AN EXPLANATION OF THE
1:250 000 HYDROGEOLOGICAL MAP SERIES, MAP SHEET 2426
THABAZIMBI

By

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FOREWORD:

Groundwater in South Africa is under-utilised, although some local over-exploitation does occur. Groundwater schemes can be implemented quickly and cheaply and are effective in conjunctive use and dispersed scenarios. With increasing pressure on scarce surface water resources, and with the priority of supplying potable water to disadvantaged rural and urban communities, groundwater will play an increasing important role in South Africa's economic and social prosperity.

A major obstacle to the realisation of this prosperity is that insufficient information about groundwater is reaching the planners, decision makers, users, and other affected parties. To rectify this situation, groundwater information locked away in expert's minds and computer databases, is being made available on maps. The second step in this program at the regional level is, the upgrading of the original "General Hydrogeological Maps" at the scale of 1: 500 000 to 4 x 1:250 000 scale hydrogeological maps i.e. Modimolle, Polokwane, Lephalale, and Thabazimbi.

The main purpose of these Hydrogeological Maps, of which the accompanying map sheet is an example, is to display in an easily understood format, what is known about basic hydrogeological properties. These General Maps represent the synthesis of the most up-to-date data and geohydrologists' knowledge. Thus, these maps are also very useful in identifying areas where additional data should be collected and further investigations need to be conducted.

Groundwater maps – the best available information for the best possible planning, development, and management of a strategic resource – will ultimately benefit all South Africans.

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Cover page: Photo taken from Koedoeskop in a southern direction. The hills in the background are part of the Bushveld Igneous Complex and consist of Nebo Granite. (Photograph: Riekie Boshoff, 15 December 2024).

PREFACE:

Except for air, water can, with little doubt, be defined as mankind's most precious resource. It is said that if food is denied, the body can sustain life for weeks, but if water is withheld, death is likely to come within a few days. The availability of water to even the remotest area is thus vital to maintain this indispensable condition for human existence.

An estimated 3% of fresh water available on Earth occurs on the surface while 97% occurs underground (Johnson Division, 1975). Owing to the lack of perennial streams in the arid to semi-arid areas, two- thirds of South Africa's surface area is largely dependent on groundwater. To tap and develop this vast amount of underground stored water, a keen knowledge of a region's environment, and above all, its diversified geology, is of the utmost importance to comprehend how and where groundwater occurs.

The Thabazimbi 1:250 000 Hydrogeological Map and the accompanying explanatory brochure introduce the current state of the groundwater knowledge and the basic geohydrological characteristics of the map area. It needs to be explained that within the map's confines, dissimilar and divergent conditions occur, which, to various degrees, may impact on groundwater. Under these circumstances, groundwater occurrence can be varied. Groundwater occurrence is thus referred to in this brochure.

The primary aim of the General Hydrogeological Map is to produce a synoptic overview of the geohydrological character of an area. The main map thus features median borehole yield per aquifer unit, aquifer type, groundwater quality, and groundwater use, which are superimposed against a slightly subdued surface lithological background. The brochure discusses these topics in more detail, as well as issues such as geological controls on groundwater yield and quality, borehole siting methods, groundwater management, groundwater levels, suggestions for future studies, etc. It is hoped that both the groundwater scientist and the interested layman will find the product useful. The map and brochure will be informative to planners and developers, especially in the light of the Reconstruction and Development Programme, and it will play a constructive role in general groundwater education, groundwater awareness building and groundwater protection.

Groundwater has always been an important source of water supply to many people and localities in the map area. Water consumers, in many areas, are solely reliant on groundwater for domestic and stock watering purposes. There is a change in focus to utilise groundwater for irrigational purposes due to the high yields intercepted in the underlying aquifers. It is hoped that this map and brochure will serve as a basis for future specialised groundwater maps and groundwater studies as suggested in the brochure.

BACKGROUND TO THE PROJECT:

The Southern African Development Community (SADC) is a regional grouping of 16 sovereign countries, comprising Angola, Botswana, Comoros, Eswatini, Democratic Republic of Congo (DRC), Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Tanzania, Zambia, and Zimbabwe. As articulated in the amended Treaty of 1992, SADC's main objective is to foster co-operation and mutual benefit by all Member Countries from the resources in the region, (Revised Sub-Grand Manual 2022).

To counter meteorological changes experienced in the region that influence water supply, the SADC- GMI (Southern African Development Community Groundwater Management Institute) was established as a Centre of Excellence in groundwater. The mandate is to build capacity in the region through targeted training and funding of groundwater related projects. To fulfil this mandate, the SADC-GMI started awarding sub-grants to Member Countries in 2017 for the implementation of groundwater related pilot projects using a grant from the World Bank through the SADC Secretariat.

After the successful completion of one of these projects, (The Sustainable Groundwater Management in SADC Member Countries, Phase 1 project), the SADC-GMI implemented phase 2 of the same project under the strategic guidance of the SADC Secretariat. Phase 2 entails the updating of the Polokwane 2326 hydrogeological map sheet and brochure. VSA Rebotile Metsi Consulting was appointed 15 January 2024 as consultant for the project on a lump-sum contract format. The Prime Partner for SADC-GMI on this project is the Department of Water and Sanitation (DWS), Republic South Africa (RSA). The function of DWS is to monitor, assist, guide, and to assess progress, deliverables, and invoices on behalf of SADC-GMI. This is done through engagement on monthly DWS internal progress meetings as well as monthly SADC-GMI Sub-Grant Project Management Progress Meetings.

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DATA AND REPORTS

DWS (Pretoria) National groundwater and water quality databases
DWS (Pretoria) Geohydrological Reports
Council for Geoscience (Pretoria) Geological information
Municipalities for the map area
VSA Rebotile Metsi Consulting

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ABBREVIATIONS AND ACRONYMS:

Abbreviation	Description
CMAs	Catchment Management Agencies (plural) single is CMA
CWS	Catchment Water Strategy
DWS	Department of Water and Sanitation
DWA	Department of Water Affairs
DWAF	Department of Water Affairs & Forestry
e.g.	Stands for the Latin phrase exempli gratia, meaning “for example.”
ELU	Existing Lawful Water Use
Et al.	An abbreviation for the Latin phrase et alia, which means "and others".
GIS	Geographic Information System
GMI	Groundwater Management Institute
GRIP	Groundwater Resource Information Project (DWS project early 2000)
GRU	Groundwater Resource Units
GW	Groundwater
GRDM	Groundwater Resource Directed Measures
i.e.	Stands for id est. which is Latin for “that is.”
IGS	Institute for Groundwater Studies
LGS	Lebowa Granite Suite
LSI	Langelier Saturation Index
MC	Management Class
MAE	Mean Annual Evaporation
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
mbgl	Meters Below Ground Level
magl	Meters Above Ground Level
mamsl	Meter Above Mean Sea Level
MCWAP	Mokolo Crocodile Water Augmentation Project
ND	Not detected (used in chemistry analysis)
NGA	National Groundwater Archive
NGDB	National Groundwater Data Base
NHS	National Hydrological Services
NWRS	National Water Resource Strategy
NWA	National Water Act of 1998
NWS	National Water Strategy
PSZ	Palala Shear Zone
RDM	Resource Directed Measures
RGS	Rashoop Granophyre Suite
RHP	River Health Programme
RLS	Rustenburg Layered Suite

Abbreviation	Description
RQOs	Resource Quality Objectives
SADC	South African Development Community
SADC-GMI	South African Development Community Groundwater Management Institute
SANS	South African National Standards
SAR	Sodium Absorption Rate
SDC	Source Directed Controls
SWD	Surface Water Dam
SW	Surface Water
TDS	Total Dissolved Solids
TOR	Terms of Reference
TWQR	Target Water Quality Range
UNESCO	United Nations Educational, Scientific and Cultural Organisation
Viz.	Stands for videlicet which is Latin for "namely", ''which is'' or ''as follows''
WARMS	The Water use Authorization & Registration Management System
WMA	Water Management Area
WMS	Water Management System
WRC	Water Research Commission
WRCS	Water Resource Classification System
WUAs	Water User Associations (plural), single WUA
WULA	Water Use License Application
e-WULAAS	Electronic Water Use License Application and Authorisation System

SYMBOLS AND UNITS:

Symbol or unit	Description
a	Annum
Ha	Hectare
HARMEAN	Harmonic mean
km	Kilometer
km^2	Square kilometer
ℓ/s	Liters per second
m	Meter
M	Million
Mm^3	Million cubic meters
meq	Milli-equivalents
mm	Millimeter
mm^2	Square Millimeter
mm/a	Millimeters per Annum
m^2	Square meters
m^3	Cubic meter
m^3/annum	Cubic meters per annum
mg/ℓ	Milligram per Liter
mS/m	milliSiemens per meter
pH	Logarithm of the hydrogen ion concentration in moles per liter
s	Seconds

1. INTRODUCTION

1.1 General:

The **Thabazimbi Hydrogeological Map, sheet 2426,** scale 1:250 000, is a reconnaissance map and it is part of an upgrade of the first general synthesis of groundwater resources within this area i.e. the 1:500 000 Polokwane Hydrogeological Map. The latter comprises 4 x 1:250 000 geological maps namely Nylstroom (Modimolle), Pietersburg (Polokwane), Thabazimbi, and Ellisras (Lephalale).

The **objective** of the map and accompanying explanation brochure is to provide the public, the professional community, and planners with a general reference for planning, development, and management of groundwater. It is also to serve as an education tool to promote groundwater as an interesting and scientific subject.

Deliverables: 1:250 000 Hydrogeological map and explanation brochure; Methodology to create these maps and brochures.

Groundwater occurrences are very heterogeneous in South Africa while the mapping standards, legend, etc. demand a high degree of conformity. Not all the important aspects of groundwater could be depicted on the map as conditions can vary dramatically from region to region. The explanatory brochure addresses some of the issues while the map portrays general hydrogeological conditions. The 1:250 000 scale might be regarded by some as relatively small. The map and brochure can thus not replace detailed site investigations needed, when for example, boreholes must be sited or when site specific conditions must be determined. It can, however, to some extent, assist in identifying potential target areas for follow-up detailed ground investigations. Despite this, **site-specific detailed investigations** will always be recommended to determine local conditions. The map and accompanying explanation brochure will however provide general information and guidelines as to which detailed investigations are required and what expected hydrogeological conditions are likely to occur.

The **main features** shown on the map are borehole median yield, aquifer type, groundwater quality, groundwater use and lithology. This brochure provides supplementary information for these topics and discusses other aspects of groundwater on an elementary level. Additional topics include recharge, storage, movement, the location of groundwater using geophysical methods, subterranean water control areas [this function is now part of the function of the Catchment Management Agencies, (CMA)], management, pollution, utilization, and future exploration.

A new **National Water Act (Act 36 of 1998)** was proclaimed in October 1998, (See section 9.1, Page 180). A brief discussion is included under groundwater management (see section 9.4, page 191) with the focus on the implication for water users and their obligations. The National Water Act is important as it provides a framework to protect water resources against over exploitation; to ensure water for social and economic development and to ensure the availability of water for future generations.

Sustainability, equity, and efficiency are the **principles** of the National Water Act that provide the framework to guide the protection, use, development, conservation, management, and control of water resources.

2. MAP COMPILATION

2.1 Data sources:

Data sources for the compilation of the map include:

- The National Groundwater Archive (NGA) under the custody of the Department of Water Affairs (DWA), now the Department of Water and Sanitation (DWS),
- Water Management System (WMS), Department of Water and Sanitation (DWS),
- Borehole data and pumping tests executed during GRIP Project,
- Available Geohydrological reports from DWS,
- Consultant reports compiled for WULAs allocations,
- Existing information from various consultancies stationed in the Limpopo Province,
- Groundwater database of the consultancy,
- Reports and information from some of the municipalities.

Table 1: Number of borehole records extracted and evaluated from the NGA and WMS.

RECORDS EVALUATED THABAZIMBI MAP SHEET					
NGA and GRIP-(Yield)		WMS and GRIP (chemistry)			
Total Number of Borehole Yields	Total Number of sources with Water Levels	Number of points after removal of duplicates	Number of time series data	Number of analyses used for evaluation - (tables)	Number of analyses used for Piper and Durov
(5906) of which 2488 is wet, 1752 dry and 1666 with no information	628	1170	366	791	543
Total records evaluated after adding Lephalale & Modimolle sheet information for adjacent similar cross border units (6 units viz. Mcl, Mva, Mas, Mag, Mkr, Ms)					
NGA and GRIP-(Yield)		WMS and GRIP (chemistry)			
Total Number of Borehole Yields	Total Number of sources with Water-levels	Number of points after removal of duplicates	Number of time series data	Number of analyses used for evaluation-(tables)	Number of analyses used for Piper and Durov
(7356) of which 3743 is wet, 1752 dry and 1861 with no information	1662	2001	785	1103	734

2.2 Main map: Thabazimbi hydrogeological map scale 1: 250 000

The total map sheet covers an area of approximately 25 237.6km² of which 7 655.6km² falls within Botswana. As one of four 1: 250 000 hydrogeological maps sheets, it represents a 24.72% portion of the upgrade of the first general synthesis of the groundwater resources of the area i.e. the 1:500 000 Polokwane Hydrogeological map that covered a total area of approximately 71 130km² (Botswana excluded). The section of the Thabazimbi map sheet within South-Africa is 17 582km².

The 1: 500 000 Polokwane map sheet is bordered by latitudes 23º and 25º south and longitudes 26º and 30º east whereas the 1: 250 000 Thabazimbi Hydrogeological map is bordered by latitudes 24º and 25º and longitudes 25º 45' and 28º. The Limpopo and the Marico Rivers that form the largest section of the international border, (on the map sheet), between South Africa and Botswana divides the map area (69.7% in RSA and 30.3% in Botswana). The aquifer units within Botswana are not included in the map sheet. Future incorporation may be possible under SADC-GMI.

The methodology followed for the 1: 500 000 Polokwane Hydrogeological map series for the delineation of the aquifer units was to use the lithostratigraphy as depicted on the relevant 1: 250 000 geological map sheets viz. Ellisras 2326, Pietersburg 2328, Thabazimbi 2426 and Nylstroom 2428. The lithostratigraphy was used to sub-divide the map sheet area into hydrogeologically relevant lithological units (referenced as aquifer resource units), which possess some degree of lithological homogeneity and similarities in rock properties. However, lithological homogeneity and similarities in rock properties were not the only consideration. Where geological formations were large enough, they were regarded as separate units, despite lithological homogeneity and similarities in rock properties with adjacent formations or lithologies.

For the Thabazimbi 1: 250 000 Hydrogeological map sheet, a similar approach was followed but due to the smaller scale and a larger number of available data points with information, it was possible to use the geological units as aquifer resource units even if these exhibited similar hydrogeological characteristics. Exceptions are the aquifer resource units i.e. Undifferentiated Pretoria Group, Undifferentiated Waterberg Supergroup, Undifferentiated Smelterskop Formation, Undifferentiated Ventersdorp Group and the Undifferentiated Rustenburg Layered Suite. The reasons are that the Thabazimbi map is extensively covered by Tertiary to Quaternary deposits that hide the underlying geology, some units are very narrow and similar to the adjacent Formations and in addition the geological map is old (1974). At the time of the compilation of the 1974 geological map sheet, there were still some stratigraphical uncertainties.

In areas where the Pretoria Group had a larger areal extent and clear outcrop areas, it was divided into separate aquifer resource units that correspond to the relevant geological formations as depicted on the 1: 250 000 geological map sheet Thabazimbi 2426.

The aquifer resource units are displayed as grey ornament on the map. A symbol/code in black representing the approximate age of the Formation, (first letter of the Erathem for example: 'M' for Mokolian or 'V' for Vaalian). Erathem was used up to the end of Namibian where after System was used. Hereafter the code/symbol is completed by the adding of two and/or three letters (author's choice) and displayed in black. The choice of the code/symbol to be used was also influenced by codes/symbols allocated to adjacent map sheets as these maps will form a unit.

It was found that the adjacent geological maps do not always match/line up, in terms of polygons, colour, or codes/symbols. This is due to the mapping being executed by many different authors and at different completion dates. This is especially true for the Thabazimbi (1974) and Ellisras (1996) geological map sheets. With the geohydrological map sheets however, the methodology followed was as such to avoid incompatible codes/symbols and polygons, thus enabling a smooth fit when these maps are joined. These lithological units were then grouped together based on the expected groundwater occurrence viz. **Intergranular (a), Fractured (b), Karst (c), and Intergranular and Fractured (d).**

The borehole yield data available on the National Groundwater Archive represents data from different populations which are non-uniformly distributed in space and which are heavily skewed in a positive direction. Because of this, the median yield is recommended as a suitable measure of centrality rather than the average. The median is also found to be a reasonable discriminator between hydrogeological regions and is easy to compute and interpret as a "typical" yield of a region. To provide sufficient resolution of the data, to permit visual portrayal in a distinguishable manner, the borehole yield data is classified according to six groupings for each of the four classes of mode of groundwater occurrence. The six borehole-yield-groupings have been selected in such a way as to provide physical meaning to the value of the borehole both in terms of the concomitant abstraction equipment and as a provider of water for a particular end water user.

