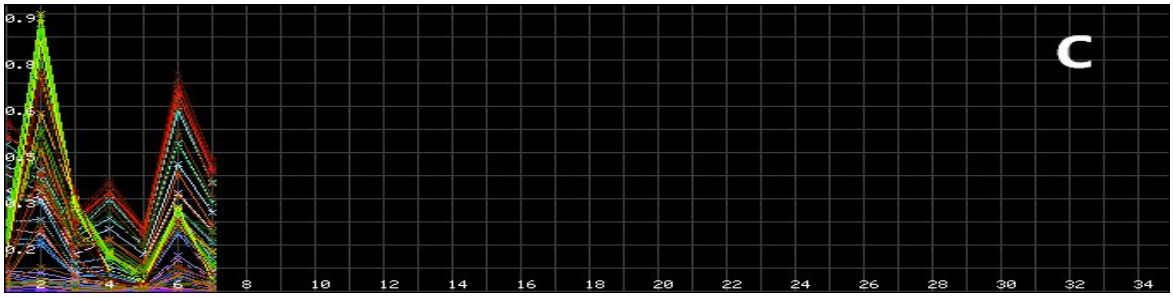



**Figure 4.27:** Ga-Ramaswikna community borehole, curve profile for autumn. Borehole drilled at point 5, 125 m deep.

### 4.6.5 Mashabela Homestead Subsurface Profile

Mashabela's borehole is located at 22 44 59S and 28 47 17E coordinates, just a few meters away from the Mogalakwena River shown (Figure 3.10) of sampling points. The borehole is drilled 30 m deep at point 3, the water is pumped continuously without getting finished seasonally. The borehole profile of Mashabela's household is associated with a low-value rock portion (low resistivity), which indicates a high presence of conductance material, and a high probability of water. The original profile is almost covered with blue colour, indicating low resistivity and high probability of water. The black spot on the profile also indicates an aquifer or water-bearing formation (Alabi et al., 2022; Hunan Paqi Electromagnetic Instrument Institute). No hardrock is present on Mashabela's borehole profile. In autumn, the borehole was adequately pumping water.

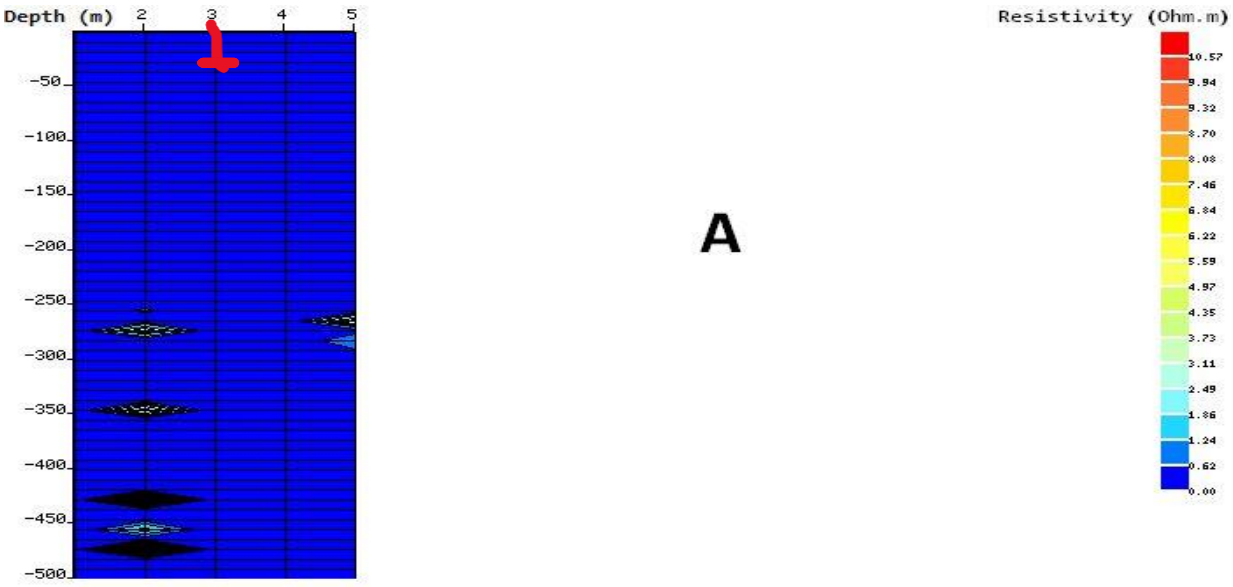



**Figure 4.28:** Mashabela autumn, raw subsurface profile. Borehole drilled at point 3, 30 m deep.



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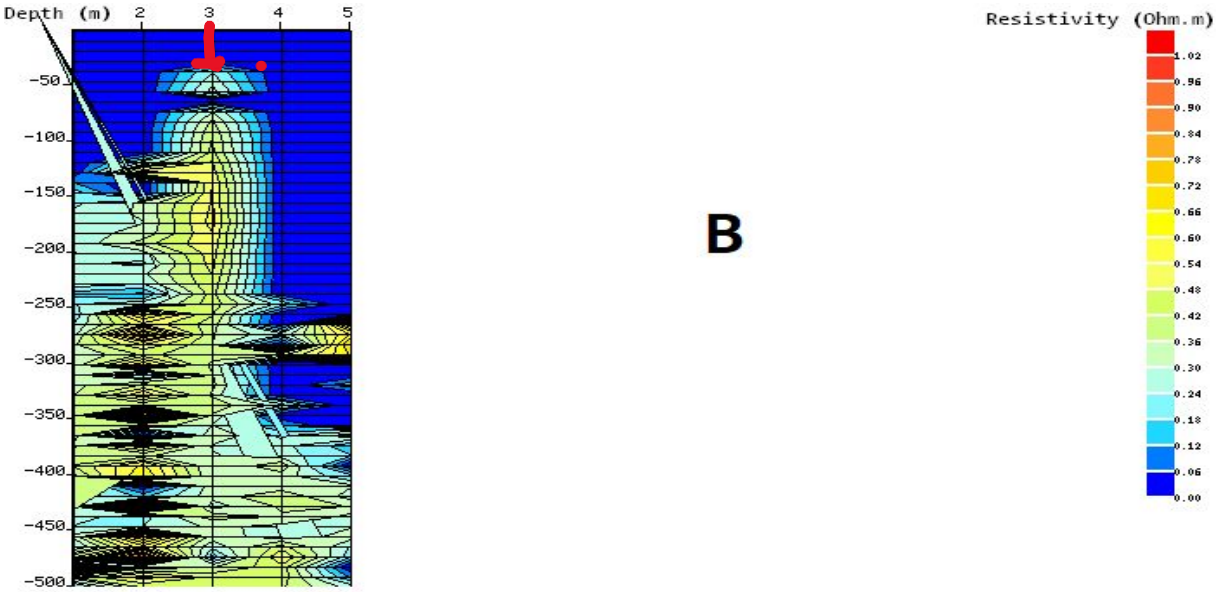



**Figure 4.29:** Mashabela autumn, processed subsurface profile. Borehole drilled at point 3, 30 m deep.

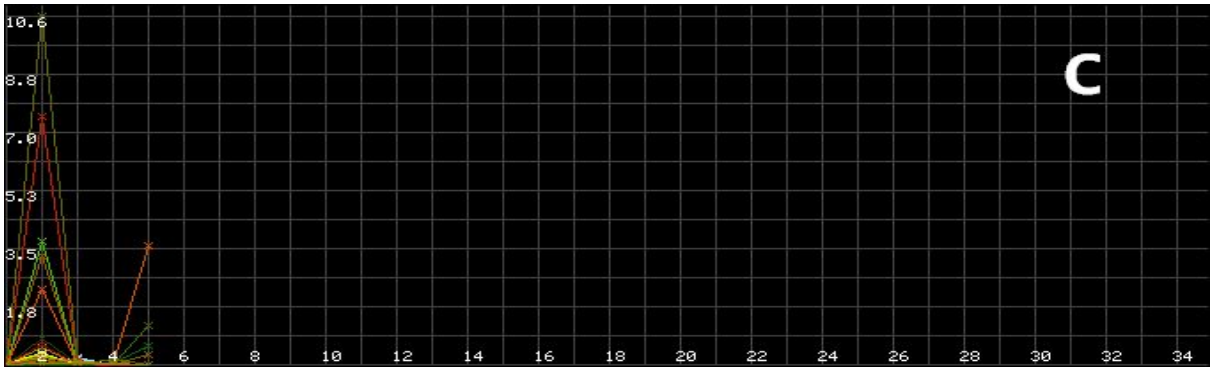



**Figure 4.30:** Mashabela autumn, curve subsurface profile. Borehole drilled at point 3, 30 m deep.



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## 4.7 Winter PQWT Electromagnetic Borehole Profiles

### 4.7.1 L99 Sepaela Winter Borehole Profile

The Sepaela borehole is drilled 70 m deep at point 4. However, the pump duration was 2 hours to fill 200 litres of a water barrel in winter. The resistivity values for areas that have a high probability of water range from 0 to 0.16 (Blue zone), 0.16 to 0.23 for a green zone, this colour also represents lesser medium strengthen rock formation, this zone or colour also represents the starting of water zones. This zone may be dry sometimes (Alabi et al., 2022). Yellow zone had a resistivity of 0.26 to 0.32, this zone is a medium strengthen rock formation. High probability for rock. It has Low potential water compared to other zones (Alabi et al., 2022; Gerginov, 2021). The orange zone ranges from (0.39 to 0.45). The red zone had a 0.48 to 0.55 resistivity range. This is the area of high rock formation (Bedrock). Water cannot be stored in this zone. Hence, no water is present in this zone. During the dry season like winter, the water table drops in this borehole, therefore, it pumps less water than the wet season. This borehole was supposed to be drilled 80 m at point 3, as shown in Figure 4.31 below.



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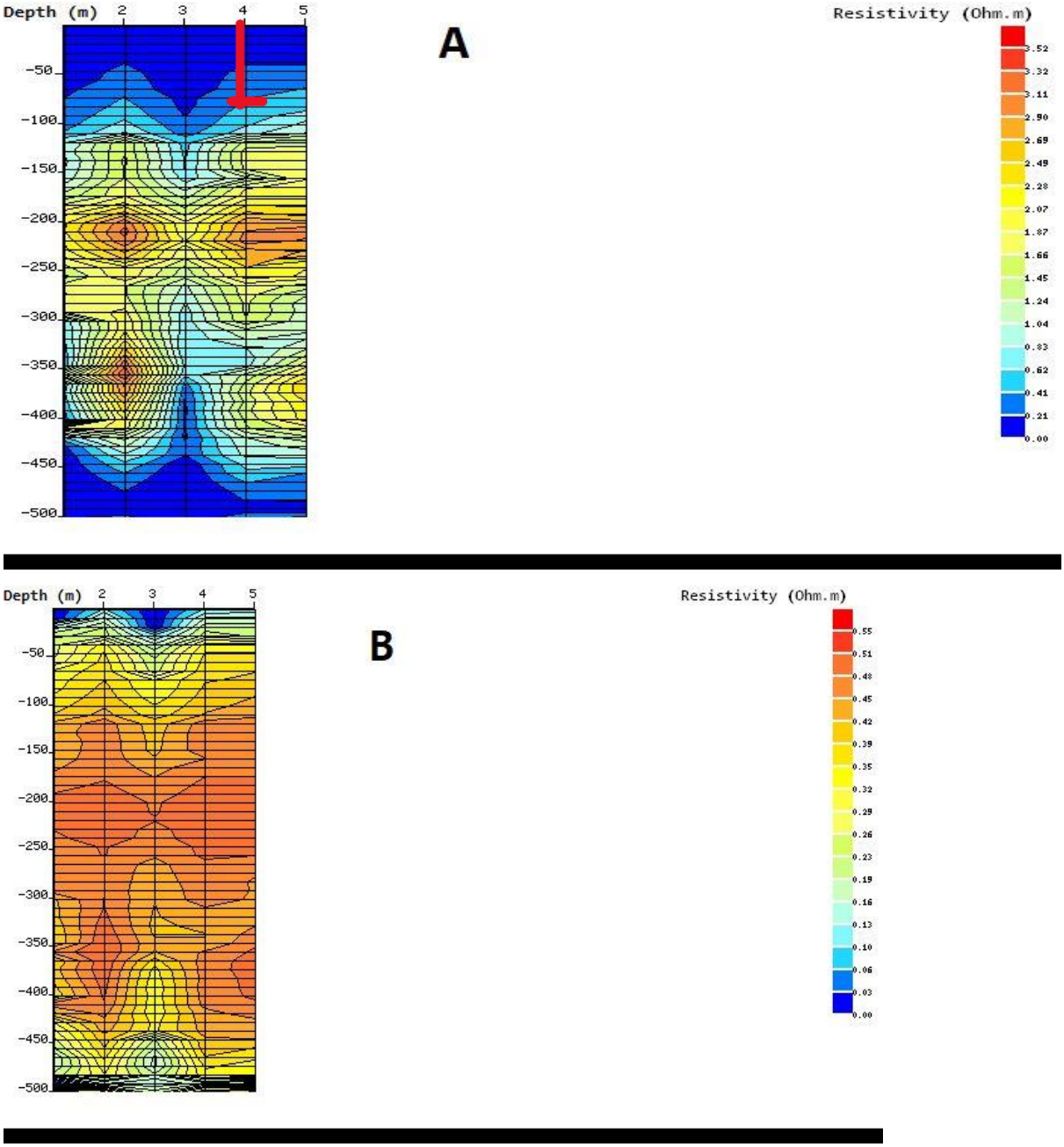