The mapping and initial delineation of groundwater-occurrence-boundaries, based on borehole yield data and the hydrogeological classification, was achieved by superimposing the available individual borehole yields, colour-coded according to the borehole yield range, over the lithological base map and determining the median yield of the different lithologies. Refining of the groundwater occurrence boundaries and the identification of regional patterns and trends was done through visual inspection; experience and knowledge of the area; information contained in geohydrological reports as well as the geology and related structures. Where supported by sufficient evidence and reason based on experience, the aquifer characteristics of geohydrologically well-defined areas were extrapolated into areas of data scarcity.

If major existing and/or licensed groundwater abstraction points equal or higher than 100 000m^3/annum occurs anywhere on the map it is shown as a filled red circle of various sizes that correspond to the estimated/reported annual volume of abstraction. Springs, thermal springs, artesian conditions, automatic water level recorders and monitoring points are shown in pink (filled circle), orange (empty circle), pink (empty circle), purple (open triangle), and purple (triangle with a dot) respectively.

Extensive use was made of the Geographic Information System (GIS), which allowed for cartographic compilation, data display, and manipulation.

2.2.1 : Inset maps:

The following inset maps have been included on the Thabazimbi Hydrogeological map sheet 2426:

An **east-west or north-south hydrogeological cross-section,** based on limited geological information and the author's own interpretation of the available information. The cross-section displays the third dimension and regional hydrogeological relationships discussed on the map. The static water level is included to show its relationship with surface topography.

Distribution of borehole data: A 1: 1 000 000 scale map to represent available groundwater source information distribution. The yellow colour represents no data points, light pink represents one data point, light blue 2-10 data points, violet 11-20 data points and the purple represent more than 20 data points.

Elevation above sea level: a 1: 1 000 000 scale, contour intervals relevant to the map at 200m. The elevation in the map area varies between 400-2000mamsl.

Mean annual precipitation: a 1:1000 000 scale, contour intervals at 100 to 200mm/a. The rainfall in the area varies from approximately 300 to just over a 1000mm/a.

Groundwater quality map: a 1:1 250 000 scale map representing contoured Electrical conductivity data, (a measure of salinity), the position of sampling points and the indication of problematic chemical species, Nitrate (concentration >10mg/l) and Fluoride (concentration >1.5mg/l). The EC intervals as well as the Nitrate and Fluoride values shown are based on the prescribed guidelines for human and livestock water consumption.

2.2.2 : Brochure:

The purpose of the explanatory brochure is to give information on the methodology followed in compiling the map, to highlight important groundwater topics and to discuss groundwater occurrences in more detail as that could be depicted on the map. The objective is also to include relevant aspects for the aquifer units from the most recent research and/or findings from available groundwater reports. Groundwater occurrence is very heterogeneous in South Africa while the mapping standards, legend, etc. demanded a high degree of conformity. Aspects of groundwater that are important, which could not be shown on the map, will vary dramatically from area to area and the brochure provides opportunities to reflect this variability. Included in the brochure are frequency diagrams on borehole yields and trilinear Piper and Durov diagrams giving information on groundwater chemistry for the various aquifer units appearing on the map. These are guideline values with the accuracy of the findings, being a function of available data and quality of data.

3. HYDROGEOLOGICAL CLASSIFICATION.

The international UNESCO classification for hydrogeological maps (UNESCO 1983) was adapted to suit South African hydrogeological conditions and groundwater occurrences. The UNESCO classification distinguishes the occurrence of groundwater only according to the primary or secondary nature of interstices. Table 2 depicts the adapted hydrogeological classification used for the Thabazimbi map sheet according to the origin and nature of the saturated interstices combined with subdivisions based on existing known blow yields, (after Orpen, 1994).

Four modes of groundwater occurrences based on the dominant porosity type are depicted on the hydrogeological map series.

- Intergranular (a),
- Fractured (b),
- Karst (c),
- Intergranular-and-Fractured (d)

Where two modes of groundwater occurrences occur at the same site such as along the Crocodile River, it is depicted as a two-layered aquifer (a/d) i.e. the upper aquifer being intergranular (a) and the bottom aquifer intergranular and fractured (d). Depending on the specifics it is portrayed in the colours of the occurrence.

The definition of the productivity ranges has been left by the UNESCO authors for the local map authors to define. Considering local conditions and equipment options for production boreholes six sub- divisions were defined. On the Thabazimbi map sheet and in Table 2 of the brochure the classes are represented by colours and the yield subdivisions by the tone of the respective colour. The subsurface lithology is presented by lithological ornaments and chronostratigraphy by alphabetical symbols. Production ranges are defined as follows:

- Very high borehole yields, generally greater than >10ℓ/s. Can be used for large scale urban and rural water supply, industry, or large-scale irrigation, (92 boreholes on map).
- High borehole yields, generally greater than 5ℓ/s to 10ℓ/s. Can be used for urban and rural water supply, industry, or large-scale irrigation, (130 boreholes on map).
- Moderate borehole yields generally, 2ℓ/s to 5ℓ/s. Can be used for urban and rural water supply to small towns, industry, or small-scale irrigation, (372 boreholes on map).

- Low borehole yields generally, 0.5ℓ/s to 2ℓ/s. Can be used for domestic and livestock watering supply to rural settlements, hospitals and health centres or small-scale irrigation at community vegetable gardens, (772 boreholes on map).

- Very low borehole yields generally 0.1ℓ/s to 0.5ℓ/s. Can be used for domestic supply to single homesteads, schools, police stations, clinics, small rural villages (250 persons) or livestock watering. Boreholes in this group are mostly equipped with hand, submersible or wind pumps, (507 boreholes on map).

- Un-economical boreholes with yields generally, < 0.1ℓ/s. Non-reticulated water supply for isolated households or for monitoring in certain cases. Suitability depends on factors such as construction, objective of monitoring, location, and geological setting (613 boreholes on map).

Table 2: Hydrogeological Classification of groundwater occurrence and borehole yields in the map area. (After Orpen, 1994).

<table>
<tr><th colspan="4">CLASS A</th><th colspan="4">CLASS B</th><th colspan="4">CLASS C</th><th colspan="4">CLASS D</th></tr>
<tr><td colspan="4">INTERGRANULAR</td><td colspan="12">HARD, CONSOLIDATED ROCK MATERIAL</td></tr>
<tr><td colspan="4" rowspan="2">A water saturated zone, generally unconsolidated but occasionally semi-consolidated. Groundwater is stored and transmitted through intergranular interstices in porous and permeable medium.</td><td colspan="12">Fissured and fractured bedrock resulting from decompression and/or tectonic forces. Groundwater flow predominantly through fractures, faults, joints, and fissures (acting as conduits), and micro-fissures in the bedrock, Rock matrix provides storage.</td></tr>
<tr><td colspan="4">Where the principal water strike is in a fracture or in contact between two different rock types, interporosity groundwater flow can occur within the rock matrix (double-porosity matrix). Groundwater is stored and transmitted in fractures, fissures and/or joints.</td><td colspan="4">In the case of carbonate rocks groundwater is stored and transmitted through incipient fissures and fractures enhanced through chemical dissolution. Some groundwater storage can also be expected in in-situ weathered residuum. Frequently extensive in area</td><td colspan="4">Fractured zone overlain by varying thicknesses of weathered saturated material. Storage and flow in both. Also able to pass vertically with relative ease between the two portions. Fractures act as conduits during abstraction, vertical recharge from intergranular zone. This situation also allows for circumstances where the intergranular portion serves primarily a storage function, the water being transmitted mainly through the fractured portion. This is a common feature of many South African Intergranular & Fractured Aquifers. Occurs when the often-substantial quantities of water stored in the intergranular voids of weathered rock can only be economically abstracted via fractures penetrated by boreholes drilled into the underlying fractured aquifer.</td></tr>
<tr><td rowspan="2">Group</td><td colspan="2">Typical borehole yield</td><td rowspan="2">Colour code</td><td rowspan="2">Group</td><td colspan="2">Typical borehole yield</td><td rowspan="2">Colour code</td><td rowspan="2">Group</td><td colspan="2">Typical borehole yield</td><td rowspan="2">Colour code</td><td rowspan="2">Group</td><td colspan="2">Typical borehole yield</td><td rowspan="2">Colour code</td></tr>
<tr><td>Range</td><td>ℓ/s</td><td>Range</td><td>ℓ/s</td><td>Range</td><td>ℓ/s</td><td>Range</td><td>ℓ/s</td></tr>
<tr><td>a1</td><td>Un-economical</td><td>0.0-0.1</td><td></td><td>b1</td><td>Un-economical</td><td>0.0-0.1</td><td></td><td>c1</td><td>Un-economical</td><td>0.0-0.1</td><td></td><td>d1</td><td>Un-economical</td><td>0.0-0.1</td><td></td></tr>
<tr><td>a2</td><td>Very low</td><td>0.1-0.5</td><td></td><td>b2</td><td>Very low</td><td>0.1-0.5</td><td></td><td>c2</td><td>Very low</td><td>0.1-0.5</td><td></td><td>d2</td><td>Very low</td><td>0.1-0.5</td><td></td></tr>
<tr><td>a3</td><td>Low</td><td>0.5-2</td><td></td><td>b3</td><td>Low</td><td>0.5-2</td><td></td><td>c3</td><td>Low</td><td>0.5-2</td><td></td><td>d3</td><td>Low</td><td>0.5-2</td><td></td></tr>
<tr><td>a4</td><td>Moderate</td><td>2-5</td><td></td><td>b4</td><td>Moderate</td><td>2-5</td><td></td><td>c4</td><td>Moderate</td><td>2-5</td><td></td><td>d4</td><td>Moderate</td><td>2-5</td><td></td></tr>
<tr><td>a5</td><td>High</td><td>5-10</td><td></td><td>b5</td><td>High</td><td>5 -10</td><td></td><td>c5</td><td>High</td><td>5-10</td><td></td><td>d5</td><td>High</td><td>5-1</td><td></td></tr>
<tr><td>a6</td><td>Very high</td><td>>10</td><td></td><td>b6</td><td>Very high</td><td>>10</td><td></td><td>c6</td><td>Very high</td><td>>10</td><td></td><td>d6</td><td>Very high</td><td>>10</td><td></td></tr>
<tr><td colspan="4">Alluvial deposits of limited extent along river terraces consisting of transported material such as sand and gravel. Weathered crystalline rock with the principal water strike in the weathered intergranular zone.</td><td colspan="4">Sedimentary rocks of arenaceous origin. Acid volcanic rocks and other igneous rocks with very limited overlying residual weathered products.</td><td colspan="4">Carbonate rocks including dolomite, limestone of marine origin.</td><td colspan="4">Sedimentary. Igneous and Metamorphic rocks with significant thicknesses of overlying saturated residual weathering.</td></tr>
<tr><td colspan="4">INTERGRANULAR</td><td colspan="4">FRACTURED</td><td colspan="4">KARST</td><td colspan="4">INTERGRANULAR AND FRACTURED</td></tr>
</table>

4. PHYSICAL ENVIRONMENT

4.1 General

The 1:250 000 Thabazimbi hydrogeological map sheet which is bounded by latitudes 24°S and 25°S and longitudes 25° 45'E and 28°E, covers an area of approximately 17 254.412km². The total area covered by the map when the Botswana portion is added amounts to 24 909.989km². The characterization of the aquifers within the Botswana portion was not included in the upgrade of the map sheet.

The map area covers one local municipality in total (Thabazimbi) and sections of other Local Municipalities viz. Lephalale (Ellisras), Ramotshere (Zeerust), Moses Kotane (Mogwase area), Bela Bela (Warmbaths) and Modimolle (Nylstroom).

Thabazimbi Local Municipality:
Water supply to Thabazimbi and Regorogile are from boreholes (4000m³/day) and surface water supplied by Magalies Water from the Vaalkop dam (7000m³/day). Northam relies on surface water also supplied by Magalies Water (4000m³/day); Leeupoort and Rooiberg are dependent on groundwater supply, [IDP, (2024-2025) document of the Thabazimbi Local Municipality].

The population figures given in the IDP, (2024-2025), document of the Municipality is 65 047 people with 44.7% being younger than 30 years, the source quoted in the IDP document is Stats, (2022).

The settlements in the Municipal area are characterized by small towns of which 3 are mining towns and 11 informal settlements. Thabazimbi is the major centre while other prominent settlements in the municipal area include Northam, Dwaalboom and Rooiberg; smaller settlements include Leeupoort, Kromdraai, Koedoeskop, Skierlik, Makoppa and Sentrum. The remaining settlements are either mining towns (Setaria, Swartklip and Amandelbult) or informal settlements (Jabulani, Smashblock, Raphuthi, Kwa Botha, Matikiring and parts of Regorogile etc).

The location of mines has heavily influenced the growth patterns of settlements. The location of the existing settlement areas is sparsely spread and fragmented. The residential townships are generally low density, with single dwellings per erf dominating the landscape. There is a distinction between the urban towns and rural towns which is basically reduced to support services and economic opportunities, where urban towns have higher access to such services. A number of informal settlements have developed adjacent to formalised towns.

Ramotshere Local Municipality (Zeerust):
In total 5 rural villages fall within the boundaries of the map sheet; they are located in the south-western section of the map sheet falls. From the IDP document of the municipality it seems that water supply to these villages is from groundwater.

Moses Kotane Local Municipality:
In total approximately 18 rural villages fall within the boundaries of the map sheet; they fall within the northern section of the municipal area. Within the Thabazimbi map sheet these falls within the central southern part of the map in an area roughly between Molatedi Dam and Northam. From the IDP document of the municipality it seems that water supply to these villages is mainly from groundwater. The long-term plans include bulk supply pipelines to some of these villages.

Bela Bela Local Municipality: (Warmbad)
Parts of the municipal area fall within the south-eastern section of the map sheet boundary, the well-known Marakele National Park occupies the largest section of this area. No rural villages or settlements occur in this area.

Modimolle Local Municipality: (Nylstroom)
Parts of the municipal area fall within centre-eastern section of the map sheet boundary, the well-known Mabula Nature Reserve occupies the largest section of this area. No rural villages or settlements occur in this area.

4.2 Terrain Morphology

The mapping area was divided by Kruger (1983) into nine terrain morphological units (Kruger, 1983) see Figure 1:

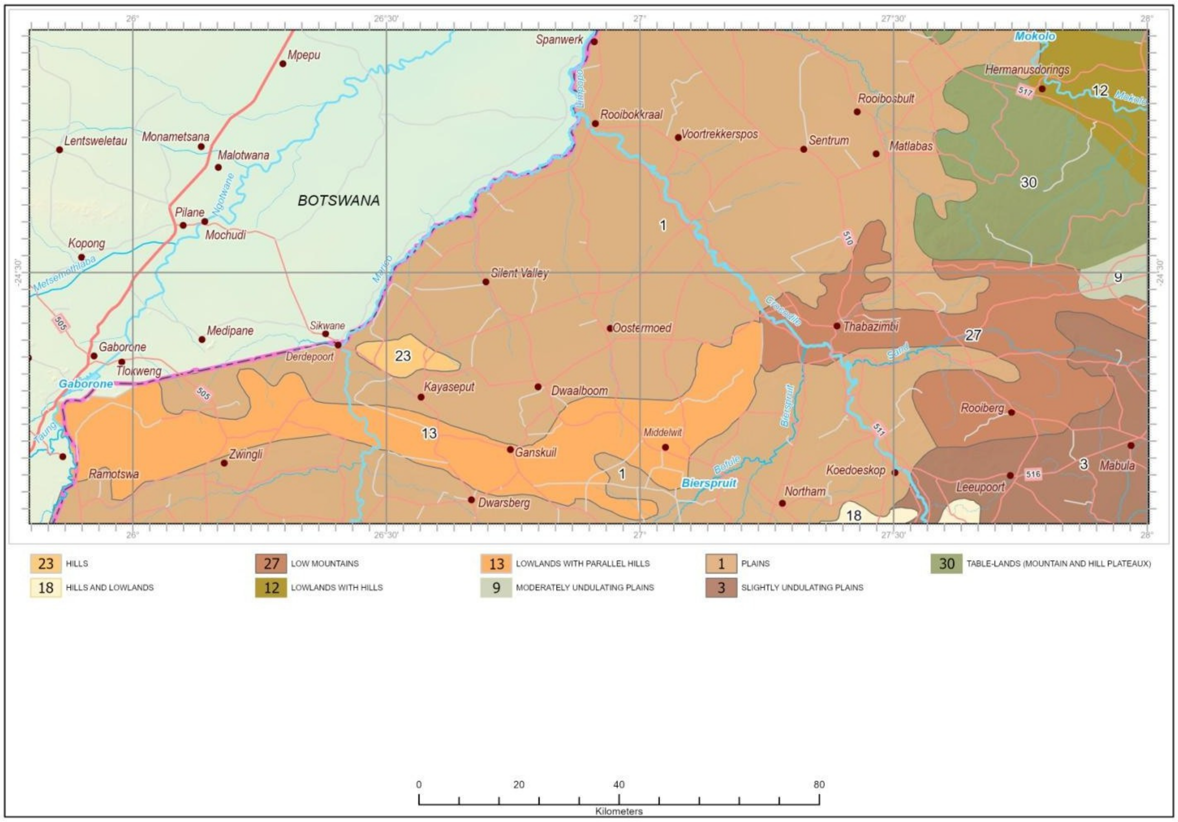


Figure 1: Terrain Morphology (Kruger, 1983).