**Figure 4.31:** Sepaela winter, Raw and processed subsurface profile. Borehole drilled at point 4, 70 m deep.

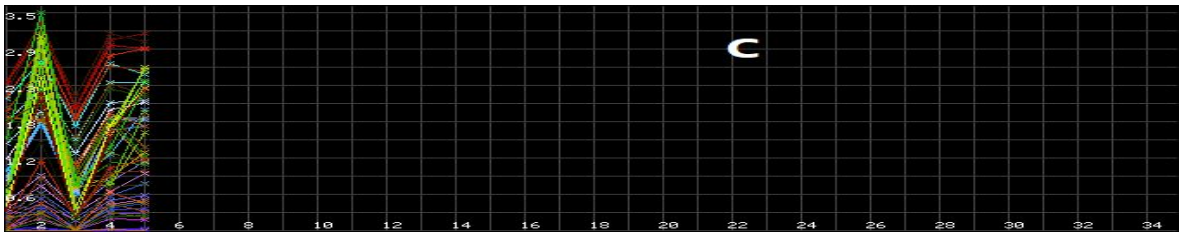



**Figure 4.32:** Sepaela winter, curve subsurface profile. Borehole drilled at point 4, 70 m deep.



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### 4.7.2 L101 Rampa Winter Borehole Profile

This borehole was 1st surveyed in winter it was pumping a 20-litre bucket per day. The figures (4.33 to 4.35) below show the borehole profile of Rampa in winter. This borehole was drilled 50m at point 3. The Rampa borehole should've been drilled 100 m deep to avoid the drop in the groundwater table during the dry season. Ga-Ramaswikana village receives a low annual rainfall as shown in (Appendix 8). The borehole interpretation based on resistivity values should be done carefully, because of factors such as saturated soil, and conductivity at the top which can influence the resistivity values. The topsoil usually represents a blue colour with low resistivity, which represents a high probability of getting water in that zone which may not always be true (Gerginov, 2021; Lateef, 2012; Alabi et al., 2022).

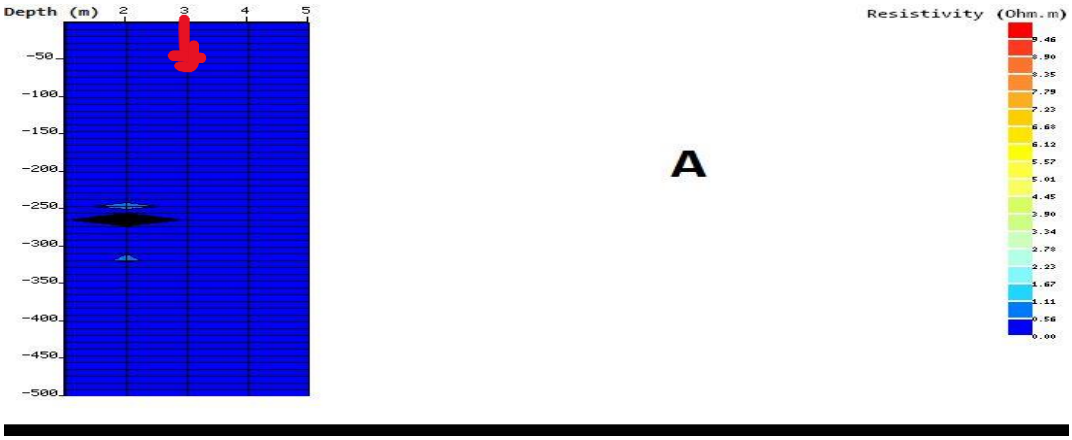



**Figure 4.33:** Rampa winter raw subsurface profile. Borehole drilled at point 3, 50 m deep.

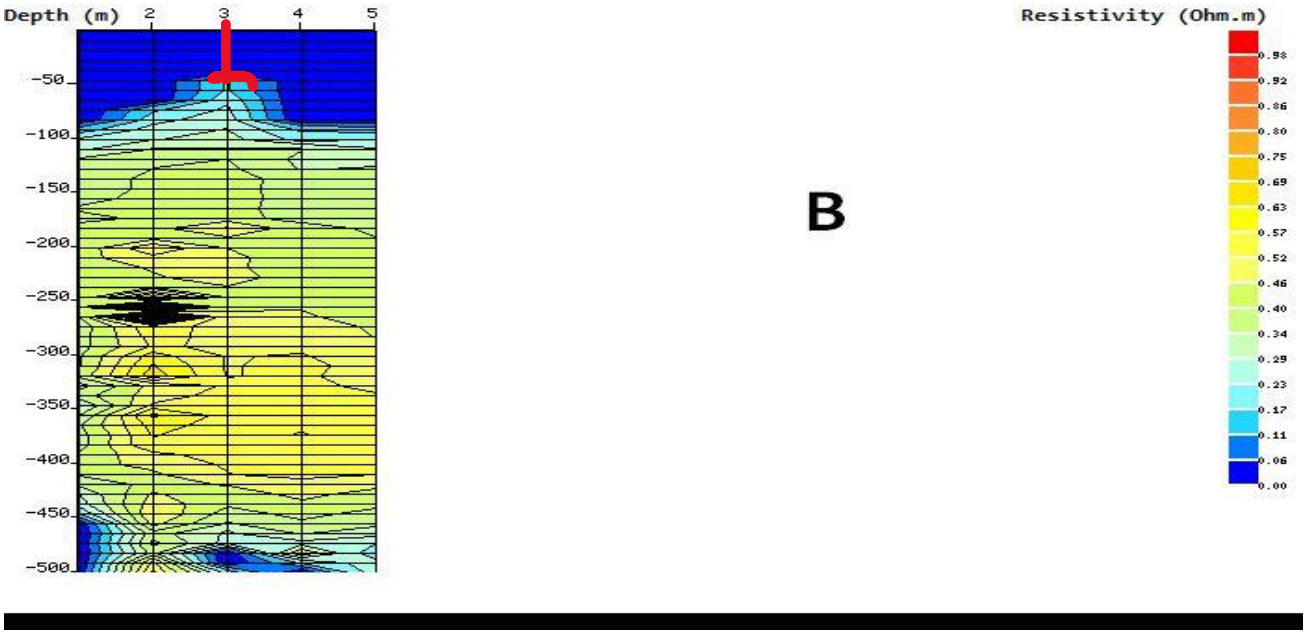



**Figure 4.34:** Rampa winter processed subsurface profile. Borehole drilled at point 3, 50 m deep.



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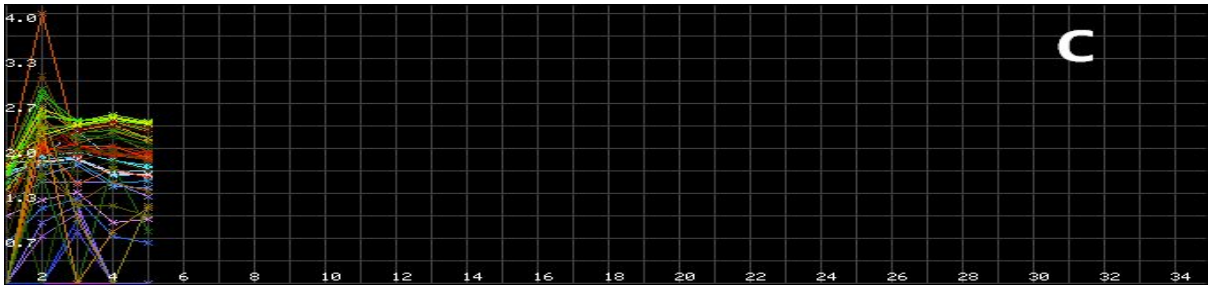



**Figure 4.35:** Rampa winter curve subsurface profile. Borehole drilled at point 3, 50 m deep.

### 4.7.3 L102 Mashabela Winter Borehole Profile

This borehole is located a few meters from the river at coordinates 22 44 59 S, 28 47 17 E, and 22 44 56 S, 28 47 14 E coordinates of the river. Hence, this may be why the borehole pumps a lot of water. This borehole may be influenced by surface and groundwater interaction, whereby the Mogalakwena River recharges the nearest boreholes (Lindle et al., 2023). This borehole was drilled 30m at point 3, therefore, it pumps lots of water. The Mashabela borehole profile is associated with soft and cracked rock formations that can store significant amounts of water. It's always advisable to use the processed profile since it shows all features of the subsurface profile, e.g. the clear visibility of bedrock, and perched and non-perched aquifers (Alabi et al., 2022; Madukwe and Talabi, 2021; Oyegoke et al., 2020). From the borehole survey (rock identification), Mashabela's borehole formation comprises sedimentary rock (ironstone concretions). Drilling a borehole within ironstone concretions could cause an increase in fluoride content in groundwater. Ironstone concretions, which are predominantly formed of iron compounds, may contain other minerals and trace metals, such as fluoride. When a borehole is drilled through such formations, it can disturb the natural structure and composition of the surrounding rock, potentially releasing minerals like fluoride into the groundwater, thereby affecting groundwater quality.



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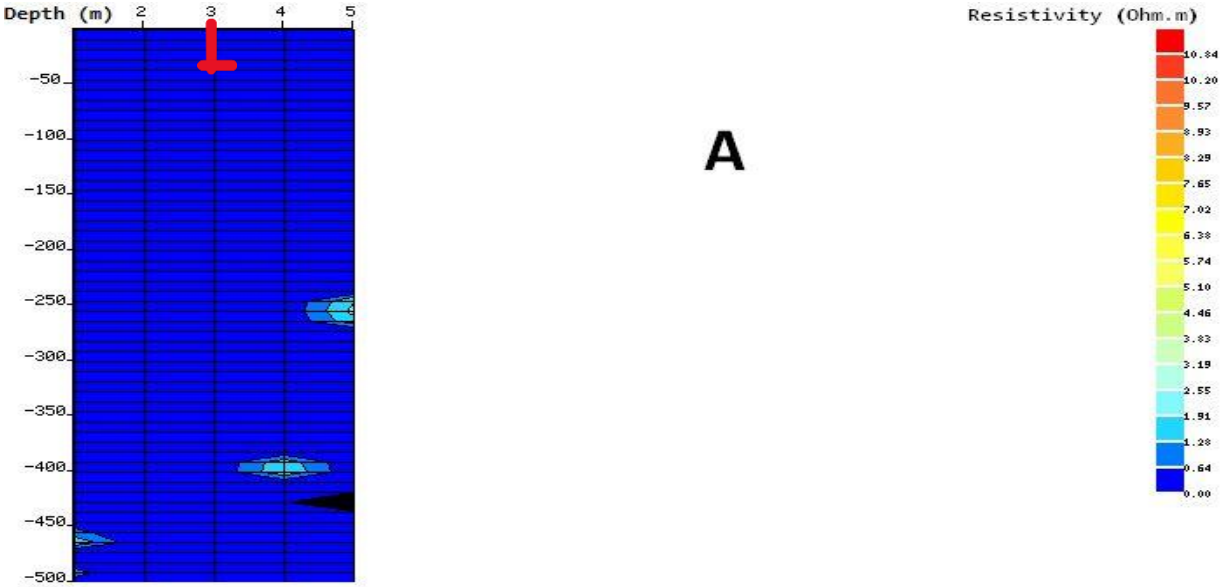



**Figure 4.36:** Mashabela winter raw subsurface profile. Borehole drilled at point 3, 30 m deep.

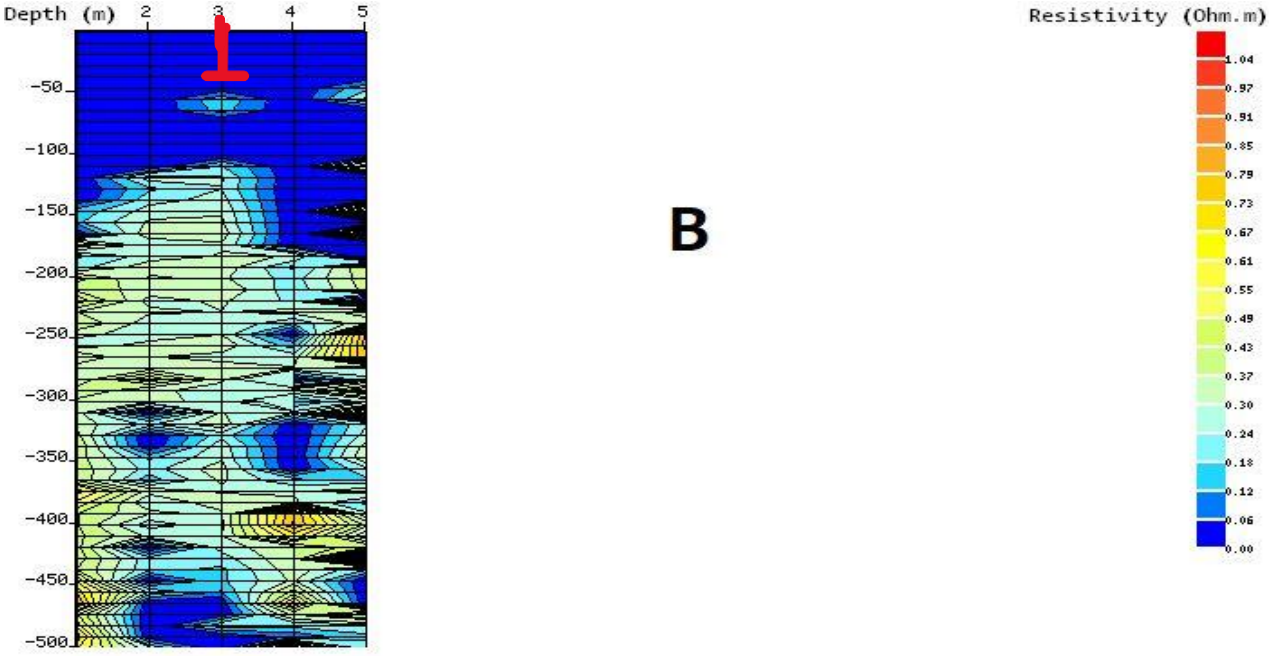



**Figure 4.37:** Mashabela winter processed subsurface profile. Borehole drilled at point 3, 30 m deep.



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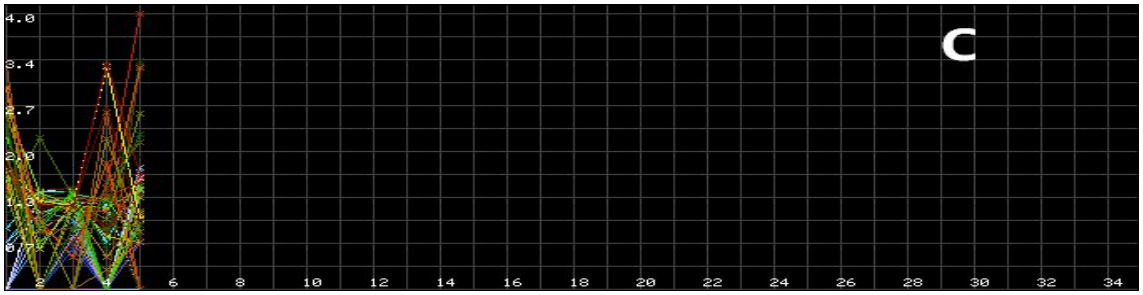



**Figure 4.38:** Mashabela winter curve subsurface profile. Borehole drilled at point 3, 30 m deep.

### 4.7.4 L103 Surveyed proposed site next to Mogalakwena River, raw profile for winter

This is a borehole recommended to be drilled at point 2 next to Mogalakwena River. This is a high-yielding borehole with a lot of water that can supply the entire village of Simson. Point 2 on the profile is associated with low resistivity values. The black spot on the profile at point 2 also indicates the aquifer (water stored in cracks). This borehole will be influenced by surface and underground water interaction (Lindle et al., 2023).

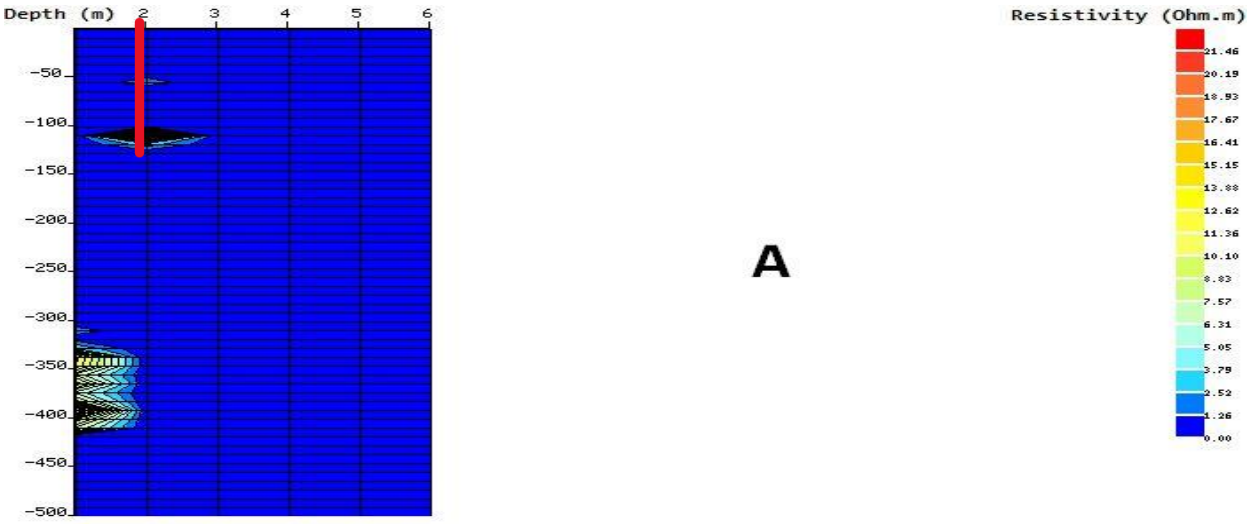



**Figure 4.39:** Mogalakwena raw subsurface profile. The proposed borehole was surveyed at point 2 beyond 50m deep.



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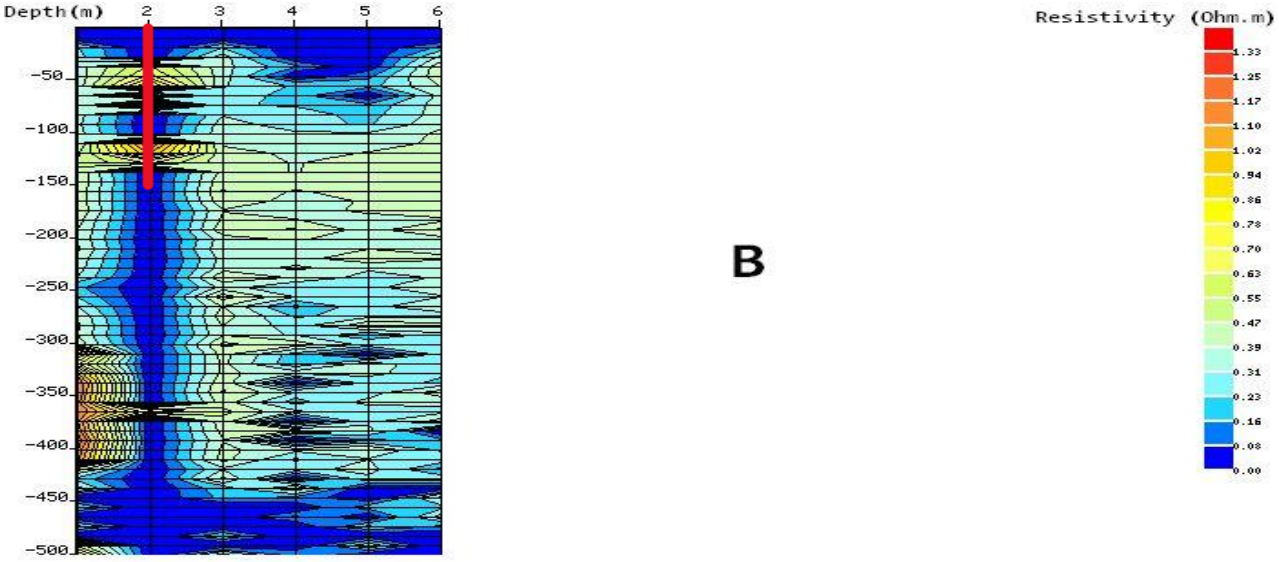



**Figure 4.40:** Mogalakwena processed subsurface profile. The proposed borehole was surveyed at point 2 beyond 50m deep.

### 4.7.5 L04 Mahladisa Winter Borehole Profile

The borehole is drilled at point 2 35m deep. This is the best site for water extraction, the borehole does not get dry. Point 2 is associated with low resistivity which ranges from 0 to 0.61 Ohm.m. Therefore, this is from the earth's surface to 300m downwards. Moreover, from 350m to 390m deep is hard rock, linked with high resistivity values ranging from 1.13 to 1.48 Ohm.m (red zone). Hence, this zone is impermeable, making it difficult to store water (Oyegoke et al., 2020; Alabi et al., 2022).

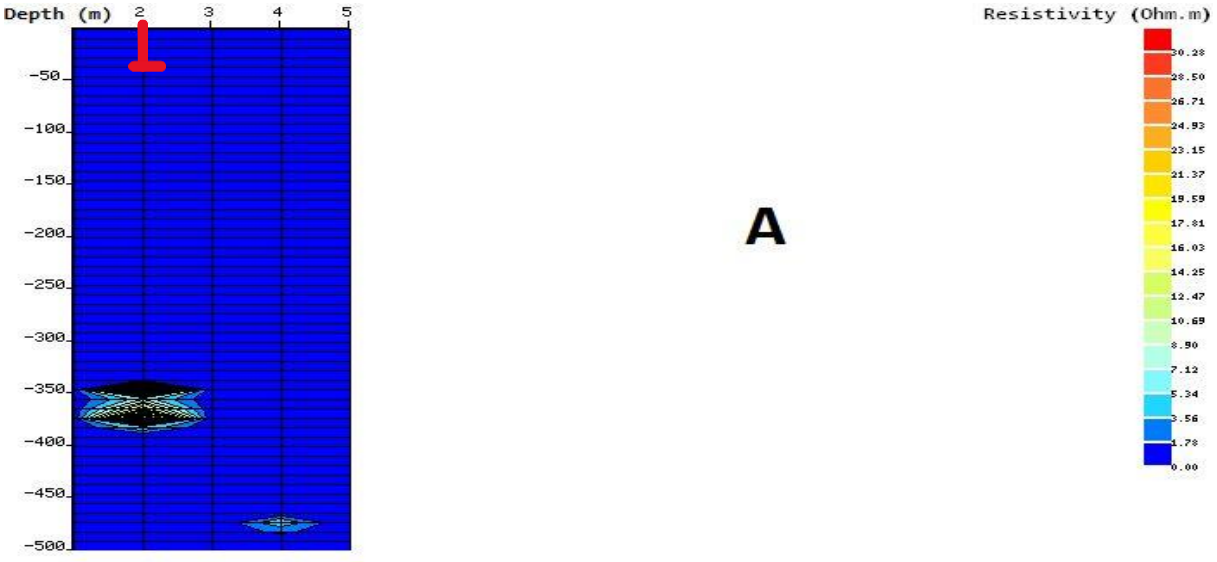



**Figure 4.41:** Mahladisa winter raw subsurface profile. Borehole drilled at point 2, 35 m deep.



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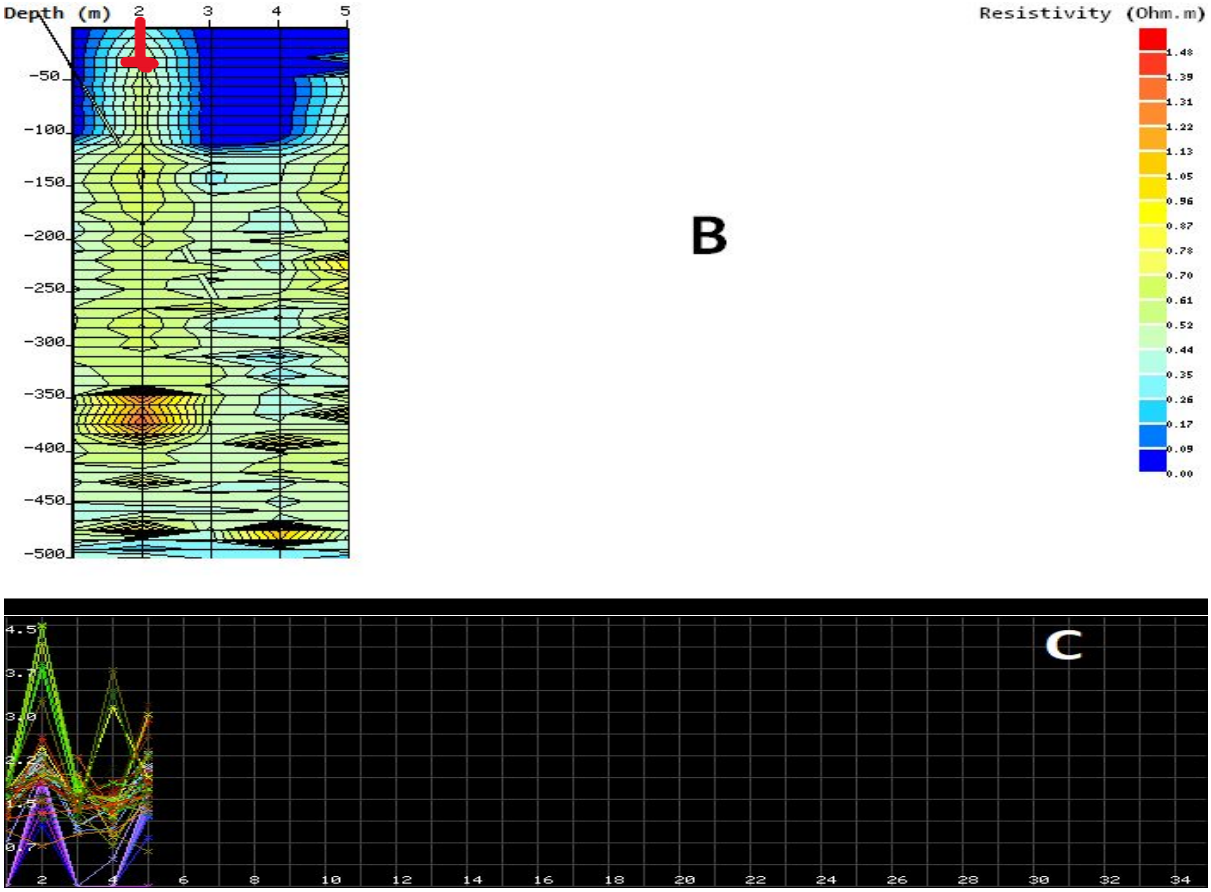



**Figure 4.42:** Mahladisa winter processed and curve subsurface profiles. Borehole drilled at point 2, 35 m deep.

### 4.7.6 L105 Community Borehole Profile for Winter

The V shape on the profile is often associated with areas of high potential zones (Alabi et al., 2022; Oyegoke et al., 2020). The red zone is bedrock, an area of high resistivity. Hence, you cannot find water in this zone. The drilled borehole in this subsurface profile is at point 5, 125 m deep.