Table 3: Detailed explanation for Figure 1, Terrain Morphology

BROAD DIVISION	MAP SYMBOL	DESCRIPTION	DRAINAGE DENSITY* (km/km²)	% OF AREA WITH SLOPES <5%
Plains with low relief	1	Plains	low - medium 0 - 2	> 80%
	3	Slightly undulating plains		
Plains with moderate relief	9	Moderately undulating plains	low - medium 0 - 2	
Lowlands, hills and mountains with moderate to high relief	12	Lowlands with hills	low - medium 0 - 2	50 - 80%
	13	Lowlands with parallel hills		
Open hills, lowlands and mountains with moderate and high relief	18	Hills and lowlands	medium 0.5 - 2	20 - 50%
Closed hills and mountains with moderate and high relief	23	Hills	medium 0.5 - 2	< 20%
	27	Low mountains		
Tablelands with moderate to high relief	30	Tablelands (mountain and hill plateau)	medium 0.5 - 2	< 80%

**Total length of drainage channels per km²*

4.3 Elevation

The elevation within the map sheet is predominantly between 800 to 1200mamsl. The Waterberg plateau within the north-eastern and eastern section of the map is between 1200 and 1600mamsl with a small section within this area to vary between 1600 and 800mamsl. Other scattered elevations between 1200 and 1600mamsl is predominantly underlain by quartzite of the Pretoria Group.

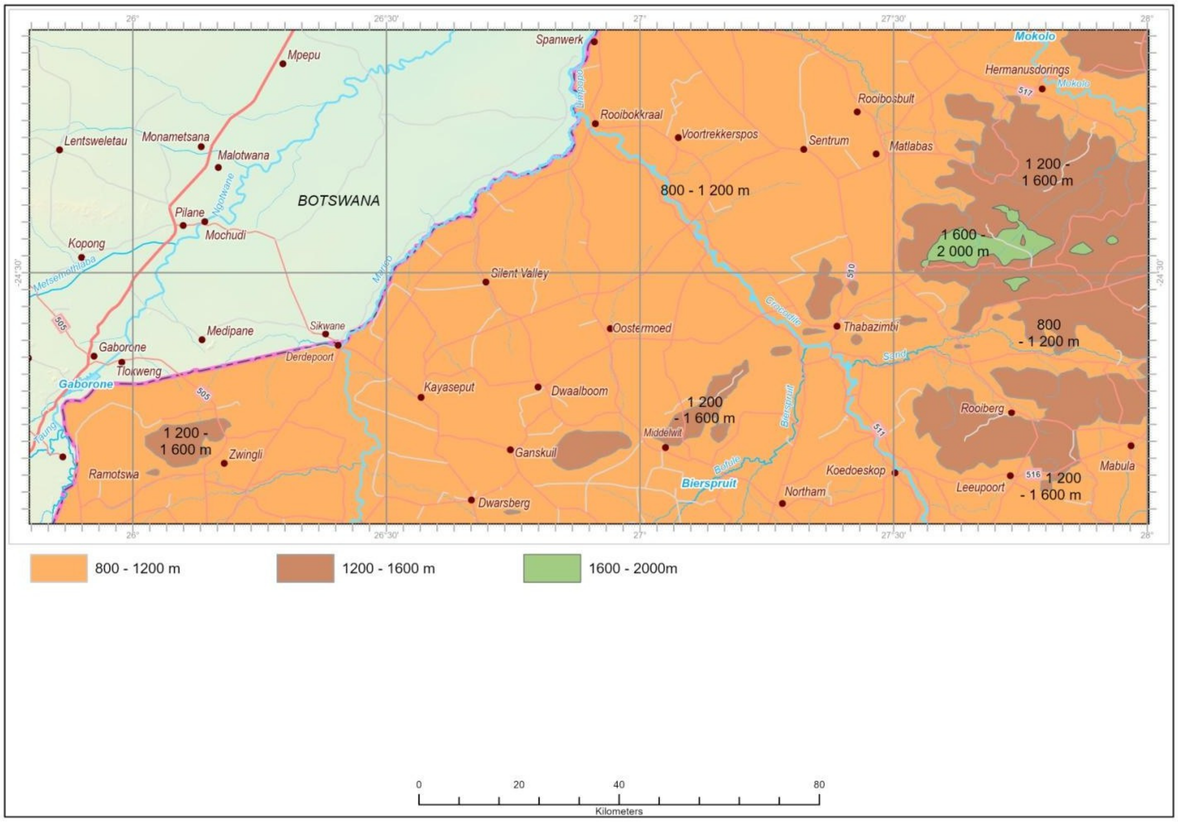


Figure 2: Elevation.

4.4 Climate

Mean Annual Precipitation (MAP), (Figure 3) varies from between 400 and 600mm/annum over most of the map area. The highest MAP, (600-800mm/annum) is predominantly within the eastern section of the map area that is dominated by elevated plateau underlain by rocks of the Waterberg Group. Rainfall occurrence over the largest part of this area is very erratic and unreliable resulting in long dry periods. This is especially true for the north to north-western section of the map sheet where the Coefficient of Variation of annual precipitation is between 25-40% while the rest of the area is predominantly between 20 to 35%. Refer to Table 4, page 12, *(data obtained from A Level 1 River Ecoregional Classification System),* Kleynhans et al., (2005). The highest average rainfall is between early to mid-summer (December to January).

Table 4: Limpopo Ecoregions and Coefficient of Variation

Ecoregion (ER)	Winter (July)		Summer (February)		Coefficient of Variation (% of annual precipitation)
	mean daily minimum temperature	mean daily minimum temperature	mean daily minimum temperature	mean daily minimum temperature	
North to north-west (Limpopo Plain ER)	2 to >10°C	20 to >24°C	16 to >20°C	26 to 32°C	25 to 40%
East (Waterberg plateau ER)	2 to 6°C	16 to 24°C	12 to 20°C	24 to 32°C	20 to 35%
East to west strip in southern section (Western Bankenveld ER)	0 to 6°C	14 to 24°C	12 to 20°C	24 to 32°C	20 to 35%
East to west strip in extreme southern section (Bushveld Basin ER)	0 to 6°C	14 to 24°C	22 to 32°C	12 to 20°C	25 to 35%

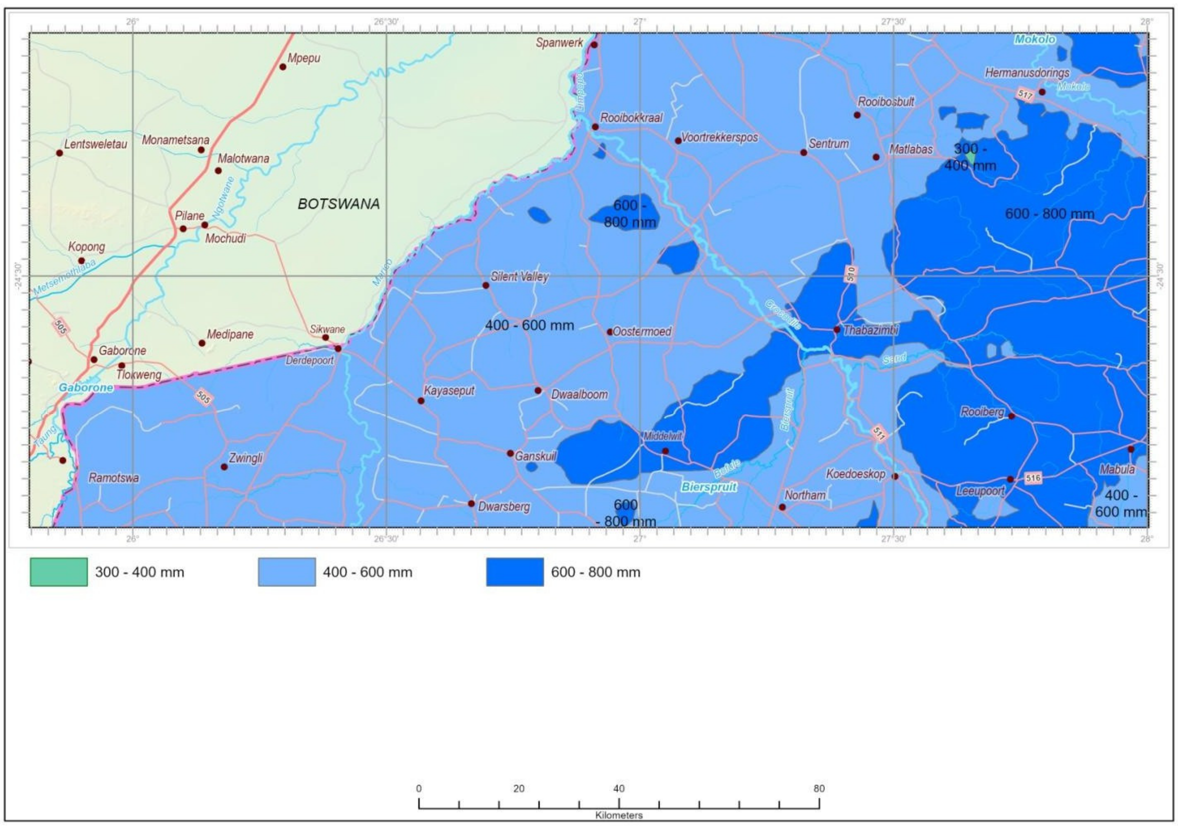


Figure 3: Mean Annual Precipitation.

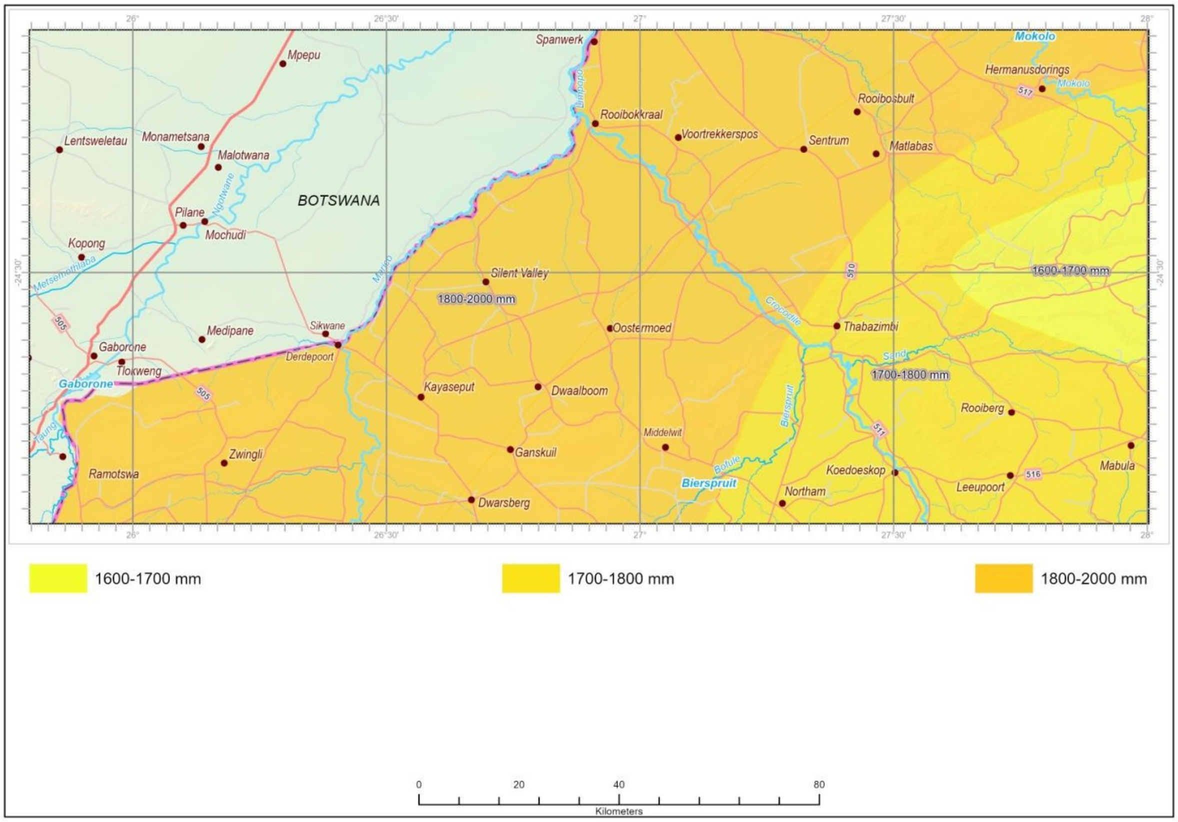


Figure 4: Mean annual evaporation.

The Mean Annual Evaporation (MAE), (Figure 4), is the highest in the west and north-western section of the map sheet, lowering slightly to the east and south-east (1700 to 1800mm) and the lowest in the centre-eastern section of the map sheet (1600 to 1700mm).

4.5 Surface Hydrology

The area falls into **one main drainage region** i.e. the Limpopo System (A). The major Tributaries for the Limpopo River in the map area are the Ngotwane, Marico, Crocodile, Matlabas and Mokolo Rivers.

The Limpopo System forms the largest drainage system in South Africa; the catchment aerial extent is 416 300km² and falls within 4 countries namely. South Africa (45%), Botswana (19%), Mozambique (21%) and Zimbabwe (15%), (Kapangaziwiri et al., (2021). Despite the large catchment and numerous tributaries, the Limpopo River is a highly seasonal river, with 90% of the mean annual runoff (MAR) occurring during the months of December to April. Flow during October and November and from May to September is extremely erratic and low – with no-flow conditions occurring mostly during these months, (Jacobsen and Kleynhans, 1993).

The major Tributaries for the Limpopo River in the eastern section of the map area arise from the Waterberg plateau. This area in the south-eastern section of the map receives in general higher rainfall than the regional average. In addition, the impermeable nature of the predominant sandstone strata favours runoff. The Tributaries in the eastern are the Matlabas and Mokolo Rivers.

The major Tributaries for the Limpopo River in the centre section to the west of the map area arise from the Highveld & Eastern Bankenveld, Western Bankenveld & flows through the Limpopo Plain Ecoregion. The Tributaries are the Crocodile and Marico Rivers

The major Tributaries for the Limpopo River in the western section of the map area arise from the Highveld Ecoregion and Botswana. The Tributary is Ngotwane.

See Table 5 to Table 9.

Table 5: Surface Hydrology, table showing the upper tributaries of the Marico River that flow into the Limpopo River.

Outermost tributaries	Early Tributaries	Early to later Tributaries	Arises (Ecoregion)	Later Tributaries	Main Tributaries	Main River System	Comment
		Unknown non perennial	Western Bankenveld	Brakfonteinspruit	**Marico**	**Limpopo**	A section of the border with Botswana is form by the Marico River. The outermost and early Tributaries mainly arise in the Highveld (No Suggestions) to the south of the map area, the outer tributaries flow east, north-east and north-west. More to the north before flowing into the Marico some of the later Tributaries arise in the Western Bankenveld Ecoregion and flowing mainly through the Bushveld Basin Ecoregion. The Western Bankenveld Ecoregion has a complex topography that varies from lowlands, hills and mountains to closed hills and mountains with the relief varying from moderate to high. Several rivers traverse this region; within the map sheet it includes the Marico and Crocodile River. Some perennial tributaries of these rivers rise in the southern part of the region in particular. The perennial tributary of the Sand River has its source in the northern part of the region.
		Unknown non perennial					
		Kgabana la Thukhwi	Western Bankenveld	Sehubyane (Sandsloot)			
	Klipspruit	Sandsloot (Sehujwane)	Highveld				
	Unknown non perennial						
	Unknown non perennial						
	Unknown non perennial	Springboklaagte	Highveld				
	Unknown non perennial						
		Lesigwane	Highveld	Tholwane			
		Metsolodi (Non perennial)					
	Fonteinskloof	Vanstraatsvlei		Madikwene Groot-Marico			
Kaaloog se loop	Ribbokfontein se loop						
Bokkraal se loop							
		Polkadraaispruit					
Kareespruit	Malamanieloop	Klein-Marico					
Unknown non perennial							
	Rhenosterfontein						
	Unknown non perennial						
	Unknown non perennial						
	Wilgeboomspruit						
		Lethlakane					
		Sedutlane (Masekolane)		Sedutlane (Masekolane)			
		Unknown non perennial	Highveld	Pitsedisulejang			
		Unknown non perennial					
			Highveld & Bushveld Basin	Kgolane (KwaKgolane Ramphamphana)			
			Western Bankenveld	Maselaje			
		Segakwane	Western Bankenveld	Rasweu			
		Unknown non perennial					
			Western Bankenveld	Elandslaagtespruit			
				Lengope la Kgamanyane			
				Lenkwane			

Table 6: Surface Hydrology, table showing the upper tributaries of the Mokolo River that flow into the Limpopo River.