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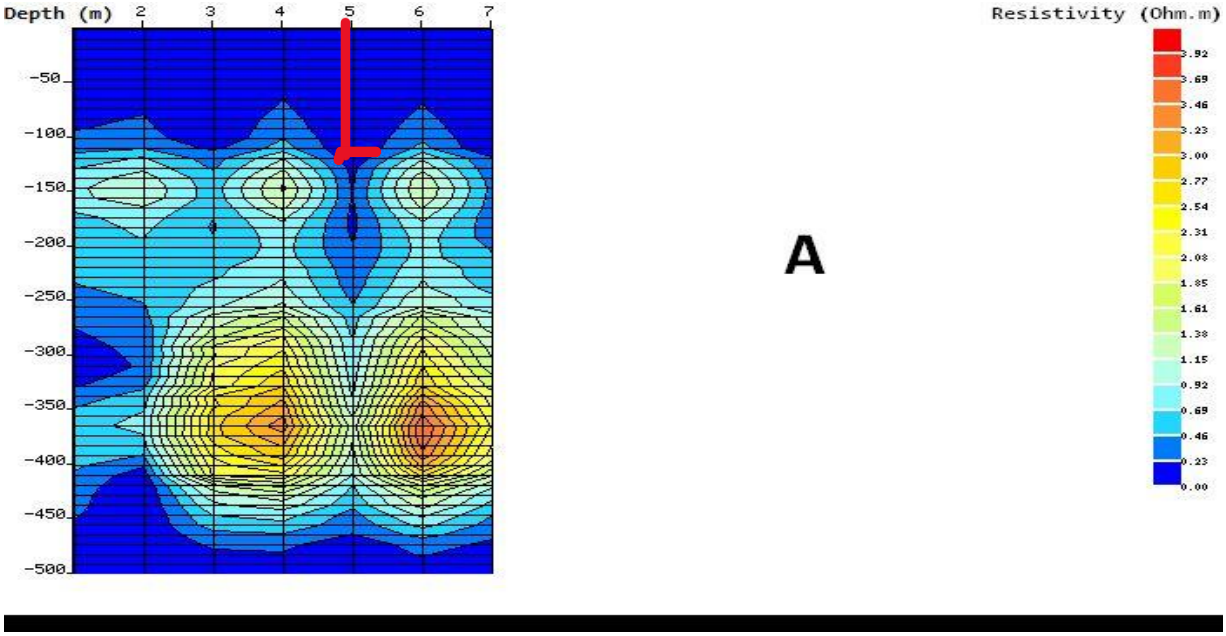



**Figure 4.43:** Community original borehole subsurface profile. Borehole drilled at point 5, 125 m deep.

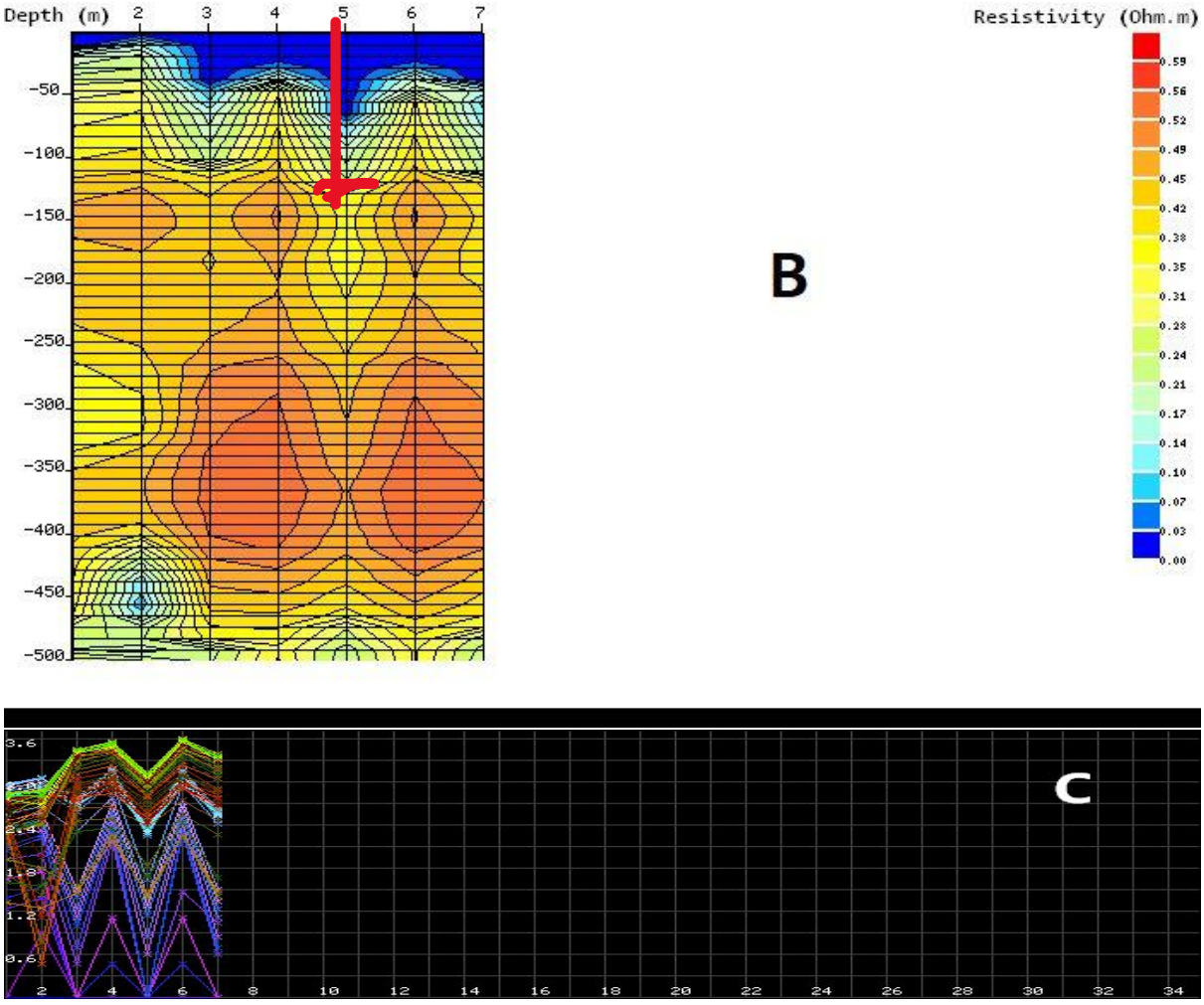



**Figure 4.44:** Community processed and curve borehole subsurface profiles. Borehole drilled at point 5, 125 m deep.



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## 4.8 PQWT Electromagnetic Borehole Profiles for Spring

### 4.8.1 L120 Sepaela Spring Borehole Profiles

In spring and summer Sepaela's borehole produced sufficient water compared to the winter and autumn seasons. The groundwater table decreased in winter compared to the spring season, shown in Figure 4.31 and Figure 4.45. The borehole is drilled at point 4 70 m deep. Point 7 (shown with green line) was the best site with sufficient water for Sepaela's borehole. As a result, it is crucial to conduct a geophysical survey, before drilling a borehole to avoid borehole placement errors.

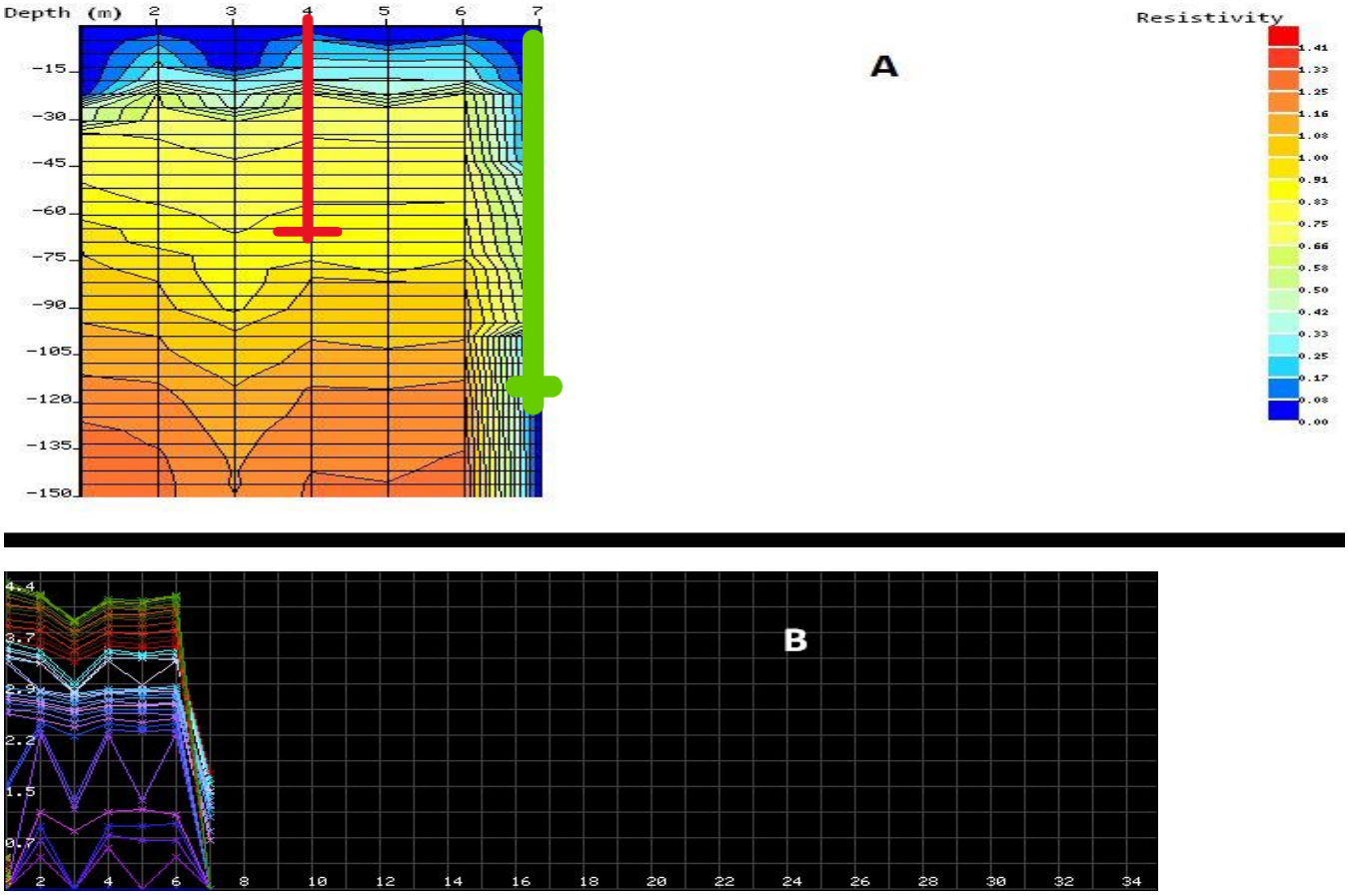



**Figure 4.45:** Sepaela spring processed and curve subsurface profiles. Borehole drilled at point 4, 70 m deep.

### 4.8.2 L121 Rampa Spring Borehole Profiles

Rampa homestead borehole is drilled at point 3, 50 m deep. The borehole needs to be deepened to 100 m deep. This is because the borehole produces low water that cannot sustain the household. Therefore, the borehole was supposed to be drilled at point 2 at least 100 m deep, as shown in the figure (Figure 4.46) below. In spring and summer, the water produced was too



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low for domestic purposes. The circled red part on point 2 on the subsurface profile below was a good point for borehole drilling in the Rampa homestead.