Early to later Tributaries	Arises (Ecoregion)	Later Tributaries	Main Tributaries	Main River System	Comment
	Waterberg	Bulspruit	Mokolo	Limpopo	Only the tributaries of the Mokolo River addressed that falls within the Thabazimbi map sheet, the boundary is more or less the Mokolo Dam (Hans Strijdom Dam). Waterberg Ecoregion: The Waterberg is predominantly a tableland with moderate to high relief. The sandstones on the tableland are almost flat lying and are important escarpment shapers. Perennial rivers such as the Mogalakwena and Lephalala have their sources in the Waterberg. Altitude (m a.m.s.l) (Modifying) 700 -900 (limited), 900-1700 and MAP (mm/a) (modifying) is between 300 to 600.
	Waterberg	Malmanies			
	Waterberg	Taaibosspruit			
Frikkiesloop	Waterberg	Sterkstroom			
Grootfonteinspruit					
	Waterberg	Brakspruit			
	Waterberg	Klein-Vaalwaterspruit			
	Waterberg	Brakspruit			
Heuningspruit	Waterberg	Dwars			
no name non perennial					
Jim se Loop					
	Waterberg	Sondagsloop			
	Waterberg	no name non perennial			

Table 7: Surface Hydrology, table showing the upper tributaries of the Ngotwane and Matlabas Rivers that flow into the Limpopo River.

Early to later Tributaries	Arises (Ecoregion)	Later Tributaries	Main Tributaries	Main River System	Comment
Unknown non perennial	Highveld		**Ngotwane**	**Limpopo**	The Ngotwane River forms part of the western border with Botswana flowing to the north into Botswana. South of Gaborone Dam within Botswana the river turns to north-easterly before joining the Limpopo River near Phala Camp, that falls within the Lephalale map sheet. The inflow is approximately 6km south from the inflow of the Matlabas into the Limpopo.
Unknown non perennial					
Unknown non perennial					
Unknown Perennial					
Numerous non perennial rivers	Botswana	Rivers flowing from the western part of Botswana			
	Waterberg	Mamba	**Matlabas**	**Limpopo**	Arises in the Waterberg Plateau and flowing predominantly north-west
		Motlhabatsi (Matlabas)			

Table 8: Surface Hydrology, table showing the upper tributaries of the Crocodile River that flow into the Limpopo River.

Outermost tributaries	Early Tributaries	Early to later Tributaries	Arises (Ecoregion)	Later Tributaries	Main Tributaries	Main River System	Comment
	Unknown non perennial	Bofule (Bierspruit)	Highveld & Western Bankenveld & Limpopo Plain	Biersspruit	Crocodile	Limpopo	The Crocodile River is predominantly a north-west flowing river, tributaries west of Northam flow predominantly north-east before joining the Crocodile River. West of Northam the tributaries flow predominantly north-west. Outside the map are the tributaries which mainly arise in the Highveld Ecoregion; the dominant flow is west or north-west further to the south. East of Thabazimbi the sand river is the major tributary to the Crocodile River. Flow is west up to the confluence, the upper tributaries flow north-west, and one is flowing south-west from the Waterberg Plateau. The **Highveld Ecoregion** is characterized by Plains with a moderate to low relief; an altitude (m a.m.s.l) of 1100-2100 and 2100-2300 (very limited); a MAP (mm) (modifying) of 400 to 1000. Several large rivers arise in the region, within the map area includes the Marico, the Crocodile (west). At the near confluence with the Limpopo River, it flows through the Limpopo Plain Ecoregion.
	Magoditshane						
Kolobeng	Kolobeng						
Mothlabe							
Lesobeng	Sefathlane (Diphiri Brakspruit)						
Sefatlhan (Moruleng)							
	Phufane						
			Highveld & Western Bankenveld & Limpopo Plain	Klipspruit (Renosterspruit Matsane)			
				Unknown non perennial			
				Unknown non perennial			
				Majadibodu			
				Motlhabe (Kopjane)			
				Matshikiti			
		Tolwane (Sand)	Highveld	Pienaars (Moretele)			
		Kutswane (Ngopedimatlhaja \ Soutpansprui)					
	Apies	Tshwane					
	Mojitla \ Stinkwaterspruit						
	Lepenya	Marierietsa (Tlholwe)					
Tooyspruit	Rietspruit (Marierietsa)						
Droekloofspruit	Kareespruit						
	Plat (Buffelspruit)	Plat (Utsane)	Highveld & Eastern				
	Bad se Loop						
			Eastern	Sleepfonteinspruit			
	Unknown non perennial	Vaalwaterspruit	Western Bankenveld & Bushveld Basin	Sand			
	Vaalwaterspruit (Bloubankleegte)						
		Sondags					
		Monyagole					
		Unknown non perennial					
		Unknown non perennial					
		Unknown non perennial					

Two **major dams** occur within the map area; Table 9 lists the basic site information and storage capacity. Both can be classed as large (> 60Mm³). The Mokolo Dam is within the boundary between the Thabazimbi and Lephalale map sheet. The dam is therefore listed in both hydrogeological brochures.

The combination of irregular precipitation patterns and high evaporation rates leads to droughts and intermittent flows in many smaller rivers and streams. Although the Limpopo River is classified as a perennial river, it often experiences periods of no surface flow during dry seasons. This is particularly occurring in its lower reaches to the east. This phenomenon is largely due to over-utilization of water resources in the river's upper catchment areas. Surface and groundwater interactions within the Limpopo River system are seasonal, with rivers alternately gaining water from or losing water to the surrounding groundwater. This dynamic depends on several factors, including river water levels, the depth of the erosion channel, the composition of riverbed materials, underlying structural geology, the presence of riparian vegetation, nearby water abstraction points, and static water tables near the river.

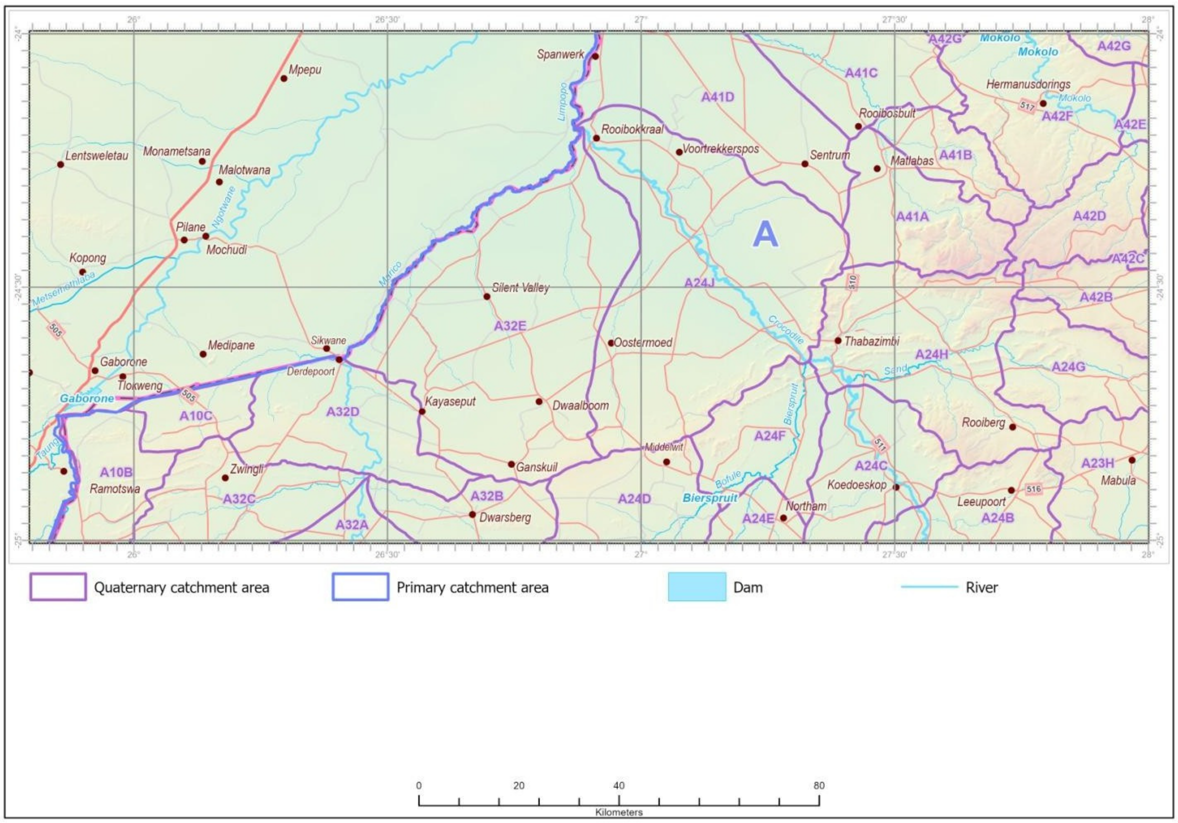


Figure 5: Drainage regions and major dams (HRU, 1981).

The water allocation from Mokolo Dam is to the area north of the dam, thus falling outside the map sheet boundary. The allocation from the dam is to the Grootegeluk mine and Lephalale town and the volume supplied is 10.1Mm³/annum, and for the Matimba Power Station, it is 7.1Mm³/annum. Water from the dam is also used for irrigation purposes that are highly dependable on regular releases from the dam.

The Molatedi Dam established in 1986, stores water for irrigation and domestic purposes. Irrigation along the Marico River near the dam seems to be less than a few years ago (Google Earth imagery evaluation); the land use in these areas changed to game farming.

Table 9: Major dams, drainage basin, supplying river and storage capacity (HRU, 1981)

DAM NAME	DRAINAGE BASIN	RIVER	FIRM YIELD (Mm³)/annum	STORAGE CAPACITY (Mm³)
Mokolo (Hans Strijdom)	A4	Mokolo	27	146
Molatedi Dam	A3	Marico River		203

5. GEOLOGY

5.1 Regional geology

The geology occurring on the Thabazimbi Hydrogeological map sheet area, almost spans the length of the South African geological history and contains many of the major stratigraphic groups in the country. A simplified geological map (Figure 6) was compiled from the 1: 250 000 Thabazimbi published geological map sheet and explanatory brochure (Council for Geoscience).

The major stratigraphic units formed the basis for the delineation of the hydrogeological aquifer resource units that were chosen according to geohydrological similarities. The boundaries of the hydrological aquifer resource units are in most cases similar to the geological boundaries. The major stratigraphic groups are as follows:

The Basement Complex and older Granite intrusives
Ventersdorp Supergroup
Transvaal Supergroup
Bushveld Complex and younger Granite intrusives
Waterberg Supergroup
Karoo Supergroup
Quaternary

The Basement Complex and older Granite intrusives

The Basement Complex of Swazian age are represented in the map sheet by the Gaborone Granite (Zga), (includes the unnamed Hyperite), Granite and Granite Gneiss, Western Transvaal Belt, (Zjt), (In later literature i.e. SACS, 1980, pp. 125, 187 and 190 the term Makoppa Granite has been applied), Modipe Gabbro Complex (Zme), Swaziland System (basic and ultrabasic rocks of the area correlated with Archaean Complex + Jamestown Complex (Zsj). The explanatory notes of the Thabazimbi geological map sheet correlated the rocks of the occurrence with that of the Jamestown Igneous Complex that is part of the Baberton Mobile Belt and the Swaziland Group associated with early cratonic rocks.

In combination the Basement Complex and older Granite intrusives cover 26.3% of the map sheet making it the largest chronostratigraphical unit. The rocks occur within an elliptical shape that is cut in half by the Botswana border in the north-western section of the map sheet. Extensive quaternary sand and soil overlay large portions of the bedrock.

These rocks formed on a large stable block of the earth crust known as the Kaapvaal Craton. It represents the oldest rocks on earth and is typically composed of granitoid rocks, greenstone belts, and high-grade metamorphic rocks. The basement rocks of the area are correlated with an older supacrustal sequence, (Swaziland System), within the Craton and are associated with the Barberton Greenstone Belt. The Jamestown Complex is in literature compared to Phanerozoic ophiolites (fragments of the ocean floor that are trapped between continental plates and island arcs, or thrust onto continental margins.), (De Wit, et al., 1983).

Granite and Granite Gneiss, Western Transvaal Belt, (The Makoppa Granite Suite)
These rocks were part of the Archean basement of the Kaapvaal Craton. It includes both intrusive granite and high-grade gneissic rocks and is associated with the Thabazimbi-Murchison Lineament. It is an intrusive batholite that forms a semi elliptical shape within the map area, the rest of the batholite occurs in Botswana. The south-western rim of the granite is unconformable overlain by volcanic rocks and sediments of the Buffelsfontein Group (listed as the Ventersdorp Group on the geological map).

The Gaborone Granite is part of a broader suite of granitoids in the region, linked to similar granitic intrusions found across the Kaapvaal Craton. It has intruded the Modipe Complex and is therefore interpreted as being of a younger age.

Ventersdorp Supergroup

The Ventersdorp Supergroup represent a massive outpouring of andesitic lava prior to deposition of the Transvaal Sequence. In the map area it is represented by the lower Klipriviersberg Group (Rk), the middle Platberg Group (Rp), and the Bothaville Formation (R-Vbo) all of which occurs in the south-western quadrant of the map sheet.

Parts of the Platberg Group occurring near Thabazimbi is now named the Buffelsfontein Group and included under the Transvaal Supergroup. A volcanic succession named in Botswana as the Kanye Volcanic Group (Rka) extends from Botswana into the map area. The Gaborone Granite intruded into this acid lava.

Transvaal Supergroup

Crocodile River Fragment
The Crocodile River Fragment consists of intensely deformed rocks and is bounded on the east and west by two major north-west striking faults. It is located within the central-southern section of the map sheet. The fragment's rocks are part of the Transvaal Sequence, which was subjected to three periods of folding. The rocks were also metamorphosed by the intrusion of the Bushveld Complex. Within the Crocodile River Fragment, a succession of pre-Black Reef rocks, known as the Wachteenbeetje Formation, has been identified. This formation is provisionally correlated with the Wolkberg, Groblersdal, and Buffelsfontein Groups. Overlying this is a sequence of siliciclastic and chemical sedimentary rocks that correspond to similar lithological units of the Transvaal Sequence found elsewhere, (Hartzer, 1989).

Other units of the Transvaal Supergroup occur as steeply dipping strata striking approximately east to west across the map sheet and folded about the Bushveld Complex. The Sequence consists of a basal (*the lowest geological layer*) quartzite, shale and basalt layer (Wolkberg Group) followed by a period of chemical sediment deposition consisting of a lower banded iron formation and chert layer (Black Reef Formation) followed by a thick sequence of dolomite with interlayered chert Chuniespoort Group.

Chemical deposition of the Chuniespoort Group was followed by cyclic episodes of quartzite and shale deposition (Pretoria Group). A capping of acidic lava (Rooiberg Group) marks the end of Transvaal deposition and the beginning of the intrusion of the Bushveld Complex.

Bushveld Complex and associated younger Granite and Granophyre

The emplacement of the complex was preceded by the intrusion of diabase sills that is largely confined to the Transvaal basin. The Bushveld Igneous Complex (BIC) is the largest layered igneous intrusion within the Earth's crust (Wikipedia, the free Encyclopedia). It has been tilted and eroded forming the outcrops around what appears to be the edge of a great geological basin: the Transvaal Basin. It is approximately two billion years old and is divided into four limbs: northern, eastern, southern, and western. It comprises the mafic and ultramafic phase of the Rustenburg Layered Suite (RLS) and the felsic phase of the Rashoop Granophyre Suite (RGS) and the Lebowa Granite Suite (LGS). The genetic relationship between the granites (LGS) and granophyres (RGS) and their relation to the underlying layered mafic-ultramafic intrusion (RLS) is not fully understood, (Earth-Science Reviews, Volume 250, id.104703, 2024). The RGS is generally more closely aligned with the pre-Bushveld Rooiberg Group, (Walraven, 1987a). Research suggests that the RGS was formed by melting of felsic volcanic rocks of the Rooiberg Group during the emplacement of the RLS, (Kinnaird, 2002). The granite intruded and formed a sill-like intrusive body over most of the complex. It has an estimated thickness of some 2.5km, (MacCaskie, 1983).

The Bushveld Complex in the map area is represented by the Rustenburg Layered Suite at two locations. It is referred in the report as the Undifferentiated Rustenburg Layered Suite groundwater resource unit as it includes all the lithological mafic and ultramafic units identified within the far-western limp. The Rashoop Granophyre Suite occurs in the centre southern section, and the Nebo Granite represents the BIC in the south-eastern section of the map sheet.

Within the western section of the map sheet the Marico Hypabyssal Suite, (MHS), represents a distinct assemblage of intrusive rocks located within the marginal zone of the Bushveld Complex. The suite is characterized by a variety of mafic to ultramafic intrusions similar in composition to the Bushveld mafic rocks but exhibits differentiation trends due to rapid cooling and emplacement at shallower crustal levels. Sills of the MHS occur throughout the Transvaal Sequence in the Marico District and vary from approximately 1-10 m in thickness. Contact metamorphism and assimilation effects are evident in the surrounding country rocks. Structurally the area is divined by minor dip-slip faults trending south to north, (Engelbrecht, 1990).

Waterberg Supergroup

The Waterberg Supergroup is preserved in two main basins, namely the Cullinan-Middelburg basin and the Waterberg Basin in which the Nylstroom, Matlabas and Kransberg Subgroups are preserved, (Jansen, Tankard *et al.*, 1982). Sedimentary studies show that the source rocks were from the Transvaal Supergroup and Bushveld Complex and transported by an active river system. Locally material could be transported and deposited by wind action during arid periods, (Tankard *et al.*, 1982).

Rocks of the Waterberg Supergroup were deposited in a fault-bounded basin in the northern part of the Kaapvaal craton. In the south the basin is bounded by the Thabazimbi-Murchison lineament and in the north the Palala shear zone, (Callaghan, 1987). This is the main basin and referred to as the Waterberg Basin.

The Waterberg basin consists of two overlapping basins. In the deep basin on the south rocks of the Nylstroom Subgroup were laid down, (central-eastern portion of the Thabazimbi map sheet). It consists of the Swaershoek and Alma Formations that overlay rocks of the Transvaal Supergroup unconformably. Rocks of the Matlabas Subgroup i.e. the Schilpadkop, Makgabeng (equivalent to the upper part of the Langkloof Formation) and Aasvoëlkop Formations, forms the base of the succession in the younger, larger but shallower basin and are transgressive over older formations, outcrop is predominately west and south of the Waterberg Plateau and continues in the west into

Botswana. This is overlain by the Kransberg Subgroup i.e. Mogalakwena, Sandriviersberg, Claremont and Vaalwater Formation that forms the Waterberg plateau in the north-eastern section of the map sheet. It is largely a succession of cross-bedded sandstone 1 250 m thick, the rocks is resistive to weathering with elevations predominantly between 1200 and 1600mamsl.

To the west the Aasvoëlkop Formation dominates the topography comprising of plains with an elevation of between 800 to 1200mamsl.

Karoo Supergroup

Within Southern Africa, rocks of the Karoo Supergroup were preserved within two major depositories in southern Africa viz. the Main Karoo and the Kalahari Basin. The accumulation of the sedimentary fill of these Karoo basins was under the influence of two main controls: tectonism and climate (Rust, 1975, Catuneanu et al, 2005). Tectonic regimes during the Karoo times varied from dominantly flexural in the south to extensional to the north. The former is related to processes of subduction, accretion, and mountain building along the Panthalassan, (palaeo- Pacific) margin of Gondwana. The latter in relation to spreading processes along the Tethyan margin of Gondwana, (Rust, 1975, Tankard et al, 1982, Turner, 1986, Smith et al, 1993, Veevers et al, 1994a, Veevers et al, 1994b, Veevers et al, 1994c, Johnson et al, 1996, Visser and Praekelt, 1996, Selley, 1997, Catuneanu et al, 1998, Pysklywec and Mitrovica, 1999).

For the smaller basins north of the main Karoo basin, such as the Springbok Flats, the Tuli, the Lebombo and Ellisras basins, tectonic regimes were dominated by extensional stresses or transtensional stresses.

Extensional stresses will lead to linear zones of localized crustal extension (Rifts). Typical rift features are central linear depressions called grabens or more commonly a half-graben with normal faulting and rift-flank uplifts mainly on one side. Superimposed on the tectonic control on basin development, climatic fluctuations also left a mark on the stratigraphic record, which shows evidence of a general shift from cold and semi-arid conditions during the Late Carboniferous- earliest Permian interval, to warmer and eventually hot climates with fluctuating precipitation during the rest of Karoo time (Keyser, 1966, Johnson, 1976, Visser and Dukas, 1979, Stavrakis, 1980, Tankard et al, 1982, Visser, 1991a, Visser, 1991b).

Within the map area rocks of Karoo age occupy a small portion within the south-eastern section of the map sheet where it forms flat country known as the Springbok Flats. The deposition of Karoo strata into the Springbok Flats intracratonic basin was controlled by changes in paleo- environments with the maximum depth in the south. Structurally the Springbok Flats Karoo Basin comprises two elongated basins i.e. Roedtan Basin (north) and Settlers-Tuinplaats Basin (south). These two basins are bordered by pre-Karoo aged tectonic features i.e. Thabazimbi-Murchison lineament (northern boundary of the Roedtan Basin) and the Droogekloof Fault Zone (northern boundary of the Settlers-Tuinplaats Basin.

A small occurrence within the center-northern section of the map sheet was identified by a geophysical survey and drilling, (Thabazimbi geological map, explanatory notes).

Quaternary

The Quaternary strata are characterised by thin sequences of Quaternary to Tertiary Aeolian Kalahari sand (not shown on map). However, it is the alluvial sand and gravel (Q) along the major drainages in the area that are the main targets for groundwater development and abstraction via sand points in the riverbed. Within the map sheet extensive irrigation using a combination of surface and groundwater occurs along the Crocodile River. The occurrence of alluvial deposits is extensively covered in the brochure under the heading ‘Tertiary-quaternary alluvial deposits (Q)’.

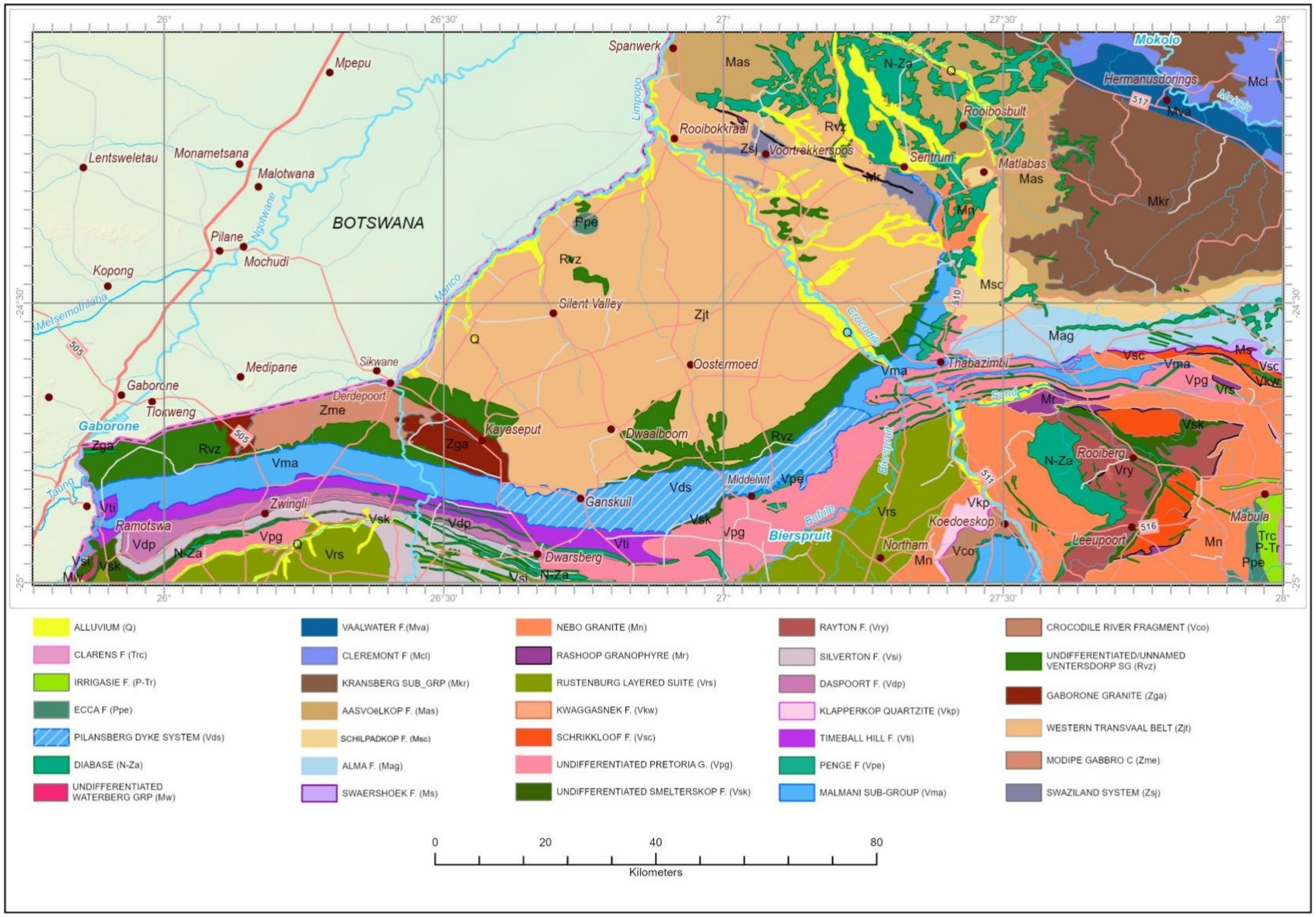


Figure 6: Simplified regional geology of the map area.

5.2 Structural geology

Diabase dykes and sills

Diabase sills (N-Za) are predominantly depicted on the map sheet to occur within the lower rocks of the Waterberg Supergroup i.e. Alma and Aasvoëlkop Formations and the Pretoria Group i.e. Timeball Hill, Daspoort and Silverton Formations. Diabase sills and dykes are however occurring in most of the lithologies within the map sheet.

As indicated above, the Waterberg Group has been intruded extensively by sills and dykes (N-Za) of predominantly diabasic composition which play a major role in the occurrence of groundwater. If dykes and sills are ignored, the groundwater potential of the Waterberg Group is generally low. Diabase dykes and sills can easily be traced on aerial photographs. Not only is the diabase less resistant to weathering than the surrounding sandstone generally resulting in the formation of depression but also produces a more fertile soil that stimulates a dense vegetation growth along the dykes. These can sometimes be traced for many kilometers. Where sills are weathered and fractured to extended depths below the water level, good supplies can be obtained from them.

The occurrence of dykes is more abundant than depicted on the geological map sheet as described in groundwater reports.

Dolerite dykes and sills

Intrusions after the deposition of the Karoo rocks are listed as dolerite intrusions. It is predominantly confined to rocks of the Karoo Supergroup. No dolerite dykes and sills are indicated on the geological map sheet.

Pilanesberg dykes

During late or post Waterberg times, the Pilanesberg Dyke System or dyke swarm intruded the middle section of the Malmani Subgroup occurrence (emplaced during early Vaalian times) of the Thabazimbi map. It is a group of dykes that radiate in a south and south-eastern direction from the Pilanesberg Alkaline Ring Complex in the Pilanesberg National Park.

The Thabazimbi-Murchison Lineament

The Thabazimbi-Murchison Lineament (TML) is a prominent tectonic feature striking from Phalaborwa in a west-south-west direction for approximately 500km. TML has significantly influenced the structural geology of the region. It forms and/or influences the boundary between the Archaean granite/greenstone terrain of the Kaapvaal Craton and the southern margin of the high-grade terrain of the Limpopo Mobile Belt, (Good et al., 1997).

Within the eastern side of the Thabazimbi map sheet, it transects the area on the southern side of the Waterberg Supergroup rocks and continues in the direction of Thabazimbi. On the western side it follows the southern boundary of the Zwazian granite up to the end of the map sheet and continues into Botswana. In the Thabazimbi map area it appears to form and / or influence the northern margin of the Transvaal Basin and the southern margin of the Waterberg Basin. It probably also influenced the emplacement of the Bushveld Complex, (Good et al., 1997).

This lineament has been reactivated several times in its long-lived tectonic history (2500 million years), (Good et al., 1997) and shows normal, strike-slip and reverses movement (Du Plessis, 1990). The stratigraphic units of the Thabazimbi region and Kumba Fe-Mine are folded, faulted, thrusted and duplicated parallel the strike of the TML fault line, (Netshiozwi, 2002; Basson and Koegelenberg, 2017).

The trust faults resulted in the duplication and, in parts, triplication of the stratigraphy i.e. Malmani dolomite and Pretoria Group, along parallel east-west trending mountain ranges (Northern, Southern, and Middle ranges that consists of banded iron stone,), (Strauss, 1964). The Middle Range developed locally between the Bobbejaanwater Thrust Fault, (BTF) (previously called Gatkop Thrust Fault) and Belt-of-Hill Thrust Fault, (BHTF), (previously called the Southern Thrust Fault). These thrusts are located south of the west-south-west trending TML and are regarded as parallel thrusts that formed due to sporadic reactivation of the TML, (Mohlahlana, 2019).

The development of thrust faults in the Thabazimbi area is attributed to a pre- to syn-Bushveld compressional deformation event (D1), which resulted in the formation of thrusts, folds, and reverse faults with a general north-western to northward vergence. This compressional event is believed to have played a crucial role in shaping the current structural framework of the Thabazimbi region, (Mohlahlana, 2019).

A structural analysis and tectonic interpretation of the Thabazimbi area by Mohlahlana, (2019) had the following findings on deformation events named D1, D2 and D3:

- The area was subjected to compressional deformation (D1), a pre-Bushveld compressional deformation event that is characterised by the development of thrusts-and-folds and reverse faults that has an overall north-west to south-west and a north to south kinematic vergence, (direction of movement of rocks near the surface relative to deeper rocks or the direction in which a fold is inclined or overturned).
- Immediately after the compressional deformation (D1) the area was subjected to a crustal extension event (D2). It is characterised by the development of east to west striking normal faults and other lineaments. This event occurred during cooling and sagging by the Bushveld Igneous Province. The Transvaal strata bulge downwards under the weight and gradually tilted into a steeply southwards dipping direction.
- The D3 deformation is characterised by the development of north-west to south-east; north-north-west to south-south-east and north-east to south-west trending lineaments. The lineaments crosscut the stratigraphic units of the Rooiberg Group and Waterberg Group. The strike of the lineaments is interpreted to follow pre-existing trends of weakness within the Kaapvaal craton and may have been reactivated over a protracted time.

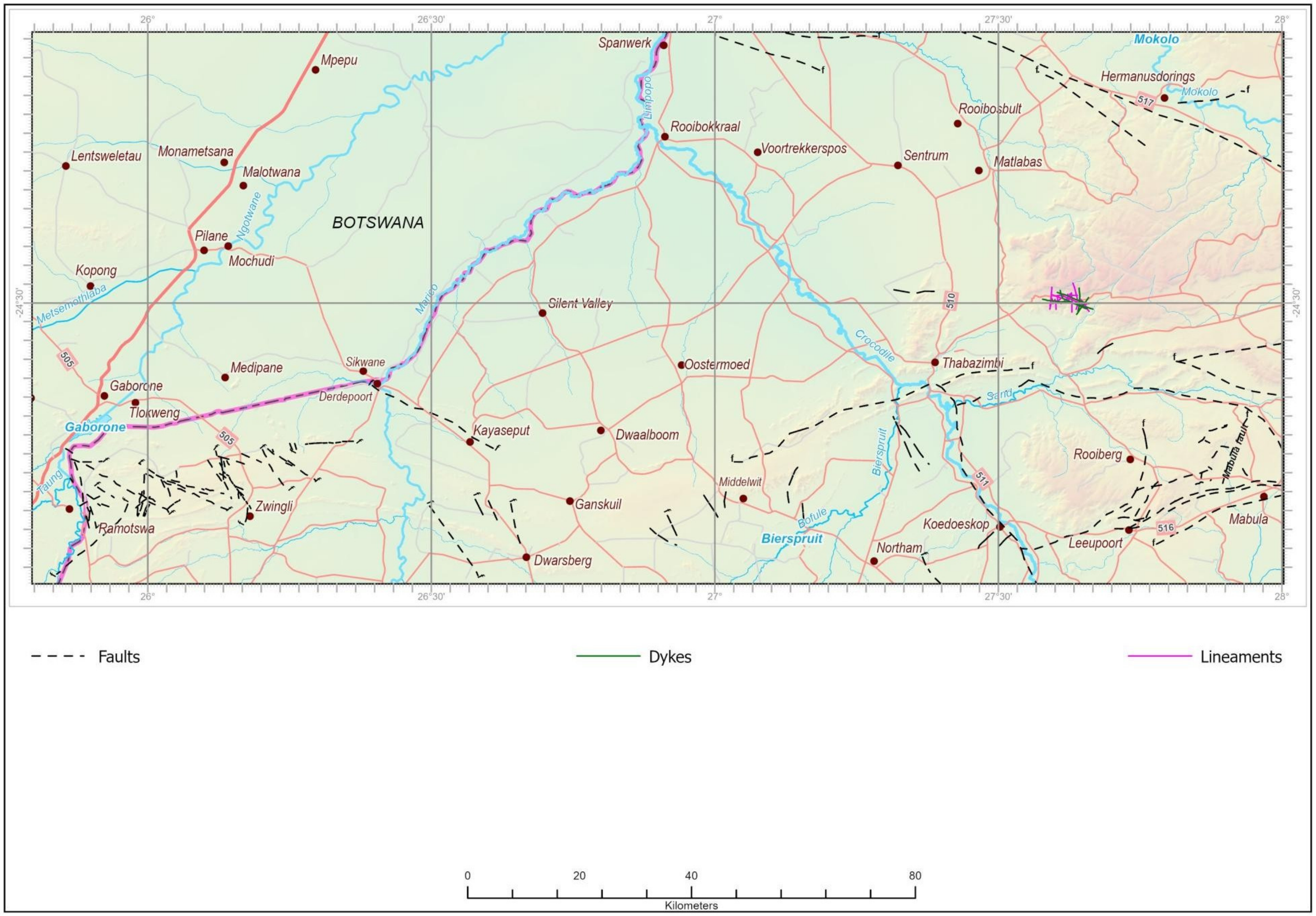


Figure 7: Inferred and observed geological lineaments.