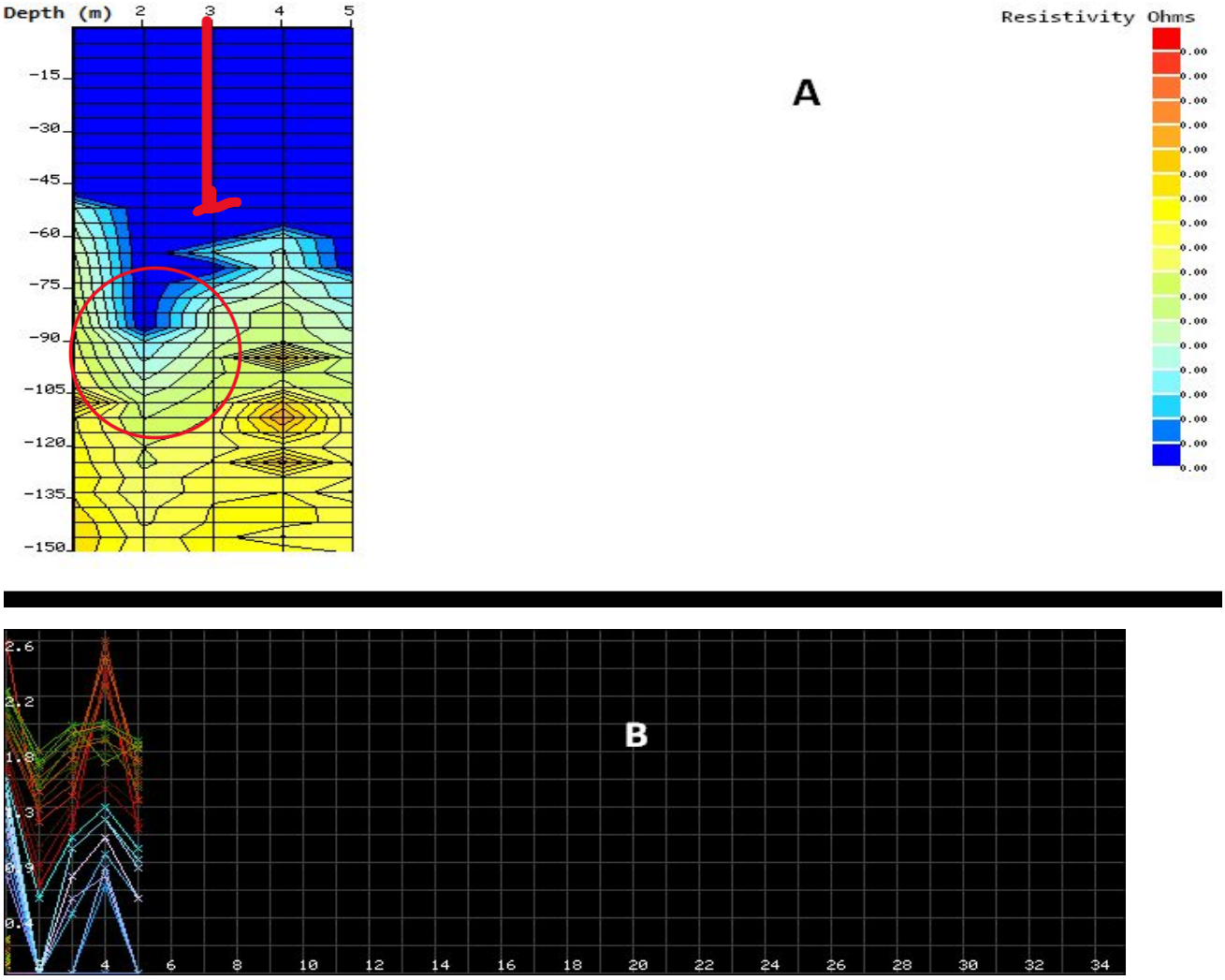



**Figure 4.46:** Rampa spring processed and curve subsurface profiles. Borehole drilled at point 3, 50 m deep.

### 4.8.3 L122 Mashabela Homestead Borehole Profile

This borehole is drilled 30 m deep at point 2. The borehole can pump water throughout all seasons. This is due to the influence of the Mogalakwena River which is close to Mashabela's homestead (Ground and surface water interaction). Mr. Mashabela stated that in the year 2000 when they experienced high rainfall of 889 mm annually according to SAWS (2023), the water from the river was flowing to their homestead. Hence, that is how close the homestead is to the river. The Mashabela subsurface profile where their borehole is located is associated with low resistivity, favouring more underground water. The aquifer of this borehole is associated with minerals causing fluoride and salt in groundwater such as fluorite, mica, apatite, and limestones



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(CGS; Brandl, 2007). Hence, everyone in this household has mottled teeth. Point 4 was also the best site for drilling Mashabela's borehole, as shown in Figure 4.47 below.

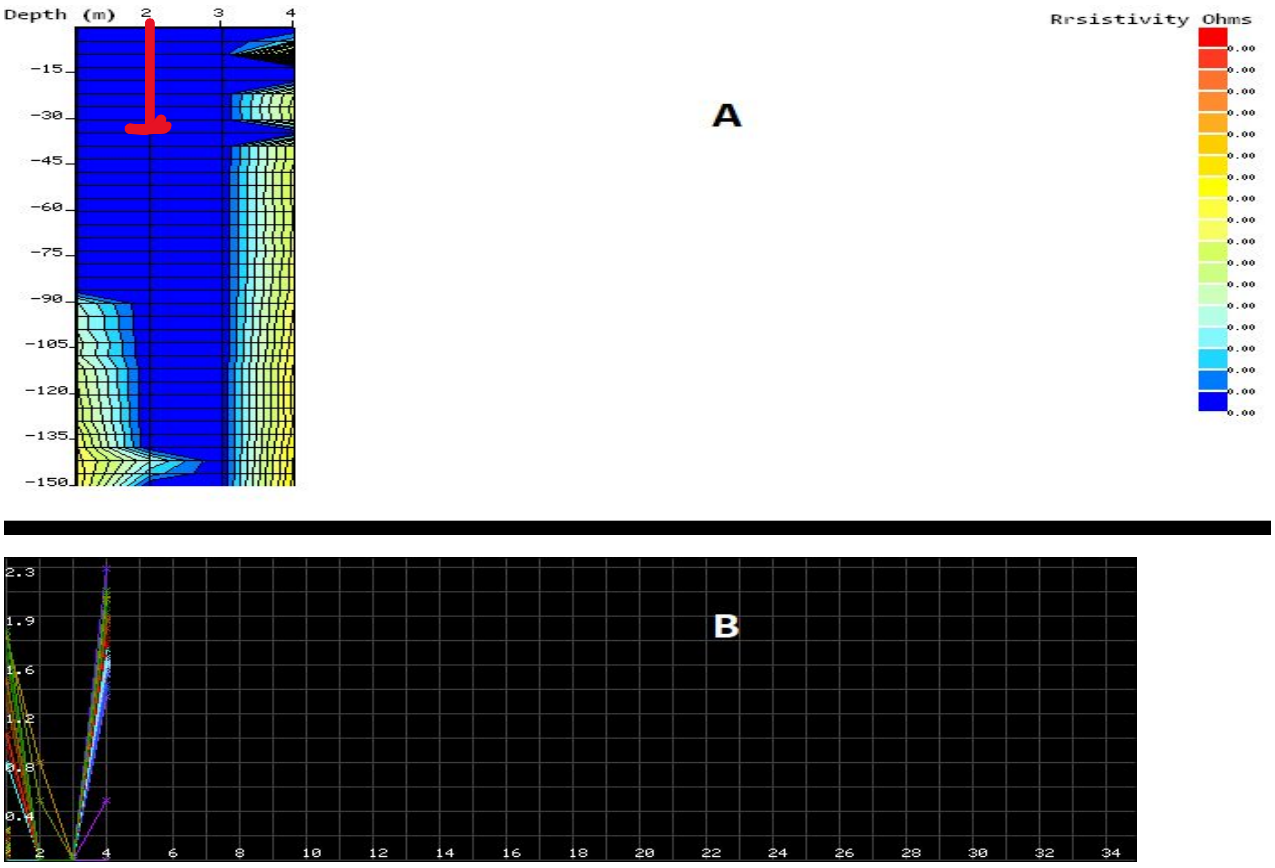



**Figure 4.47:** Mashabela spring subsurface processed and curve profiles. Borehole drilled at point 2, 30 m deep.

### 4.8.4 L123 Proposed borehole site near Mogalakwena River

The proposed site for drilling a community borehole nearby the Mogalakwena River was also surveyed in spring, therefore, the site still shows a good point for water drilling as shown in Figure 5.2 of processed subsurface profile. This will be the best site for drilling a good high-yielding borehole. Point 4 in the (Figure 5.2) of subsurface profile will be the best site for public borehole.

### 4.8.5 L124 Public Borehole Profiles

The community borehole is drilled at point 3 125 m deep. However, the borehole was supposed to be drilled at point 1 illustrated with green line in the figure 4.48 below. In wet seasons, spring and summer the borehole was pumping high turbid water, brown in colour as shown in (Figure 4.7). Figure 4.48 below shows a subsurface profile of where the community borehole is located. The borehole drilled at point 3 is always pumping high turbid water, even after the cleaning of



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storage tanks. Therefore, this may be influenced by rock strata where the borehole was drilled. The circled red part on the profile below may be influencing turbid water.

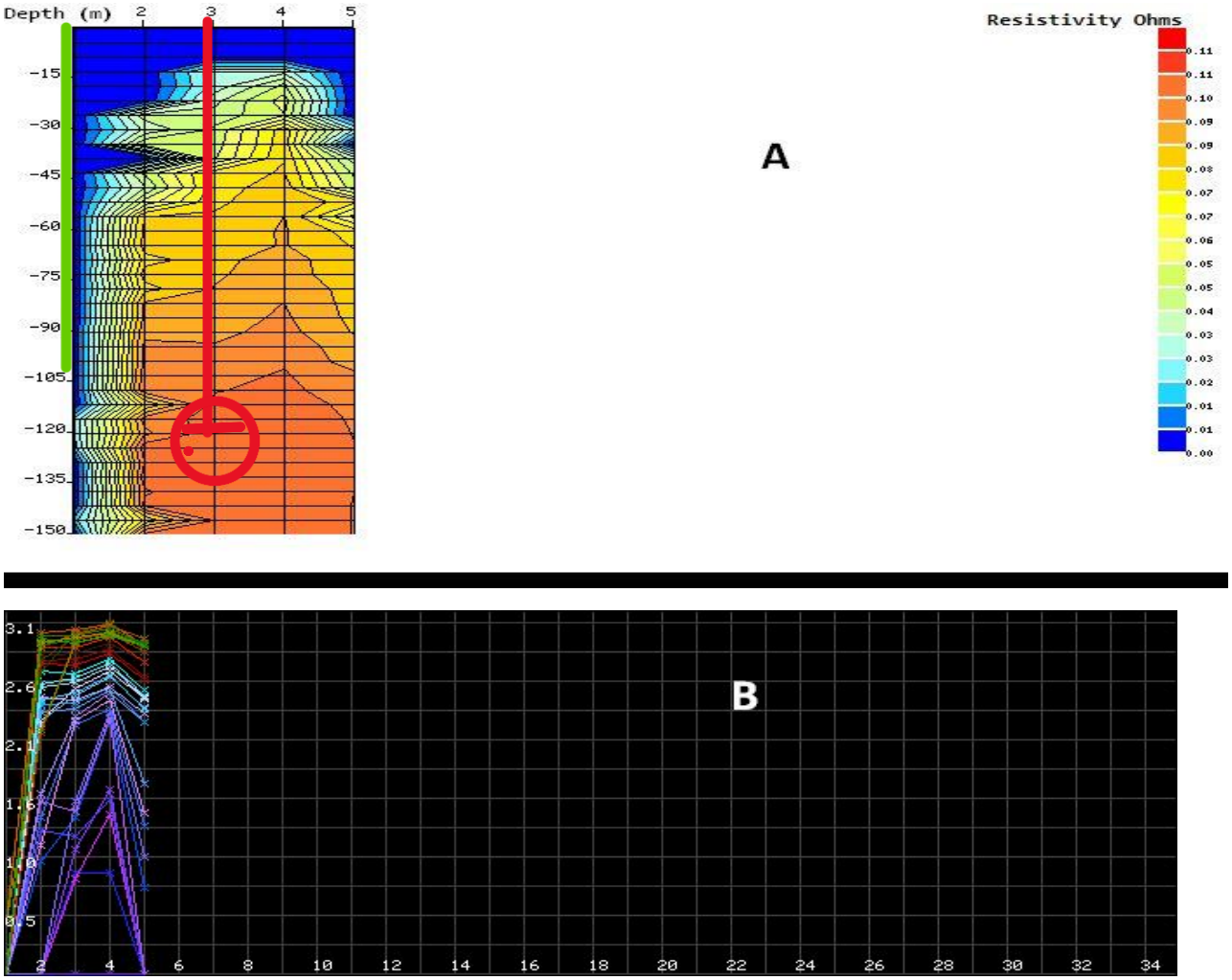



**Figure 4.48:** Spring public borehole subsurface profile processed and curve profiles. Borehole drilled at point 3, 125 m deep.

### 4.8.6 L125 Mahladisa Borehole Profiles

Mahladisa borehole in spring produced enough water to sustain the entire homestead and for their small backyard irrigation. In this subsurface profile, the existing borehole is at point 3, which is sufficiently recharged in wet season as shown in (Figure 4.49) below of borehole profile. The subsurface profile of Mahladisa's homestead from 1 to 5 m apart is associated with a good site for groundwater yielding, therefore, it is a good site for borehole drilling. The entire subsurface profile is allied with low resistivity values, which is mostly regarded as a good site for borehole sitting. During winter season, this borehole recharges salty water.