6. GENERAL: HYDROCHEMISTRY AND AQUIFER UNITS

The chemical composition of groundwater is the result of interaction between rainwater, soils, and various rock types. Most of this interaction takes place in the unsaturated zone and later in the saturated zone along the groundwater flow path, where physical and geochemical properties of the rock types influence the type and character of the groundwater quality.

To characterise and compare the chemical composition of groundwater in the various rock formations, complete chemical analysis of 1103 groundwater samples, taken during the period from 1972 to 2023, was utilized.

The chemical data was predominantly obtained from WMS, NGA, e-WULAAS and from the database of the consultancy. The first combined data worksheet consisted of data for the area covered by the 1:500 000 Polokwane map sheet.

The total data points for the larger area numbered 41 942 data points. After removing duplicates and calculating the harmonic mean for time series data the number of data points decreased to 13 320 data points.

Duplicates were first removed from the combined total list before the data points occurring on the Thabazimbi map sheet were separated. Therefore, the total number of duplicates removed for the Thabazimbi area is not known as part of the statistics for the larger area. The time series data were however counted for each borehole point. For the Thabazimbi map sheet and the cross over units in the Lephalale and Modimolle map sheets, 2001 samples were available after the removal of duplicates. The number of data points after the calculation of the harmonic mean for time series data was 1216 thus 785 samples represent time series data. Of these data, 1103 analyses were used for the evaluation of chemistry with the results summarized in various tables. In total 734 analyses were used for the Piper and Durov diagrams.

The reason for the large number of duplicates was that in the past data was captured by many entities and at few occasions the various groundwater data databases were combined with the DWS database and vice versa. The coordinates of the available analysis points were used to divide the data within the relevant Aquifer Units.

The accuracy of the chemical analysis was checked by the plausibility of the Electrical Conductivity (EC) and Electro Neutrality (E.N). The calculations are as follows: EC is [∑anions (meq/L) =∑cations (meq/L)] =EC/100(µS/cm) and for the E.N. it was calculated as follows, [∑cations (meq/L) +∑anions (meq/L)] / [∑cations (meq/L) -∑anions (meq/L)]*100%, (≤10%). This was mainly for the samples that were plotted on the trilinear Piper and Durov diagrams as the major cations and anions are used. Samples that failed the (EN) and (EC) evaluation were predominantly due to incomplete data for the major anions and cations. For the summary tables listing statistical information such as the maximum and minimum concentration for parameters some of the analysis was used even if the plausibility checks were not acceptable.

The Brochure for the 1: 500 000 Polokwane hydrogeological map sheet used a basic method of general characterisation of water composition known as the Kurlov method (Kurlov, 1928). It is based on the relative concentrations of (meq/l) of major cations and anions. The data was used to create a stiff diagram that was described in terms of the dominant cations and anions.

For the 1: 250 000 Thabazimbi map sheet, the limitations of the stiff diagram used as a single interpretation method was re-evaluated. Stiff diagrams are more suited to spatial comparisons by plotting each analysis on a map to identify trends and to identify water types on individual analysis. Spatial analysis based on stiff diagrams plotted on the map sheet area was not done but can be considered as a methodology for possible future smaller scale hydrogeological maps.

For the chemical evaluation of each aquifer unit as described in this explanatory brochure for the map sheet the methodology is as follows:

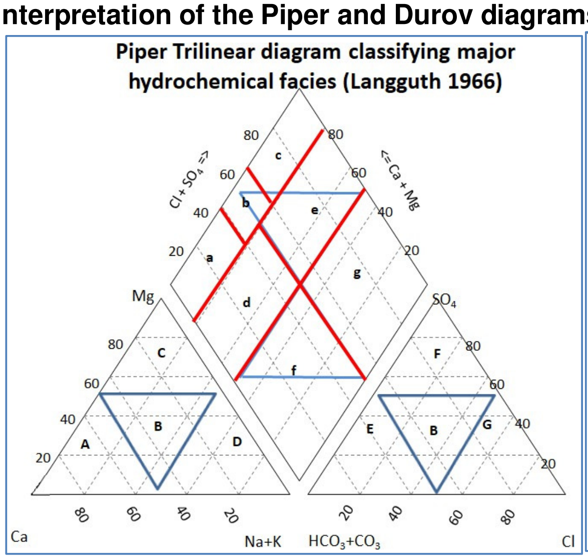
- A summary table within the general section of the document that lists the major cations, anions and physical properties as presentations falling within the ideal, good, and moderate water ranges (DWS guideline document, Class 0-2). The last range is called unacceptable and represents the DWS guideline Class 3 & 4.
- A summary table within the section of each aquifer unit that constitutes a list of the combined samples in each aquifer. Information in the table includes but is not limited to: the number of analyses, maximum, minimum, percentiles (10%, 50% & 90%) and statistics on variation.
- The use of Piper and Durov diagrams for the evaluation of the water chemistry for each unit. It was used to identify water types and hadrochemical processes.

For both the Piper and Durov diagrams the major ions are displayed as percentages of milli-equivalents in two ternary (trilinear) graphs, one for cations and one for anions (each parameter plots on one of the three axis). For the piper, the plot point for the major cations (Ca^{2}, Mg^{2}, Na^{+} + K^{+}) and anions (HCO_3^{-}, SO_4^{2-}, Cl^{-}) for each sample, in their respective triangular fields are projected along lines parallel to the triangular grid axes, ensuring a unique location in the central diamond field where a single plot point is created. This single point represents the composition of the cations and anions for each water analysis.

A similar procedure is followed for the Durov diagram, but the plot points are extended into a central square field along lines parallel to the proportional axes of the triangular grid. This ensures a unique location (single plot point) in the square for each sample. This single point represents both the anions and cations (thus 6 values are presented as one point).

- The assertion is that most natural water contains cations and anions in chemical equilibrium. It is assumed that the most abundant cations are two “alkaline earths” that is calcium (Ca^{2}) and magnesium (Mg^{2}) and one “Alkali” that is sodium (Na^{+}). For the plot, sodium, and potassium (K^{+}) is combined on one axis. The most common anions are one “weak acid” viz. bicarbonate (HCO_3^{-}) and two “strong acids” viz. sulphate (SO_4^{2-}) and chloride (Cl^{-}).

Interpretation of the Piper and Durov diagrams:



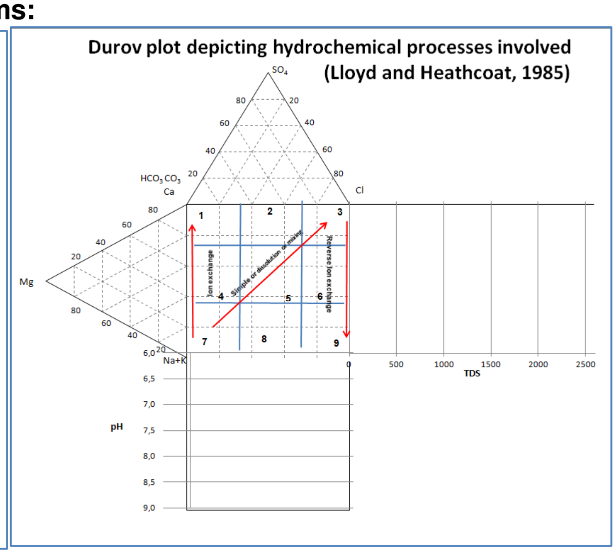


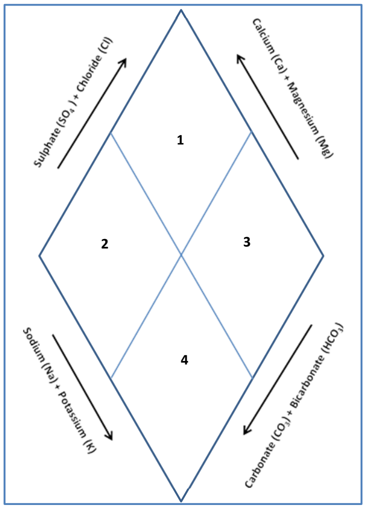
Table 10: Classification of water based on Piper diagram (Langguth, 1966), Water types

Section	Diamond shape diagram	Triangles	
a	Normal earth alkaline water with prevailing bicarbonate	A	Calcium type
b	Normal earth alkaline water with prevailing bicarbonate and sulphate or chloride	B	No Dominant type
c	Normal earth alkaline water with prevailing sulphate or chloride	C	Magnesium type
d	Earth alkaline water with increased portions of alkalis with prevailing bicarbonate	D	Sodium type
e	Earth alkaline water with increased portions of alkalis with prevailing sulphate and chloride	E	Bicarbonate type
f	Alkaline water with prevailing bicarbonate	F	Sulphate type
g	Alkaline water with prevailing sulphate or chloride	G	Chloride type

Table 11: Classification of water types based on Durov diagram (Lloyd and Heathcote, 1985).

Section	Water Types
1	HCO_3^- and Ca^{2+} dominant frequently indicates recharging waters in limestone, sandstone and many other aquifers
2	The water is dominated by Ca^{2+} and HCO_3^-, which typically suggests fresh, recharging groundwater, but if Mg^{2+} is also present in significant amounts, it suggests ion exchange processes might be occurring. However, those samples in which Na^+ is significant and $Ca^{2+}/Mg^{2+} < 1$ an important ion exchange is presumed.
3	HCO_3^- and Na^+ are dominant, normally indicates ion exchanged water, although the generation of CO_2 at depth can produce HCO_3^- where Na^+ is dominant under certain circumstances.
4	SO_4^{2-} dominates, or anion discriminate and Ca^{2+} dominant, Ca^{2+} and SO_4^{2-} dominant, frequently indicates recharge water in lava and gypsiferous deposits, otherwise mixed water exhibiting simple dissolution may be indicated.
5	No dominant anion or cation, indicates water exhibiting simple dissolution or mixing, plots along the dissolution or mixing line.
6	SO_4^{2-} dominates, or anion discriminate and Na^+ dominant, is a water type that is not frequently encountered and indicate probable mixing or uncommon dissolution influences.
7	Cl^- and Na^+ dominant is frequently encountered unless cement pollution is present. Otherwise, the water may result from reverse ion exchange of Na-Cl waters.
8	Cl^- dominant anion and Na^+ dominant cation, indicate that the ground waters be related to reverse ion exchange of Na-Cl waters
9	Cl^- and Na^+ dominant is frequently indicated end-point down gradient waters through dissolution.

Interpretation: Piper diamond shaped diagram



Section	Hydrochemical facies, general interpretation of chemical dominance
1	Strong acids exceed weak acids; Alkaline earths exceed alkaline.
2	Weak acids exceed strong acids; Alkaline earths exceed alkaline.
3	Strong acids exceed weak acids; Alkaline exceed alkaline earths.
4	Weak acids exceed strong acids; Alkaline exceed alkaline earths.

The samples within division 1 & 2 represents the dominance of alkaline earths over alkalies viz. (Ca^2 + Mg^2) > (Na^+ + K^+) and division 3 & 4 represents the dominance of alkalies over alkaline earths viz. (Na^+ + K^+) > (Ca^2 + Mg^2).

The samples within division 2 & 4 represent the dominance of weak acidic anions over strong acidic anions viz. (CO_3^{2-} + HCO_3^-) > (SO_4^{2-} + Cl^-) and division 1 and 3 represent dominance of strong acidic anions over weak acidic anions viz. (SO_4^{2-} + Cl^-) > (CO_3^{2-} + HCO_3^-).

Water quality in terms of Electrical Conductivity (EC)

The general water quality in terms of EC in each of the units is described as:

- Ideal (EC < 70mS/m),
- Good (EC ≥ 70 < 150mS/m),
- Moderate (EC ≥ 150 < 370mS/m),
- Unacceptable (EC ≥ 370mS/m).

Table 12 below (after DWA, 1996), was used as reference document. The words in the table, viz. suitable, tolerable, unacceptable, and totally unacceptable, were not used in the document. The terminology, ideal, good, moderate and unacceptable was used. This corresponds to the terminology used in the document 'Quality of Domestic Water Supplies, Volume 1: Assessment Guide, DWAF 1998'.

Table 12: Guidelines for groundwater quality and suitability (DWA, 1996)

ELECTRICAL CONDUCTIVITY RANGE (mS/m)	SUITABILITY		
	DOMESTIC	LIVESTOCK	IRRIGATION
<70	Suitable	Suitable	Suitable
70 - 150	Suitable - slightly salty taste	Suitable	Suitable - salt sensitive crops may show a 10% decrease in yield. Wetting of foliage should be prevented
150 - 370	Tolerable - a marked salty taste	Suitable	Suitable for moderately salt tolerant crops although a 10% decrease in yield can be expected. Wetting of foliage should be prevented
370 - 520	Unacceptable - tolerable for short term consumption	Suitable - some loss in productivity	Tolerable for moderately salt tolerant crops although a 20% decrease in yield can be expected. Wetting of foliage should be prevented
>570	Totally unacceptable	Tolerable - may be refused by animals not accustomed to the water	Generally unacceptable

Note: The water quality in terms of EC in the document is described as ideal (EC < 70mS/m); good (EC ≥ 70 < 150mS/m); moderate (EC ≥ 150 < 370mS/m); unacceptable (EC ≥ 370mS/m).

6.1 Aquifer Hydrochemistry

Data obtained from the National Water Quality Database (WMS), NGA, e-WULAAS and the groundwater data bank of the consultancy was utilised for hydrochemical data analysis and interpretation. Data was also received from various groundwater consultants in the Limpopo Province. The data points were plotted and sorted for each aquifer unit.

Data is presented in various tables of which Table 13 to Table 24 are within Section 6 viz. General: Hydrochemistry and Aquifer Units.

Table 13 & Table 14 represent the identification of the water types for each unit by using the Piper Diagram and the classification as proposed by Langguth 1966. More than one water type was identified for most of the units. This is as many of the units have a large areal extent and interact with various other units in a lateral and vertical direction. The water types were identified but no attempt was made to link the different water types to a geolocation for further assessment.

Table 15 & Table 16 summarize statistics for the major cations and anions within each aquifer unit. In the summary table the median value (50^{th} percentile) is presented. This table will give an indication of the median concentration in mg/l for each of the major cations and anions within the aquifer but do not show the percentages of samples that fall within the acceptable or unacceptable range. Table 17 & Table 18 summarize the values of the 90th percentile for the major anions and cations.

Table 19 & Table 20 summarize statistics for the major anions and Table 21 & Table 22 for the major cations within each aquifer unit. The data presented entails the percentages of each parameter that fall within the acceptable (ideal, good, marginal) and unacceptable limits for domestic use. These statistics are very useful in terms of problematic constituents that can be expected in each of the units during the planning phase of groundwater development projects. The water quality ranges used to divide the data for each parameter are according to the DWS guideline viz. Class 0, class 1 and class 2; the final range represents the classes 3 & 4 referred to in the table as the unacceptable limit range.

Table 23 & Table 24 represent the physical properties viz. Electrical Conductivity and pH as well as the anion Fluoride. The same methodology was followed as in Table 19 to Table 22.

For each of the aquifer units another summary table is included within the description for each unit. This gives statistics on concentrations for various parameters such as minimum, maximum, 10, 50 and 90th percentiles. It also includes the corrosiveness of the water and the suitability for irrigation in terms of the Sodium adsorption ratio (SAR) that can be used for desktop studies.

In total 9 aquifer units did not have any chemistry data available for analysis. They are Clarens Formation (Trc), Waterberg Group (Mw), Smelterskop Formation (Vsk), Silverton Formation (Vsi), Daspoort Formation (Vdp), Penge Formation (Vpe), Kwaggasnek Formation (Vkw), Ecca Formation (Ppe) and Modipe Gabbro Complex (Zme).

Another 9 units have only between 1 to 10 analyses available that may result in a less accurate evaluation of the characterization of the unit in regard to chemistry.

A: Normal earth alkaline water with prevailing Bicarbonate

- **Calcium Magnesium Bicarbonate water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} and the anion HCO_3^-. The Groundwater Resource Units dominated by this water are typically associated with carbonate rocks like dolomite [$CaMg(CO_3)_2$] or limestone ($CaCO_3$). This type of water chemistry forms primarily due to the dissolution of these rocks, which release calcium (Ca^{2+}), magnesium (Mg^{2+}), and bicarbonate (HCO_3^-) ions into the groundwater. Additionally, weathering of other rock types containing silicate minerals (feldspars, pyroxenes) and/or secondary minerals like clays can result in cation exchange processes, increasing Ca^{2+} and Mg^{2+} concentrations in groundwater over time. This water type may also reflect contributions from recent recharge, where infiltration of CO_2-rich water enhances the dissolution of minerals. The units dominated by this water type are Alluvium (Q); Cleremont Formation (Mcl), Kransberg Subgroup (Mkr); Aasvoëlkop Formation (Mas); Swaershoek Formation (Ms) and Gaborone Granite (Zga) that have only one available analysis.

It was also identified as a second but not the dominant water type in the Malmani Subgroup (Vma); Alma Formation (Mag); Klapperkop Quartzite (Vkp); Undifferentiated Ventersdorp Group (Rvz) and Swaziland System (Basic to ultrabasic rocks of the area correlated with Archaean & Jamestown Complexes (Zsj). It also occurs as a non-dominant water type in seven other units but as a low percentage (2.2 to 112.5%).