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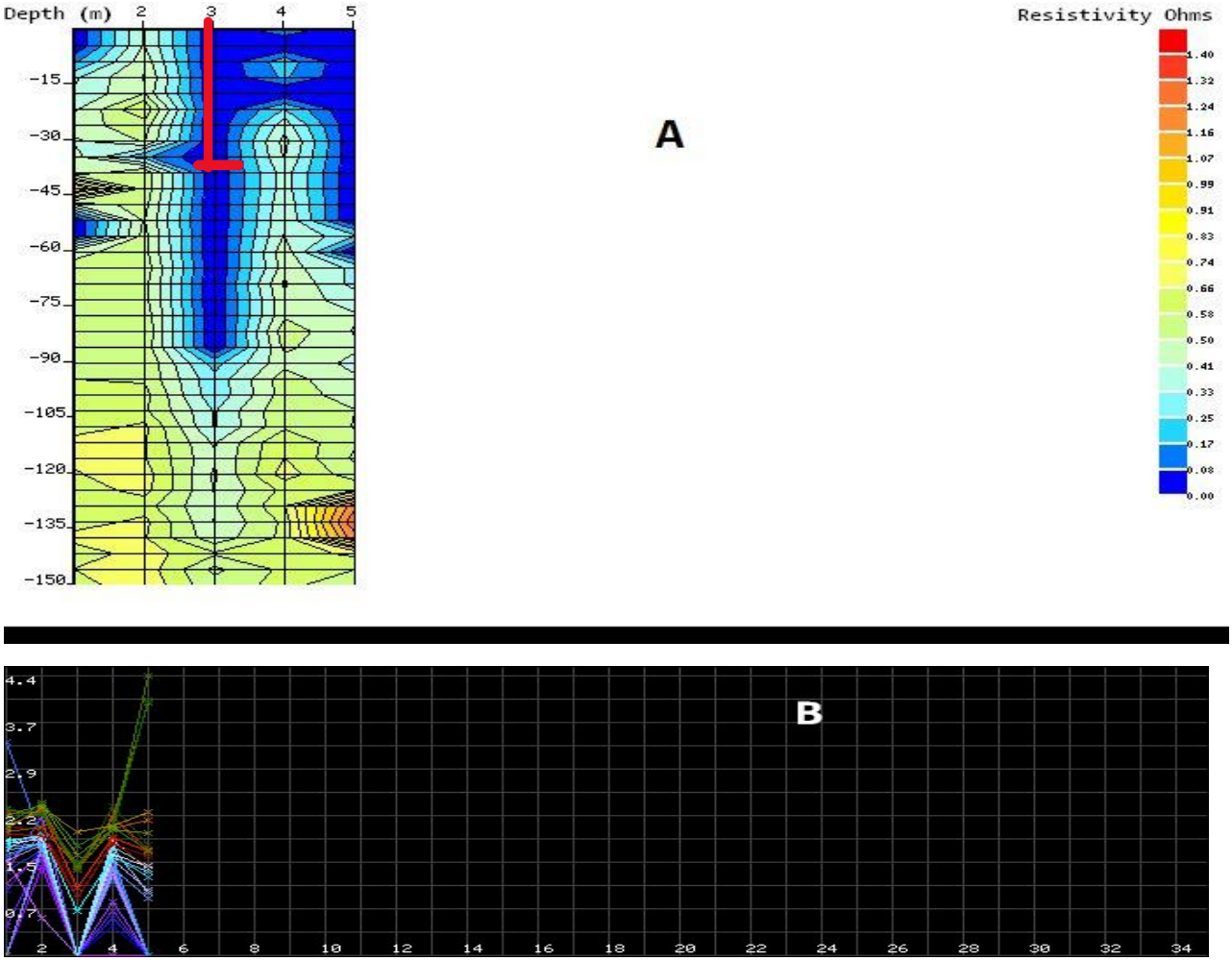



**Figure 4.49:** Mahladisa homestead subsurface profile for spring (processed and curved). Borehole drilled at point 3, 35 m deep.

## 4.9 Rainfall Data of Ga-Ramaswikana Village



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This is the monthly rainfall (mm) data of the nearest station (07631496) Tolwe-Pol, for a period of 30 years. Appendix 8 shows the monthly rainfall data from 1993 to 2023. However, from the data below it is revealed that Ramaswikana village receives a decreasing annual rainfall. Therefore, this poses a serious threat to groundwater resources in Ga-Ramaswikana village. The most annual rainfall occurred in the year 2000 (889mm) and the least was in 2003 (117mm). South Africa is considered a semi-arid area. There is a decrease trend in annual rainfall patterns in Ga-Ramaswikana, however, this area is regarded as a dry area, influencing the decrease in groundwater levels. In the past two years 2022 and 2023 the area received an annual rainfall of 215.1 mm and 198.5 mm respectively, which was very low according to South African Weather Bureau. Therefore, this had a significant impact on groundwater resources in this village, most boreholes in the study are no longer functional due to the drop in groundwater level resulting from little groundwater recharge. The borehole geophysical survey and rainfall data from the South African Weather Service indicate that the Ramaswikana village falls under dry and semi-dry areas with low annual rainfall.

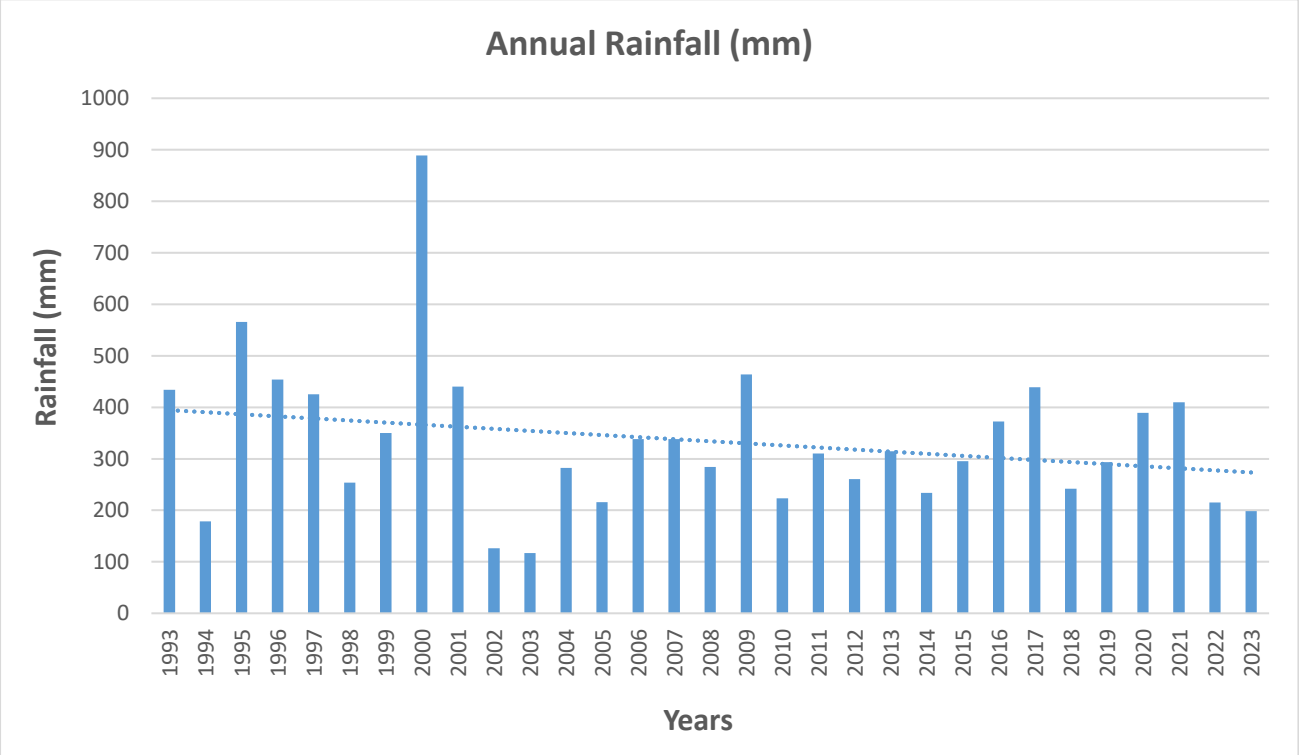



**Figure 4.50:** Annual rainfall timeline of Ramaswikana village (SWS, 2024).

## CHAPTER 5: CONCLUSION AND RECOMMENDATIONS



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## 5.1 Preamble

This chapter summarises the outcomes of the study and gives recommendations on what should be done to groundwater quality, geological contamination of groundwater, and inadequate water supply within Ga-Ramaswikana village.

## 5.2 Conclusions

Groundwater is a major source of domestic use in the Ga-Ramaswikana (Simson) village. However, there's a massive challenge to the availability and production of groundwater and groundwater quality. The study's main objective was to evaluate the status of groundwater quality for human consumption, geological formation of boreholes, and subsurface profiling of boreholes. Five existing boreholes and 2 proposed surveyed boreholes were selected based on a previous study by Sethokga, (2021). The study found that the groundwater from this village is prone to arsenic in some weather seasons, and high fluoride concentration causing the brown or mottled teeth to residents. In homesteads such as Mashabela, Mahladisa, and community boreholes where the fluoride levels are very high if the water is consumed for a long duration may lead to skeletal fluorosis. Most water samples in the study had a highly salty taste, such that it becomes difficult for residents to consume the water, especially if it's not cold. The water from Rampa (P18) and Mahladisa's boreholes (P12) in spring exceeded the arsenic limit of 0.01 mg/l of WHO guidelines. Hence, this also includes the following boreholes in summer, Sepaela (P13), Rampa (P14), and Community boreholes (P15). The public borehole is the most dependent source of water in the community. However, the highest turbidity of water was found in the public borehole. Although the community was advised to often clean its storage tank the water would still come brown. Hence, this may be due to the geochemical influence on groundwater.

The geochemistry of groundwater in Ga-Ramaswikana Village is dominated by calcium chloride ($CaCl_2$) water type in most boreholes. The most dominant cation and anion are calcium and chloride. $CaCl_2$ is a type of hard water that influences a salty taste of water depending on the ratio of the concentrations (Kriger R.A, 1963). The groundwater chemistry of a public borehole is $CaCl_2$ throughout all weather seasons. This tells that the public borehole is drilled on a calcium chloride rock formation.



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Simpson Village lacks access to safe, adequate drinking water that is sustainable. The geophysical survey has revealed that some boreholes in the study were wrongly sited, and some are associated with the geological material that alters the water quality. High fluoride concentration in groundwater is caused by fluoride-causing minerals and is influenced by geochemical processes. The geological formation of Ga-Ramaswikana belongs to the Gneiss suite. Gneisses are metamorphic rocks that commonly originate from granites or sedimentary rocks. This means they can get minerals from their parent rocks. Granites, a frequent parent rock for gneisses, contain fluoride-bearing minerals such as fluorite, apatite, and mica. As a result, the Alldays Gneiss Group may contain these minerals, which could contribute to fluoride levels in groundwater.

The boreholes geophysical survey and rainfall data from the South African Weather Service (SAWS) indicate that the Ramaswikana village falls under dry and semi-dry areas due to low annual rainfall. Therefore, this had a significant impact on groundwater resources in the area, most boreholes in the study are no longer functional due to the drop in groundwater level resulting from little groundwater recharge.

### 5.3 Recommendations

- Introduce fluoride removal technology since various boreholes are prone to high fluoride concentrations. Hence, most residents in Simson village have mottling teeth (brown teeth), this is because of the high presence of fluoride concentrations in groundwater which they depend on.
- Saline drinking water treatment like reverse osmosis (RO), distillation, and Ion exchange.
- Seasonal groundwater quality monitoring. The groundwater quality must be tested for safe consumption.
- Since metal concentrations might change throughout the year, it is suggested to broaden the scope to incorporate seasonal fluctuation in groundwater quality. Establishing long-term monitoring programs would also yield useful information for tracking trends over time and guiding the development of more potent intervention plans.
- Introducing the geophysical survey of groundwater to avoid drilling boreholes on the wrong sites. High-yielding boreholes will provide sufficient and sustainable water to the community.



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- Drill a high-yielding public borehole next to the Mogalakwena River. Hence, the surveyed subsurface profile of the suggested site to drill borehole was found to have a lot of water which can sustain the entire community of Ramaswikana as shown in figures (5.1 and 5.2)
- Construction of a fenced public borehole with solar panels, like in figure 5.4 of borehole drilling in Zimbabwe, Harare.
- Monitoring rainfall patterns to predict future drought events.
- Construction of a water treatment plant connected to the Mogalakwena River and use the treated River water as an alternative.
- The pit latrines should be located a distance from the borehole. Mahladisa pit toilet was located 4.5m from the borehole.
- Seasonal cleaning of water storage tanks.

**L64 Proposed site to drill public borehole next to Mogalakwena River**

The underground profile of the proposed borehole to be drilled near the Mogalakwena River shows promising areas with a high likelihood of containing adequate water shown in (figure 5.1 and figure 5.2). From points 1 to 6 which are 1 meter apart, the geo-profile shows good water zones, but in this case, the best site for drilling a high-yielding borehole that can supply the entire community is point 4 shown in the (Figure 5.1 and 5.2) below. Point 4 is a good site for drilling a borehole next to the Mogalakwena River. Hence, a vertical rock fracture at point 4 and blue zones represents low resistivity from the earth's surface to 200m deep. Therefore, you can still drill further to 500 m deep on this point. This makes point 4 good for drilling a borehole with a lot of water. Therefore, the geo-profile surveyed next to the Mogalakwena River is covered with a lot of water. A V-shaped formed at point 4 represents the high-water zone area (Bon et al., 2022; Hunai Paqui Water Environmental Institute). It is also advisable to make your drillings based on all geo-profiles of PQWT (Original/raw; Processed and Curved Profile) (Bon et al., 2022; Oyegoke et al., 2020; Alabi et al., 2022). This is a site proposed for drilling a good high-yielding borehole.



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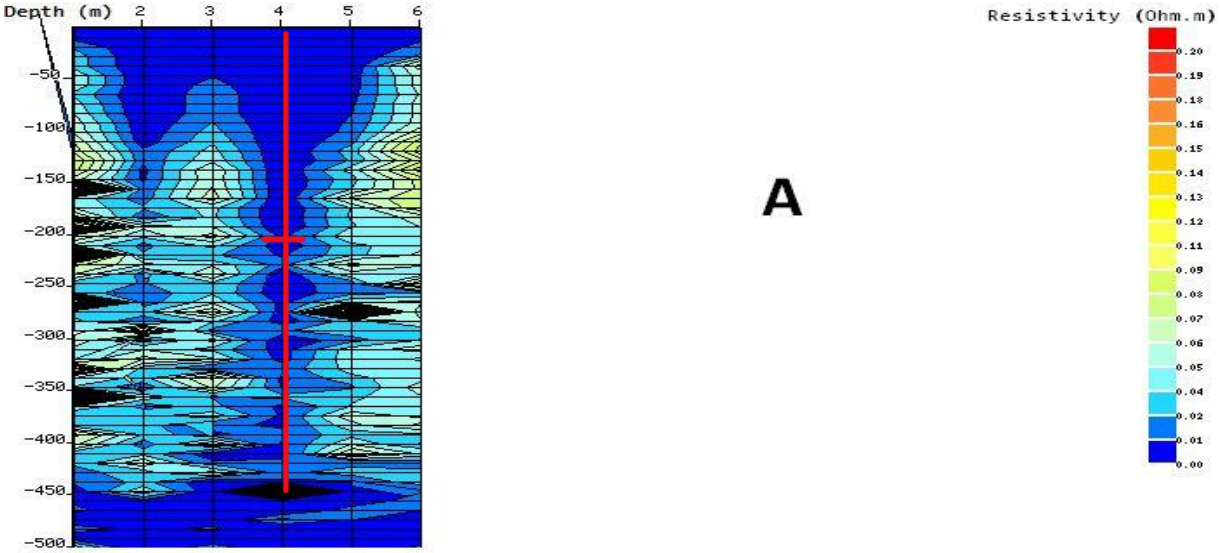



**Figure 5.1:** Surveyed proposed site next to Mogalakwena River, raw profile

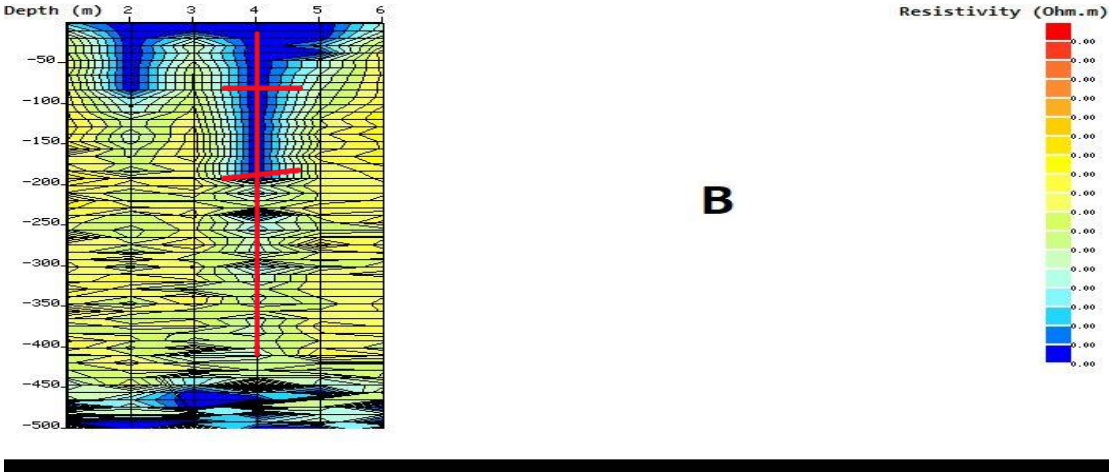



**Figure 5.2:** Surveyed proposed site next to Mogalakwena River, processed profile

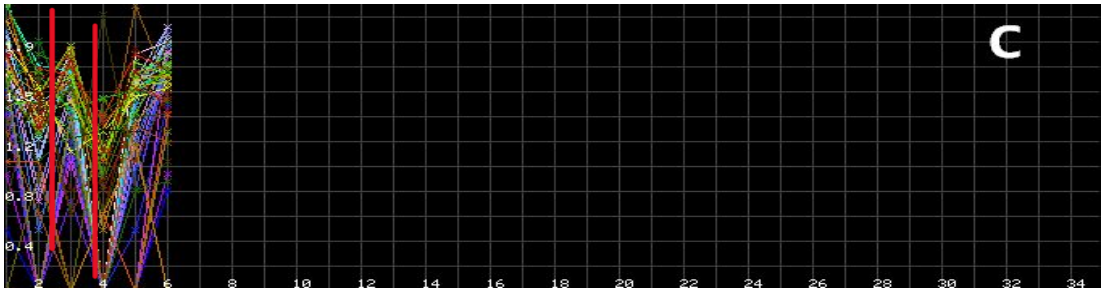



**Figure 5.3:** Surveyed proposed site next to Mogalakwena River, curve profile



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**Figure 5.4.** Borehole drilling with solar panels in Zimbabwe Harare, 2024

## 5.4 Future Avenues for Further Research

- Implementation of new low-cost water treatment technologies for rural areas to ensure potable drinking water.
- Investigation of the history and origin of the geological formation of Ga-Ramaswikana village.

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## Appendices

**Appendix 1:** Autumn Physicochemical Water Quality Parameters

| Sample ID | Lines | EC | TDS | Salinity | pH | Temperature | Turbidity |
|---|---|---|---|---|---|---|---|
| Sepaela | L40 | 1400 | 1052 | 713 | 7,86 | 26,7 | 0 |
| | | 1409 | 1056 | 738 | 7,79 | 27,5 | 0 |



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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1465 | 1046 | 746 | 7,88 | 27,8 | 0 |
| **Average** | | **1424,67** | **1051,33** | **732,33** | **7,84** | **27,33** | **0** |
| **S tandard deviation** | | **35,22** | **5,03** | **17,21** | **0,05** | **0,57** | **0** |
| **CV (%)** | | **2,47** | **0,48** | **2,35** | **0,60** | **2,08** | **0** |
| Community BH | L45 | 1197 | 865 | 613 | 8,17 | 26,3 | 0,63 |
| | | 1209 | 862 | 607 | 8,14 | 25,7 | 2,19 |
| | | 1236 | 865 | 614 | 8,12 | 24,8 | 1,5 |
| **Average** | | **1214** | **864** | **611,33** | **8,14** | **25,6** | **1,44** |
| **Standard deviation** | | **19,975** | **1,73** | **3,79** | **0,03** | **0,755** | **0,782** |
| **CV (%)** | | **1,65** | **0,20** | **0,62** | **0,31** | **2,95** | **54,29** |
| Mashabela | L46 | 1979 | 1422 | 1002 | 7,2 | 27,9 | 0 |
| | | 1991 | 1426 | 1006 | 7,18 | 27,3 | 0 |
| | | 2220 | 1710 | 1240 | 7,13 | 29,6 | 0 |
| **Average** | | **2063,33** | **1519,33** | **1082,67** | **7,17** | **28,27** | **0** |
| **Standard deviation** | | **135,81** | **165,13** | **136,27** | **0,036** | **1,19** | **0** |
| **CV (%)** | | **6,58** | **10.87** | **12,59** | **0,50** | **4,22** | **0** |
| Mahladisa | L65 | 2210 | 1550 | 1100 | 7,7 | 26,3 | 0 |
| | | 2220 | 1560 | 1120 | 7,63 | 27,1 | 0 |
| | | 2210 | 1560 | 1140 | 7,55 | 26,9 | 0 |
| **Average** | | **2213,33** | **1556,67** | **1120** | **7,63** | **26,77** | **0** |
| **Standard deviation** | | **5,77** | **5,77** | **0,08** | **0,08** | **0,42** | **0** |
| **CV (%)** | | **0,26** | **0,37** | **0,01** | **0,98** | **1,56** | **0** |

**Appendix 2:** Winter Physicochemical Water Quality Parameters

| Sample ID | Lines | EC | TDS | Salinity | Temperaure | Ph | Turbidity |
|---|---|---|---|---|---|---|---|
| Sepaela | L99 | 1563 | 1093 | 714 | 23.4 | 7.65 | 0 |
| | | 1560 | 1085 | 720 | 23.6 | 7.67 | 0 |
| | | 1564 | 1077 | 772 | 23.1 | 7.66 | 0 |
| Average | | 1,562,333 | 1085 | 7,353,333 | 23.4 | 7.66 | 0 |



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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| SD | | 2.082 | 8 | 31.90 | 0.252 | 0.01 | 0 |
| CV (%) | | 0.0001 | 0.7373 | 0.0004 | 1.0755 | 0.1305 | 0.0000 |
| Rampa | L100 | 1947 | 1394 | 1005 | 22.3 | 7.97 | 26.85 |
| | | 1955 | 1400 | 1002 | 22.4 | 8 | 22.87 |
| | | 1995 | 1397 | 1009 | 22.9 | 8.02 | 16.26 |
| Average | | 1,965,667 | 1397 | 1,005,333 | 22.5 | 8 | 22 |
| SD | | 25.716 | 3 | 3.512 | 0.321 | 0.0252 | 5.349 |
| CV (%) | | 0.001 | 0.215 | 0.000 | 1.429 | 0.315 | 24.314 |
| Mashabela | L101 | 2580 | 1680 | 1300 | 23.2 | 7.56 | 0 |
| | | 2554 | 1770 | 1320 | 23.1 | 7.45 | 0 |
| | | 2570 | 1779 | 1228 | 22.6 | 7.35 | 0 |
| Average | | 2568 | 1743 | 1,282,667 | 2,296,667 | 7.45 | 0 |
| SD | | 13.115 | 54.745 | 48.387 | 0.321 | 0.105 | 0 |
| CV (%) | | 0.51 | 3.14 | 0.00 | 0.00 | 1.41 | 0 |
| Mahladisa | L103 | 1970 | 1480 | 1006 | 25.8 | 7.55 | 1.16 |
| | | 2006 | 1470 | 1008 | 24.1 | 7.66 | 0.3 |
| | | 2011 | 1480 | 1007 | 25.9 | 7.8 | 0.24 |
| Average | | 1,995,667 | 1,476,667 | 1007 | 25.3 | 7.67 | 0.6 |
| SD | | 22.368 | 5.774 | 1.000 | 1.012 | 0.125 | 0.515 |
| CV (%) | | 0.001 | 0.000 | 0.099 | 3.998 | 1.634 | 85.786 |

**Appendix 3:** Spring Physicochemical Water Quality Parameters

| Seasons | Sample ID | Line | EC (µ/S) | TDS (mg/l) | Salinity (ppm) | Ph | Temperature | Turbidity |
|---|---|---|---|---|---|---|---|---|
| Spring | Sepaela | L120 | 1587 | 1105 | 768 | 7,8 | 24,8 | 0,17 |
| | | | 1582 | 1113 | 787 | 7,73 | 25,3 | 0,19 |
| | | | 1594 | 1096 | 795 | 7,78 | 25,6 | 0,24 |



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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Average | | 1587,7 | 1104,7 | 783,3 | 7,77 | 25,2 | 0,2 |
| | SD | | 6,03 | 8,50 | 13,87 | 0,04 | 0,40 | 0,04 |
| | CV (%) | | 0,4 | 0,8 | 2 | 0,5 | 1,6 | 18 |
| Spring | Rampa | L121 | 2370 | 1650 | 1210 | 7,44 | 24,3 | 1,35 |
| | | | 1210 | 1650 | 1210 | 7,54 | 24,5 | 0,05 |
| | | | 2370 | 1650 | 1210 | 7,45 | 24,6 | 0,11 |
| | Average | | 1983,3 | 1650 | 1210 | 7,5 | 24,5 | 0,5 |
| | SD | | 669,73 | 0 | 0 | 0,06 | 0,15 | 0,73 |
| | CV (%) | | 34 | 0 | 0 | 0,74 | 0,62 | 146 |
| Spring | Mashabela | L122 | 2490 | 1750 | 1280 | 7,91 | 25,3 | 0,58 |
| | | | 2480 | 1750 | 1290 | 8,01 | 25,7 | 0,53 |
| | | | 2500 | 1748 | 1260 | 7,99 | 26 | 0,59 |
| | Average | | 2490 | 1749,3 | 1276,7 | 8,0 | 25,7 | 0,6 |
| | SD | | 10 | 1,15 | 15,28 | 0,05 | 0,35 | 0,03 |
| | CV (%) | | 0,4 | 0,1 | 1,2 | 0,7 | 1,4 | 5,7 |
| Spring | Community Borehole | L124 | 1146 | 805 | 569 | 8,33 | 25,7 | 104 |
| | | | 1144 | 809 | 570 | 8,32 | 25,9 | 94,8 |
| | | | 1156 | 807 | 563 | 8,32 | 25,9 | 106 |
| | Average | | 1148,7 | 807 | 567,3 | 8,3 | 25,8 | 101,6 |
| | SD | | 6,43 | 2 | 3,79 | 0,01 | 0,12 | 5,97 |
| | CV (%) | | 0,6 | 0,25 | 0,67 | 0,1 | 0,45 | 5,88 |
| Spring | Mahladisa | L125 | 2120 | 1353 | 1070 | 7,73 | 25,7 | 0,36 |
| | | | 2130 | 1460 | 1375 | 7,71 | 25,8 | 0,35 |
| | | | 2120 | 1399 | 1384 | 7,7 | 26 | 0,33 |
| | Average | | 2123,3 | 1404 | 1276,3 | 7,7 | 25,8 | 0,3 |
| | SD | | 5,77 | 53,67 | 178,75 | 0,02 | 0,15 | 0,02 |
| | CV (%) | | 0,3 | 3,8 | 14 | 0,20 | 0,6 | 4,4 |
| Spring | Mogalakwena River | L123 | 386 | 274 | 176 | 7,95 | 25,3 | 3,3 |
| | | | 394 | 275 | 184 | 7,93 | 25,5 | 2,44 |
| | | | 391 | 276 | 186 | 7,95 | 25,7 | 2,25 |
| | Average | | 390,3 | 275 | 182 | 7,9 | 25,5 | 2,7 |
| | SD | | 4,04 | 1 | 5,29 | 0,012 | 0,2 | 0,56 |
| | CV (%) | | 1,04 | 0,36 | 2,91 | 0,15 | 0,78 | 21,01 |