- **Calcium Bicarbonate water**

This water type is dominated by the cation Ca^{2+} and the anion HCO_3^-. This water type is typically associated with aquifers predominantly connected to limestone ($CaCO_3$) or areas where the dissolution of calcite is the dominant geochemical process. In areas where there is no hydrogeological connection to dolomite calcium and bicarbonate ions can still form from the weathering of calcium-bearing silicate minerals such as Plagioclase feldspar and secondary clays (e.g.,kaolinite or smectite), in igneous or metamorphic rocks. Other processes that can lead to the dominance of this water type are when groundwater interacts with clay minerals (e.g., smectite or illite), leading to cation exchange, where sodium (Na^+) or potassium (K^+) in the water is replaced by calcium (Ca^{2+}) or magnesium (Mg^{2+}) from the clay.

No Groundwater Resource Unit is dominated by this type of water. It was however identified as a non-dominant water type in nine of the units; it constitutes between 6.1 to 21.1% in those units.

- **Magnesium Bicarbonate water**

This water type is dominated by the cation Mg^{2+} and the anion HCO_3^-. The dominance of Mg^{2+} can relate to the presence of dolomite, the weathering of magnesium silicates (olivine, pyroxene), or evaporite minerals. Recharge through soils with high CO_2 or calcium exchange with magnesium rich clays can increase the magnesium concentration. It was identified as a dominant water type in the Schilpadkop Formation (Msc); Malmani Subgroup (Vma); Undifferentiated Rustenburg Layered Suite (Vrs) and Granite and granite gneiss Western Transvaal belt (Zjt).

It was also indentified as a second but not the dominant water type in the Undifferentiated Pretoria Group (Vpg) and Schrikkloof Formation (Vsc) Groundwater Resource Units. The water type occurs in another 5 units but as low percentages 2.9 to 12.5%.

B: Normal earth alkaline water with prevailing Bicarbonate and Sulphate or Chloride

The water type may represent a transition from fresh recharge water rich in ($Ca\text{-}HCO_3$), towards more evolved groundwater influenced by additional mineral dissolution and ion exchange over time. This water type can be linked to carbonate (limestone, dolomite, and marble) and evaporite rocks [Gypsum ($CaSO_4 2H_2O$); Anhydrite ($CaSO_4$) → Contribute Ca^{2+} and SO_4^{2-}] and [Halite ($NaCl$) → Introduces Cl^-], thus shifting water chemistry from a bicarbonate dominance toward chloride influence. It may also be linked to some siliciclastic formations and mixed sediments; [Alluvial and glacial deposits with mixed lithology → Provide a combination of Ca^{2+}, Mg^{2+}, HCO_3^-, SO_4^{2-}, and Cl^-] and [Sandstones and conglomerates with carbonate cements → Release Ca^{2+} and HCO_3^- into solution].

- **Calcium Magnesium Bicarbonate Sulphate water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} and the anions HCO_3^- and SO_4^{2-}. In aquifers where evaporite rocks (Gypsum ($CaSO_4 \cdot 2H_2O$) or Anhydrite ($CaSO_4$) are present or hydraulically connected, sulphate concentrations in the groundwater increase alongside bicarbonate. Only one unit was identified with this water type, it dominates the Rayten Formation (Vry). The interpretation was done based on the availability of only one chemical analysis.

- **Calcium Magnesium Bicarbonate Chloride water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} and the anions HCO_3^- and Cl^-. Groundwater Resource Units dominated by this water type are the Undifferentiated Ventersdorp Group (Rvz) and the Crocodile River Fragment (Vco).

It was also identified as a second but not the dominant water type in the Alluvium (Q); Swaershoek Formation (Ms) and Undifferentiated Pretoria Group (Vpg) units. This water type occurs in another 4 units, but at low percentages 3.9 to 12.5%

- **Calcium Bicarbonate Chloride water**

This water type is dominated by the cation Ca^{2+} and the anions HCO_3^- and Cl^-.
No units were identified with this water type as the dominant type. Two units exhibit a small percentage (< 6.9%) that is leaning to a Calcium Bicarbonate type.

- **Magnesium Bicarbonate Chloride water**

This water type is dominated by the cations Mg^{2+} and the anions HCO_3^- and Cl^-. No units were identified with this water type as the dominant type. The water type occurs in 6 units but as low percentages 1.9 to 14.3%

C: Normal earth alkaline water with prevailing Sulphate or Chloride

This water type indicates groundwater that has evolved beyond the early recharge stage (Ca- HCO_3^- type) and has undergone additional mineral dissolution, cation exchange, or mixing with older water. If gypsum or halite is present, bicarbonate dominance may shift to sulphate or chloride. If **s**andstone and clays are present with evaporites as the binding chemical cementation, the water type can mitigate over time by slow dissolution of gypsum or halite from pore spaces.

- **Calcium Magnesium Sulphate water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} and the anion SO^{2-}. The sulphate water is usually associated with groundwater encountered in lavas and gypsum deposits. In the map area one unit was identified with this water type. It shares the dominant water type with 50/50 with a mixed calcium magnesium chloride type, [Malmani Subgroup intergrated with Pilanesberg dykes (Vds)]. This is not a common water type encounter in any of the upgraded 1:250 000 map sheets of the 1:500 000 Polokwane hydrogeological map sheet area.

- **Calcium Magnesium Chloride water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} and the anion Cl^-. Where Ca^{2+} and Mg^{2+} are dominant, water is related to reverse ion exchange (replacement of Na^+ with Ca^{2+} and Mg^{2+}). Groundwater Resource Units dominated by this water type is the Nebo Granite (Mn) and the Klapperkop Quartzite (Vkp). Another unit have a large percentage dominated by this type namely, 25.5% of the analysis of the Aasvoëlkop Formation (Mas). The water type occurs in another 8 units but as low percentages 2.2 to 10.55%, except for the unit Alluvium (Q) where it constitutes 19.6%.

- **Magnesium Chloride water**

This water type is dominated by the cation Mg^{2+} and the anion Cl^-. The type is indicative of reverse ion exchange. No unit is dominated by this water type, but it occurs in 6 units where it constitutes 3.2 to 11.7% of the water types.

- **Calcium Chloride water**

This water type is dominated by the cation Ca^{2+} and the anion Cl^-. Only one unit was identified with this water type. It constitutes 5.3% of the water found in the Malmani Subgroup (Vma).

D: Earth alkaline water with increasing portions of alkalis with prevailing Bicarbonate

This water type represents a transitional stage between calcium-magnesium-bicarbonate (Ca-Mg-HCO_3) and sodium-bicarbonate (Na-HCO_3) or mixed-alkali-bicarbonate (Na-K-HCO_3) water types. It suggests progressive water evolution due to mineral dissolution, cation exchange, and prolonged groundwater interaction with rocks. Rock types associated with the evolution of this water type includes siliciclastic rocks and clay-rich sediments that will be the source of Na^+ and K^+, it includes Feldspar-bearing rocks (granite, gneiss, arkosic sandstone) where the weathering of alkali feldspars (e.g., orthoclase, plagioclase) releases Na^+ and K^+.

This increases Na^+ and K^+ concentrations, shifting the water type toward an alkali dominance. Clay minerals such as illite, montmorillonite, and kaolinite participate in cation exchange reactions, replacing Ca^{2+} and Mg^{2+} with Na^+ and K^+. Volcanic Rocks such as basalt, rhyolite and trachyte are another potential source of alkalis and silica where weathering of volcanic glass and feldspar minerals releases Na^+ and K^+, thus increasing the alkali contribution.

- **Mixed Calcium Magnesium Bicarbonate water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} but with increased Na^+ concentration with the dominant anion HCO_3^-. This water type is dominant in four units, namely, the Vaalwater Formation (Mva); Alma Formation (Mag); Rashoop Granophyre (Mr) and Diabase Intrusions (N- Za). In another unit it constituted 10.2% of the water types.

E: Earth alkaline water with increasing portions of alkalis with prevailing Sulphate and Chloride

This water type represents a transition from calcium-magnesium dominance to increasing sodium and potassium proportions, with sulphate (SO_4^{2-}) and chloride (Cl^-) prevailing. The evolution of this water type can relate to a combination of evaporite dissolution, cation exchange, and prolonged groundwater residence time. The hydrochemical process and evaporite dissolution is a primary source of SO_4^{2-} and Cl^-. With the dissolution of gypsum, anhydrite, halite, and sylvite the elements Ca^{2+}, Na^+, K^+, SO_4^{2-}, and Cl^- are released. This is a major driver of sulphate-chloride dominance in groundwater.

The hydrochemical process in which cation exchange dominates relates the abundance of clay minerals such as illite, montmorillonite, smectite and kaolinite. Over time Ca^{2+} and Mg^{2+} is replaced with Na^+ and K^+ and will lead to a progressive shift from Ca-Mg-SO_4-Cl water to Na-K- SO_4-Cl water.

Other processes such as silicate weathering will release Na^+ and K^+, thus enhancing the alkali proportions in the groundwater. This relates to the weathering of feldspar that contributes to the gradual enrichment of Na^+ and K^+ over time. This process occurs more in deep groundwater or areas with prolonged rock-water interaction.

- **Mixed Calcium Magnesium Sulphate water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} but with increased Na^+ concentrations and the anion SO_4^{2-}. None of the units are dominated by this type of water.

- **Mixed Calcium Magnesium Chloride water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} but with increased Na^+ concentrations and the anion Cl^-. In 7 of the aquifer units this type was identified, it dominates in one namely, Malmani Subgroup integrated with Pilanesberg dykes (Vds).

- **Mixed Calcium Magnesium Bicarbonate Chloride water**

This water type is dominated by the cations Mg^{2+} and Ca^{2+} but with increased Na^+ concentrations and the anions HCO_3^- and Cl^-. This water type was identified within 8 of the units and dominates in one of those. The unit is Granite and granite gneiss Western Transvaal belt (Zjt) where the dominant water type is shared 50/50 with a Magnesium Bicarbonate type.

• Mixed Calcium Magnesium Chloride Sulphate water

This water type is dominated by the cations Mg^{2+} and Ca^{2+} but with increased Na^+ concentrations and the anions Cl^- and SO_4^{2-}. This water type was identified within three of the units. It dominates in one namely Schrikkloof Formation (Vsc) where it constitutes a 50/50 percentage with the water type Magnesium Bicarbonate. In the other two units this water type constitutes 2.2 to 4.9%.

F: Alkaline water with prevailing Bicarbonate

This water type is typically characterized by high Na^+ and K^+ concentrations with HCO_3^- as the dominant anion. It results from long-term rock-water interactions, cation exchange, and silicate weathering, with minimal influence from evaporite dissolution or seawater intrusion.

Associated rock types with this water type is feldspar-rich rocks such as igneous and metamorphic rocks (granites and gneisses); volcanic rocks (basalt, andesite, rhyolite, trachyte and tuff); carbonate rocks, (that may only be the original source of HCO_3^-), quartz-rich sandstones, (contain feldspars and clay minerals that release Na^+ and K^+ upon weathering) and clay-rich sediments, (shale, mudstone, and alluvial deposits that contain clay minerals, (montmorillonite, illite, kaolinite), which exchange Ca^{2+} and Mg^{2+} for Na^+ and K^+ (cation exchange), thus shifting the groundwater chemistry to a Na-HCO_3 type.

• Sodium Bicarbonate water

This water type is dominated by the cation Na^+ and the anion HCO_3^-. This type of water is generally related to the movement of groundwater from intensive recharge areas and normally indicates a cation exchange process. The water type was identified in 11 units, it does not dominate in any of these, but it constitutes 17.4% of the aquifer unit, Vaalwater Formation (Mva); 15.8% of the unit Cleremont Formation (Mcl) and 15.4% of the unit Alma Formation (Mag). For the other units these water types constitute between 2.8 and 8.3%.

G: Alkaline water with prevailing Sulphate or Chloride

This water type is dominated by Na^+ and K^+ as the primary cations, with SO_4^{2-} and/or Cl^- as the dominant anions. It is commonly associated with evaporite dissolution, cation exchange, and prolonged groundwater residence time. It often occurs in arid or semi-arid regions, deep aquifers, or coastal settings.

Associated rock types include evaporites (gypsum, anhydrite, halite, sylvite), feldspar-rich igneous/metamorphic rocks (granite, gneiss), volcanic rocks, (basalt, andesite, rhyolite, trachyte and tuff) and clay-rich sediments.

• Sodium Sulphate water

This water type is dominated by the cation Na^+ and the anion SO_4^{2-}. The sulphate water is usually associated with groundwater encountered in lavas and gypsum deposits. This water type was not identified in any of the units within the boundary of the map sheet.

• Sodium Chloride water

This water type is dominated by the cation Na^+ and the anion Cl^-. Within 13 units this water type was identified. The units that have a large percentage of water falling within this type are the Nebo Granite (Mn) at 15.4%; the Aasvoëlkop Formation (Mas) at 26.3% and the Alma Formation (Mag) at 15.4%. This type dominates in one unit viz. Swaziland System (Basic to ultrabasic rocks of the area correlated with Archaean & Jamestown Complexes (Zsj). For the remaining 9 units this water type constitutes between 2.9% to 13.4%.

- **Sodium Mixed Bicarbonate-Chloride and / or Sulphate water**

This water type is dominated by the cation Na^+ and the anions Cl^- and SO_4^{2-}. Bicarbonate (HCO_3^-.) prevails. This water type was identified within 7 aquifer units; it constitutes 2.8% to 7.5% except in the unit Kransberg Subgroup (Mkr) where it constitutes 19.9%.

Other problematic chemical species, which occur in the area covered by the map sheet, include Nitrate and Fluoride (inset map main map sheet), see also Figure 8, page 53. Nitrate and nitrite concentrations reported as N greater than 10mg/l can cause Methemoglobinemia (blue baby syndrome) in children younger than two years. Fluoride concentrations greater than 1.5mg/l can cause brown staining and the crumbling of teeth and bone structure.

Table 13: Interpretation of the hydrochemical facies as percentages, water type; first page.

Symbol and number of samples		A: Normal earth alkaline water with prevailing Bicarbonate			B: Normal earth alkaline water with prevailing Bicarbonate and Sulphate or Chloride				C: Normal earth alkaline water with prevailing Sulphate or Chloride					E: Earth alkaline water with increasing portions of alkalis with prevailing Sulphate and Chloride					G: Alkaline water with prevailing Sulphate or Chloride		
Aquifer Unit	Samples used	Calcium Magnesium Bicarbonate	Calcium Bicarbonate	Magnesium Bicarbonate	Calcium Magnesium Bicarbonate Sulphate	Calcium Magnesium Bicarbonate Chloride	Calcium Bicarbonate	Magnesium Bicarbonate Chloride	Calcium Bicarbonate Chloride	Calcium Magnesium Chloride	Magnesium-Chloride	Calcium-Chloride	Mixed Calcium Magnesium Bicarbonate	Mixed Calcium Magnesium Bicarbonate	Mixed Calcium Magnesium Chloride	Mixed Calcium Magnesium Bicarbonate Chloride	Mixed Calcium Magnesium Chloride-Sulphate	Sodium Bicarbonate water	Sodium Sulphate water	Sodium Chloride water	Sodium Mixed Bicarbonate Chloride and/or Sulphate
Category A: Intergranular aquifers																					
Q		27.5		2.9		24.5		1.9		19.6						10.0	4.9	1.9		2.9	3.9
Category B: Fractured aquifers																					
Trc																					
Mw																					
Mva		2.2	6.5	6.5				4.3		2.2			39.1		2.2	10.9		17.4		4.3	4.4
Mcl		52.6	10.5							10.55					10.55			15.8			
Mkr		46.7	6.7			6.7									13.3					6.7	19.9
Mas		29.2					0.7			25.5				10.2	3.0	0.7	2.2	2.2		26.3	
Msc				100.0																	
Mag		19.2				3.9		3.8					42.3					15.4		15.4	
Ms		40.0	8.0			28.0				4.0								8.0		12.0	
Vpg		25.0		25.0		25.0		8.4										8.3		8.3	
Vry					100.0																
Vsk																					
Vsi																					
Vdp																					
Vti																					
Vkp		25.0								75.0											
Vpe																					
Rvz		16.1	9.7	9.7		42.0				9.7	3.2							6.4			3.2
Vkw																					
Vsc				50.0													50.0				
Note: Dominant type highlighted, values represent percentages (%)																					

Table 14: Interpretation of the hydrochemical facies as percentages, water type; second page.