**Appendix 4:** Summer Physicochemical Water Quality Parameters

| Seasons | Sample ID | Line | EC (µ/S) | TDS (mg/l) | Salinity (ppm) | Ph | Temperature | Turbidity |
|---|---|---|---|---|---|---|---|---|
| Summer | Sepaela | L120 | 824 | 584 | 453 | 7,6 | 26,7 | 0 |
| | | | 821 | 581 | 455 | 7,58 | 26,9 | 0 |



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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 784 | 578 | 457 | 7,52 | 27,1 | 0 |
| | Average | | 810 | 581 | 455 | 7,57 | 26,9 | 0 |
| | SD | | 22,3 | 3 | 2 | 0,04 | 0,2 | 0 |
| | CV (%) | | | | | | | |
| Summer | Rampa | L121 | 851 | 580 | 475 | 7,47 | 26,6 | 15,67 |
| | | | 856 | 577 | 476 | 7,49 | 26,7 | 8,68 |
| | | | 854 | 595 | 474 | 7,48 | 26,8 | 4,61 |
| | Average | | 853,7 | 584 | 475 | 7,48 | 26,7 | 9,7 |
| | SD | | 2,5 | 9,64 | 1 | 0,01 | 0,1 | 5,6 |
| | CV (%) | | | | | | | |
| Summer | Mashabela | L122 | 865 | 604 | 483 | 8,35 | 26,7 | 0,16 |
| | | | 864 | 602 | 484 | 8,33 | 26,9 | 0,03 |
| | | | 862 | 607 | 483 | 8,34 | 27 | 0 |
| | Average | | 863,7 | 604,3 | 483,3 | 8,3 | 26,9 | 0,1 |
| | SD | | 1,53 | 2,52 | 0,58 | 0,01 | 0,15 | 0,09 |
| | CV (%) | | 0,0018 | 0,0042 | 0,0012 | 0,0012 | 0,0057 | 1,3429 |
| Summer | Community Borehole | L124 | 800 | 546 | 430 | 8 | 26 | 33,01 |
| | | | 792 | 547 | 433 | 8,04 | 27,6 | 32,22 |
| | | | 787 | 550 | 436 | 8,03 | 27,4 | 32,11 |
| | Average | | 793,0 | 547,7 | 433,0 | 8,0 | 27,0 | 32,4 |
| | SD | | 6,56 | 2,08 | 3,00 | 0,02 | 0,87 | 0,49 |
| | CV (%) | | 0,0083 | 0,0038 | 0,0069 | 0,0026 | 0,0323 | 0,0151 |
| Summer | Mahladisa | L125 | 836 | 600 | 606 | 7,61 | 27,5 | 0 |
| | | | 834 | 591 | 607 | 7,62 | 27,2 | 0 |
| | | | 833 | 588 | 609 | 7,6 | 27,6 | 0 |
| | Average | | 834,3 | 593,0 | 607,3 | 7,6 | 27,4 | 0,0 |
| | SD | | 1,53 | 6,24 | 1,53 | 0,01 | 0,21 | 0,00 |
| | CV (%) | | 0,0018 | 0,0105 | 0,0025 | 0,0013 | 0,0076 | 0,0000 |
| Summer | Mogalakwena River | L123 | 653 | 459 | 368 | 7,79 | 27,2 | 28,24 |
| | | | 651 | 458 | 366 | 7,77 | 27,4 | 27,13 |
| | | | 653 | 457 | 363 | 7,78 | 27,6 | 26,26 |
| | Average | | 652,3 | 458 | 365,7 | 7,78 | 27,4 | 27,21 |
| | SD | | 1,15 | 1 | 2,52 | 0,01 | 0,2 | 0,99 |
| | CV (%) | | 0,0018 | 0,0022 | 0,0069 | 0,0013 | 0,0073 | 0,0365 |

**Appendix 5:** Major anions results (IC)

| Seasons | Sample Code | Sample Name | $HCO_3^-$ (mg/L) | Cl- (mg/L) | $SO_4^{2-}$ (mg/L) | $NO_3^-$ (mg/L) |
|---|---|---|---|---|---|---|
| Autumn | P1 | Sepaela Borehole | 63,12 | 12,5 | 6,58 | |



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| | | | | | | |
|---|---|---|---|---|---|---|
| | P2 | Mahladisa Borehole | 245 | 150,8 | 110,47 | |
| | P3 | Public borehole | 43,54 | 125 | 61,45 | |
| | P4 | Mashabela Borehole | 323 | 304,4 | | |
| Winter | P5 | Rampa Borehole | 150,8 | 0,18 | 73,72 | |
| | P6 | Mahladisa Borehole | 440,8 | 55,8 | 62,77 | |
| | P7 | Sepaela Borehole | 17,23 | 61,5 | 86,08 | |
| | P8 | Mashabela Borehole | 580 | 258,71 | | |
| Spring | P9 | Sepaela Borehole | 50,8 | 6,14 | 53,86 | |
| | P10 | Rampa Borehole | 7,12 | 0 | 13,46 | |
| | P11 | Public borehole | 14,014 | 113,81 | | |
| | P12 | Mashabela Borehole | 600,4 | 263,83 | 94,54 | 0,0087 |
| | P13 | Mahladisa Borehole | 140,63 | 94,1 | 69,92 | |
| | P14 | Mogalakwena River | 0,0178 | 0 | | 4,63 |
| Summer | P15 | Sepaela Borehole | 0,0087 | 11,74 | 14,44 | |
| | P16 | Mogalakwena River | 0,0074 | 0 | 19,05 | 10,41 |
| | P17 | Public borehole | 17,89 | 207 | 89,28 | |
| | P18 | Mashabela Borehole | 186,43 | 303,24 | | 3,84 |
| | P19 | Mahladisa Borehole | 50 | 80,45 | 23,09 | |
| | P20 | Rampa Borehole | 23,14 | 0 | | 0,094 |

**Appendix 6:** Ion Chromatography (IC) Sample codes

| **Seasons** | **Sample Code** | **Sample Name** |
|---|---|---|
| Autumn | P1 | Sepaela Borehole |
| | P2 | Mahladisa Borehole |



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| | | |
|---|---|---|
| | P3 | Public borehole |
| | P4 | Mashabela Borehole |
| Winter | P5 | Rampa Borehole |
| | P6 | Mahladisa Borehole |
| | P7 | Sepaela Borehole |
| | P8 | Mashabela Borehole |
| Spring | P9 | Sepaela Borehole |
| | P10 | Rampa Borehole |
| | P11 | Public borehole |
| | P12 | Mashabela Borehole |
| | P13 | Mahladisa Borehole |
| | P14 | Mogalakwena River |
| Summer | P15 | Sepaela Borehole |
| | P16 | Mogalakwena River |
| | P17 | Public borehole |
| | P18 | Mashabela Borehole |
| | P19 | Mahladisa Borehole |
| | P20 | Rampa Borehole |

**Appendix 7**: ICP-OES Sample Codes

| **Seasons** | **Sample Code** | **Sample Name** |
|---|---|---|
| Autumn | P1 | Sepaela Borehole |



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| | | |
|---|---|---|
| | P2 | Public Borehole |
| | P3 | Mahladisa Borehole |
| | P4 | Mashabela Borehole |
| Winter | P5 | Sepaela Borehole |
| | P6 | Rampa Borehole |
| | P7 | Mashabela Borehole |
| | P8 | Mahladisa Borehole |
| Spring | P9 | Sepaela Borehole |
| | P10 | Public Borehole |
| | P11 | Mashabela borehole |
| | P12 | Mahladisa Borehole |
| Summer | P13 | Sepaela Borehole |
| | P14 | Rampa borehole |
| | P15 | Public Borehole |
| | P16 | Mogalakwena River |
| | P17 | Mahladisa borehole |
| | P18 | Rampa Borehole **Note: For Spring** |
| | P19 | River water sample **Note: For Spring** |
| | P20 | Mashabela Borehole |

**Appendix 8:** SAWS monthly rainfall data of Ga-Ramaswikana village, station (07631496), Tolwe-Pol 22.98 50 28.57 50 1993 – 2023 08:00 (Extracted 2024/02/27 10:46).



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| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1993 | 113.7 | 30 | 6 | 0 | 0 | 0 | 0 | 0 | 17 | 4 | 126.6 | 136.5 | 433.8 |
| 1994 | 14.5 | 44 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 16 | 71 | 178.5 |
| 1995 | 120.5 | 26 | 207.5 | 33 | 31 | 0 | 0 | 1.6 | 0 | 7.5 | 104.5 | 34 | 565.6 |
| 1996 | 60 | 168 | 0 | 0 | 0 | 0 | 53 | 0 | 14 | 32 | 96 | 31 | 454 |
| 1997 | 15 | 44 | 156.5 | 6 | 0 | 0 | 0 | 0 | 23 | 51 | 74.5 | 55 | 425 |
| 1998 | 68 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12.5 | 15.5 | 97 | 61 | 254 |
| 1999 | 118.5 | 15.5 | 50 | 0 | 0 | 0 | 5 | 0 | 0 | 48.5 | 59.5 | 53 | 350 |
| 2000 | 118.5 | 422 | 109.5 | 32 | 0 | 5.5 | 0 | 5 | 0 | 29 | 69 | 98.5 | 889 |
| 2001 | 31 | 85 | 57 | 28.5 | 14.5 | 9.5 | 0 | 0 | 0 | 36.5 | 129 | 49 | 440 |
| 2002 | 20 | 35.5 | 12 | 21 | 0 | 0 | 0 | 0 | 0 | 25 | 0 | 13 | 126.5 |
| 2003 | 0 | 34 | 24 | 0 | 0 | 11.5 | 0 | 0 | 0 | 5 | 42.5 | 0 | 117 |
| 2004 | 48.8 | 64 | 62 | 26.5 | 0 | 0 | 0 | 0 | 0 | 32.2 | 17.5 | 31.3 | 282.3 |
| 2005 | 44 | 60.5 | 42.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 69.5 | 216.1 |
| 2006 | 27.5 | 40 | 94 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 89.6 | 81 | 338.1 |
| 2007 | 54.9 | 20 | 45.5 | 0 | 0 | 0 | 0 | 0 | 54.5 | 13 | 89.6 | 61 | 338.5 |
| 2008 | 99 | 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 66.9 | 65 | 283.9 |
| 2009 | 191 | 23.1 | 73 | 0 | 0 | 0 | 0 | 0 | 5 | 22 | 65 | 84.5 | 463.6 |
| 2010 | 32.4 | 0 | 52.5 | 54 | 0 | 0 | 0 | 0 | 0 | 15.5 | 36 | 33.1 | 223.5 |
| 2011 | 59.1 | 17 | 30.5 | 29 | 0 | 0 | 0 | 0 | 0 | 71 | 26 | 77.8 | 310.4 |
| 2012 | 108 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 64.2 | 5 | 63.2 | 260.4 |
| 2013 | 112 | 0 | 30 | 56.2 | 0 | 0 | 0 | 0 | 0 | 27 | 21 | 68.6 | 314.8 |
| 2014 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21 | 200 | 234 |
| 2015 | 35.5 | 16.5 | 91 | 62.2 | 0 | 0 | 0 | 0 | 0 | 0 | 56 | 34 | 295.2 |
| 2016 | 65 | 65 | 36 | 0 | 0 | 0 | 0 | 0 | 0 | 5.5 | 92 | 109 | 372.5 |
| 2017 | 149.5 | 76.5 | 1.5 | 24 | 6 | 0 | 0 | 0 | 24 | 39 | 53 | 65.5 | 439 |
| 2018 | 8 | 76.5 | 12.5 | 21 | 6.5 | 0 | 0 | 0 | 0 | 2 | 39 | 76.5 | 242 |
| 2019 | 58 | 58 | 13 | 47.5 | 0 | 0 | 0 | 0 | 0 | 2.5 | 61 | 53.5 | 293.5 |
| 2020 | 66.5 | 86.5 | 17.4 | 0 | 0 | 0 | 0 | 0 | 0 | 61 | 79 | 79 | 389.4 |
| 2021 | 110 | 115 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |  | 96.4 | 88.6 | 410 |
| 2022 | 19.2 | 11.2 | 23 | 10.4 | 9 | 0 | 0 | 0 | 0 | 80.4 | 39.4 | 22.5 | 215.1 |
| 2023 | 68.4 | 94.6 | 0 | 0 | 0.5 | 0 | 0 | 0 | 0 | 10 | 25 | 0 | 198.5 |



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