Symbol and number of samples		A: Normal earth alkaline water with prevailing Bicarbonate			B: Normal earth alkaline water with prevailing Bicarbonate and Sulphate or Chloride				C: Normal earth alkaline water with prevailing Sulphate or Chloride				D: Earth alkaline water with increasing portions of alkalis with prevailing Bicarbonate	E: Earth alkaline water with increasing portions of alkalis with prevailing Sulphate and Chloride				F: Alkaline water with prevailing Bicarbonate	G: Alkaline water with prevailing Sulphate or Chloride		
Aquifer Unit	samples used	Calcium Magnesium Bicarbonate	Calcium Bicarbonate	Magnesium Bicarbonate	Calcium Magnesium Bicarbonate Sulphate	Calcium Magnesium Bicarbonate Chloride	Calcium Bicarbonate Chloride	Magnesium Bicarbonate Chloride	Calcium Magnesium Sulphate	Calcium Magnesium Chloride	Magnesium-Chloride	Calcium-Chloride	Mixed Calcium Magnesium Bicarbonate	Mixed Calcium Magnesium Sulphate	Mixed Calcium Magnesium Chloride	Mixed Calcium Magnesium Bicarbonate Chloride	Mixed Calcium Magnesium Chloride-Sulphate	Sodium Bicarbonate water	Sodium Sulphate water	Sodium Chloride water	Sodium Mixed Bicarbonate Chloride and/or Sulphate
Category C: Karst aquifers																					
Vds									50.0						50.0						
Vma		15.8	5.3	57.7		5.3				5.3		5.3				5.3					
Category D: Intergranular and Fractured aquifers																					
P-Tr																					
Ppe																					
Mn		3.1	6.1							43.1						23.1		6.1		15.4	3.1
Mr													100.0								
N-Za		7.5	6.1	2.5		12.5		2.5			10.0		36.4					5.0		10.0	7.5
Vrs		5.7		34.4				14.3			5.7				17.1	17.1				5.7	
Vco		6.7	6.7			59.8				6.7	6.7									13.4	
Zga		100.0																			
Zjt		6.9		20.7			6.9			9.0	11.7				7.5	20.7		2.8		11.0	2.8
Zme																					
Zsj		9.1		9.1						9.1			18.2			18.2				36.3	
	No chemical data was available for this unit																				
Note: Dominant type highlighted, values represent percentages (%)																					

Table 15: Hydrochemistry of the Thabazimbi Map Area, 50th percentile (median); first page.

Symbol	Total number of samples				50th Percentile (median) and comparison to SANS 241:2015 maximum acceptable limits										
Aquifer Unit	After manipulation	Missing major anions or cations	E.N. ≤ ±10% & EC ≤ 20%	Used for piper and Durov	pH Ideal 6 to 9	EC mS/m	NO_3 mg/l	F mg/l	TAL as (CaCO3) mg/l	Na mg/l	Mg mg/l	SO_4 mg/l	Cl mg/l	K mg/l	Ca mg/l
						370	20	1.5		400	200	600	600	100	300
Category A: Intergranular aquifers															
Q	**149**		55.7%	102	7.7	104	2.3	0.7	280	70	51	56	104	2.9	59.8
Category B: Fractured aquifers															
Trc	**0**				No data available										
Mw	**0**				No data available										
Mva	**60**	0	51.7%	46	8.2	52	1.1	0.4	190	43	12	11	25	1.6	28
Mcl	**31**	5	35.5%	19	7.4	15	1.1	0.1	51	8	3	4	7	0.9	8
Mkr	**29**	4	41.4%	15	7.1	11	0.7	0.2	42	6	4	4	5	1.1	4
Mas	**186**	6	49.5%	138	7.6	132	4.2	0.8	294	123	49	27	134	5.3	77
Msc	**2**	2	0.0%	0	7.2	60	0.2	4.6	44			81	105		
Mag	**47**	1	25.5%	26	7.4	39	0.4	0.3	132	26	11	7	13	1.3	29
Ms	**54**	10	37.0%	25	7.3	12	0.6	0.2	50	7	3	2	6	0.9	12
Vpg	**23**	3	21.7%	12	7.1	52	1.2	0.6	184	21	20	10	22	1.8	26
Vry	**2**	0	100.0%	1	7.3	94	1.4	1.9	269	33	43	159	25	1.7	94
Vsk	**0**				No data available										
Vsi	**0**				No data available										
Vdp	**0**				No data available										
Vti	**2**	1	0.0%	4	7.7	100.4	4.214	0.275	531.4	56.6	101	27.7	12.4	5.1	23.5
Vkp	**4**	0	75.0%	4	7.8	253	8.6	0.6	334	166	149	69	552	3.8	151
Vpe	**0**				No data available										
Rvz	**36**	2	55.6%	31	8.0	108	3.4	0.4	322	71	58	44	77	3.6	61
Vkw	**0**				No data available										
Vsc	**2**	0	0.0%	2	7.2	75	24.7	0.1	249	6	123	60	43	1.3	30
Manipulation of samples: removing duplicates and calculation of the harmonic mean for time series data, further elimination in some cases by plausibility of EN and EC. In most of the unit's analysis with EN up to ±15% was used if the calculated EC difference was acceptable.															

Table 16: Hydrochemistry of the Thabazimbi Map Area, 50th percentile (median); second page.

Symbol	Total number of samples				50th Percentile (median) and comparison to SANS 241:2015 maximum acceptable limits										
Aquifer Unit	After manipulation	Missing major anions or cations	E.N. ≤ ±10% & EC ≤ 20%	Used for piper and Durov	pH Ideal 6 to 9	EC mS/m	NO_3 mg/l	F mg/l	TAL as (CaCO3) mg/l	Na mg/l	Mg mg/l	SO_4 mg/l	Cl mg/l	K mg/l	Ca mg/l
						370	**20**	**1.5**		**400**	**200**	**600**	**600**	**100**	**300**
Category C: Karst aquifers															
Vds	5	1	20.0%	5	7.9	127.5	2.3	0.5	311.3	20.5	110.1	76.3	12.5	2.7	84.9
Vma	39	13	17.9%	39	7.7	89.4	2.9	0.3	405.7	13.2	67.6	17.6	28.0	2.1	81.5
Category D: Intergranular and Fractured aquifers															
P-Tr	**2**	0	0.0%	0	7.5	40	2.0	0.7	169	21	17	9	5	1	37
Ppe	**0**			0	No data available										
Mn	**88**	5	40.9%	65	7.6	107.4	3.1	1.0	274.2	77.3	41.8	40.5	103.0	3.4	74.3
Mr	**1**	0	100.0%	1	7.2	14.5	0.0	2.2	68.6	15.8	3.5	2.0	3.0	0.6	8.4
N-Za	**51**	1	49.0%	40	7.5	93.9	3.1	0.7	265.4	77.0	48.7	23.8	76.0	3.7	57.6
Vrs	**58**	4	51.7%	35	7.7	117.6	2.5	0.3	382.2	36.6	102.0	58.4	75.5	1.7	47.0
Vco	**20**	0	65.0%	15	7.7	190.0	4.7	0.8	372.3	146.6	86.7	127.2	227.2	4.0	80.1
Zga	**1**	0	0.0%	1	8.3	103.5	24.2	0.4	460.0	59.1	53.3	2.0	30.9	1.1	96.1
Zjt	**200**	16	56.5%	141	7.9	121.4	4.5	0.7	351.4	83.4	74.3	42.4	111.7	3.8	70.7
Zme	**0**			0	No data available										
Zsj	**11**	0	100.0%	11	8.2	101.2	14.1	0.7	344.4	164.8	49.6	87.1	165.0	4.5	51.3

Manipulation of samples: removing duplicates and calculation of the harmonic mean for time series data, further elimination in some cases by plausibility of EN and EC. In most of the unit's analysis with EN up to ±15% was used if the calculated EC difference was acceptable.

Table 17: Hydrochemistry of the Thabazimbi Map Area, 90th percentile (median); first page.

Symbol	Total number of samples	90th Percentile (median) and comparison to SANS 241:2015 maximum acceptable limits													
Aquifer Unit	After manipulation	pH Ideal 6 to 9	EC mS/m	NO_3 mg/l	F mg/l	TAL as (CaCO3) mg/l	Na mg/l	Mg mg/l	SO_4 mg/l	Cl mg/l	K mg/l	Ca mg/l	Fe mg/l	Mn mg/l	Zn mg/l
			370	20	1.5		400	200	600	600	100	300	2	1	10
Category A: Intergranular aquifers															
Q	**149**	8.08	307.6	17.76	1.40	560.77	227.80	153.00	125.64	646.90	5.99	187.00	0.370	0.457	0.020
Category B: Fractured aquifers															
Trc	**0**	No data available													
Mw	**0**	No data available													
Mva	**60**	8.44	82.2	4.11	1.70	339.55	111.84	49.18	50.48	87.36	5.66	51.50	0.167	0.050	0.055
Mcl	**31**	7.95	43.2	4.44	0.43	160.70	24.08	14.51	12.63	26.62	1.47	34.11	0.050	0.066	0.665
Mkr	**29**	7.91	115.7	12.08	0.38	348.10	85.02	56.12	20.34	184.48	8.17	59.14	0.402	0.048	3.317
Mas	**186**	7.97	331.6	24.10	3.25	441.54	308.61	96.46	246.50	624.80	12.75	189.99	1.290	0.160	0.130
Msc	**2**	7.99	92.8	0.25	8.12	60.00			131.40	165.00					
Mag	**47**	8.02	117.3	3.4292	1.65	400.15	79.17	60.67	39.69	73.45	4.43	93.89	0.050	0.235	0.143
Ms	**54**	7.92	42.7	13.842	1.24	153.14	35.62	22.43	16.00	77.52	6.08	43.60	0.110	0.310	1.249
Vpg	**23**	8.09	78.1	3.9	1.01	451.60	57.47	73.34	39.00	73.34	4.41	88.28	0.056	0.052	1.307
Vry	**2**	7.30	93.7	1.4	1.90	269.00	33.13	43.25	158.99	25.00	1.69	93.98	0.010	0.010	
Vsk	**0**	No data available													
Vsi	**0**	No data available													
Vdp	**0**	No data available													
Vti	**2**	7.7	100.4	4.21	0.28	531.40	56.60	101.00	27.70	12.40	5.10	23.50			
Vkp	**4**	8.0	301.2	19.04	0.72	353.94	209.33	165.28	86.80	709.63	5.93	187.79			
Vpe	**0**	No data available													
Rvz	**36**	8.18	160.0	105.92	0.79	523.00	137.51	86.58	60.79	220.33	10.00	99.00	0.346	0.082	0.033
Vkw	**0**	No data available													
Vsc	**2**	7.85	130.2	44.40	0.18	436.49	8.94	219.87	92.97	73.87	1.57	52.34	0.013	0.002	0.025

Manipulation of samples: removing duplicates and calculation of the harmonic mean for time series data, further elimination in some cases by plausibility of EN and EC. In most of the unit's analysis with EN up to ±15% was used if the calculated EC difference was acceptable.

Table 18: Hydrochemistry of the Thabazimbi Map Area, 90th percentile (median); second page.

Symbol	Total number of samples	90th Percentile (median) and comparison to SANS 241:2015 maximum acceptable limits													
Aquifer Unit	After manipulation	pH Ideal 6 to 9	EC mS/m	NO_3 mg/l	F mg/l	TAL as (CaCO3) mg/l	Na mg/l	Mg mg/l	SO_4 mg/l	Cl mg/l	K mg/l	Ca mg/l	Fe mg/l	Mn mg/l	Zn mg/l
			370	20	1.5		400	200	600	600	100	300	2	1	10
Category C: Karst aquifers															
Vds	5	8.7	153.6	6.0	0.5	351.2	124.3	112.7	535.7	179.6	3.7	149.1	0.0	0.5	0.0
Vma	39	8.1	168.3	10.7	0.5	489.5	41.5	120.5	74.0	190.3	5.7	169.5	0.220	0.560	0.236
Category D: Intergranular and Fractured aquifers															
P-Tr	**2**	7.57	43.3	3.07	1.01	168.88	29.47	24.01	11.47	5.50	0.55	39.19			
Ppe	**0**	No data available													
Mn	**88**	8.0	229.9	23.7	3.2	426.4	276.7	82.8	119.7	518.9	8.9	152.4	0.091	0.118	0.120
Mr	**1**	7.2	14.5	0.0	2.2	68.6	15.8	3.5	2.0	3.0	0.6	8.4			
N-Za	**51**	7.9	170.7	17.4	3.2	459.3	217.2	75.9	133.6	238.7	10.2	95.6	1.080	0.210	3.853
Vrs	**58**	8.2	250.6	13.7	0.7	564.0	191.1	182.8	206.3	493.6	5.9	130.6	0.050	0.236	0.081
Vco	**20**	8.0	275.8	38.1	1.6	509.2	334.1	148.6	215.5	534.7	8.4	162.8			
Zga	**1**	8.3	103.5	24.2	0.4	460.0	59.1	53.3	2.0	30.9	1.1	96.1			
Zjt	**200**	8.2	299.9	40.6	1.6	576.0	267.3	133.8	163.1	538.9	8.3	139.0	0.064	0.025	0.366
Zme	**0**	No data available													
Zsj	**11**	8.3	224.0	72.0	1.2	459.2	353.0	125.0	198.8	347.5	6.0	53.3	0.005	0.040	0.268
Manipulation of samples: removing duplicates and calculation of the harmonic mean for time series data, further elimination in some cases by plausibility of EN and EC. In most of the unit's analysis with EN up to ±15% was used if the calculated EC difference was acceptable.															

Table 19: Summarized Major Anions: Chloride, Nitrate and Sulphate concentration ranges within aquifer units, first page.

Anions		Chloride Cl (mg/l)				Nitrate NO2 + NO3 as N (mg/l)				Sulphate SO4 (mg/l)			
Symbol	**Number of samples after manipulation**	**Class 0 (Ideal)**	**Class I (Acceptable)**	**Class II (Maximum Allowable)**	**Un-acceptable**	**Class 0 (Ideal)**	**Class I (Acceptable)**	**Class II (Maximum Allowable)**	**Un-acceptable**	**Class 0 (Ideal)**	**Class I (Acceptable)**	**Class II (Maximum Allowable)**	**Un-acceptable**
Limit Ranges		**100**	**200**	**600**	**>600**	**6**	**10**	**20**	**>20**	**200**	**400**	**600**	**>600**
Category A: Intergranular aquifers													
Q	149	48.5%	26.5%	12.5%	12.5%	69.6%	11.5%	11%	7.4%	95.6%	2.9%	0.7%	0.7%
Category B: Fractured aquifers													
Trc	0	No data available											
Mw	0	No data available											
Mva	60	93.3%	3.3%	3.3%		94.8%	3.4%	1.7%		100.0%			
Mcl	31	100.0%				93.3%	3.3%		3.3%	100.0%			
Mkr	29	84.0%	4.0%	12.0%		88.9%			11.1%	100.0%			
Mas	186	35.0%	31.1%	22.8%	11.1%	59.1%	15.5%	13.3%	12.2%	85.6%	7.2%	3.3%	3.9%
Msc	2	50.0%	50.0%			100.0%				100.0%			
Mag	47	91.5%	2.1%	2.1%	4.3%	93.3%		2.2%	4.4%	100.0%			
Ms	54	90.6%	3.8%	5.7%		83.7%	4.1%	8.2%	4.1%	100.0%			
Vpg	23	100.0%				90.5%	4.8%		4.8%	100.0%			
Vry	2	100.0%				100.0%				100.0%			
Vsk	0	No data available											
Vsi	0	No data available											
Vdp	0	No data available											
Vti	2	100.0%				100.0%				100.0%			
Vkp	4	25.0%		25.0%	50.0%	50.0%		25.0%	25.0%	100.0%			
Vpe	0	No data available											
Rvz	36	58.8%	26.5%	14.7%		55.9%	5.9%	5.9%	32.4%	97.1%	2.9%		
Vkw	0	No data available											
Vsc	2	100.0%				50.0%			50.0%	100.0%			
Note: 0% occurrences removed to make the table more readable													

Table 20: Summarized Major Anions: Chloride, Nitrate and Sulphate concentration ranges within aquifer units, second page.

Anions		**Chloride Cl (mg/l)**				**Nitrate NO2 + NO3 as N (mg/l)**				**Sulphate SO4 (mg/l)**			
Symbol	**Number of samples after manipulation**	**Class 0 (Ideal)**	**Class I (Acceptable)**	**Class II (Maximum Allowable)**	**Un-acceptable**	**Class 0 (Ideal)**	**Class I (Acceptable)**	**Class II (Maximum Allowable)**	**Un-acceptable**	**Class 0 (Ideal)**	**Class I (Acceptable)**	**Class II (Maximum Allowable)**	**Un-acceptable**
Limit Ranges		**100**	**200**	**600**	**>600**	**6**	**10**	**20**	**>20**	**200**	**400**	**600**	**>600**
Category C: Karst aquifers													
Vds	5	75.0%		25.0%		75.0%	25.0%			75.0%			25.0%
Vma	39	84.6%	3.8%	11.5%		71.0%	16.1%	6.5%	6.5%	100.0%			
Category D: Intergranular and Fractured aquifers													
P-Tr	2	100.0%				100.0%				100.0%			
Ppe	0	No data available											
Mn	88	47.0%	28%	20.5%	4.8%	64.7%	11%	12.9%	11.8%	97.6%	1%		1.2%
Mr	1	100.0%				100.0%				100.0%			
N-Za	51	62.0%	22%	14.0%	2.0%	65.3%	12%	12.2%	10.2%	98.0%			2.0%
Vrs	58	55.2%	17%	20.7%	6.9%	70.7%	12%	12.1%	5.2%	89.7%	7%	2%	1.7%
Vco	20	20.0%	25%	55.0%		50.0%	10%	20.0%	20.0%	80.0%	20%		
Zga	1	100.0%							100.0%	100.0%			
Zjt	200	47.0%	18%	26.5%	8.6%	53.0%	14%	15.2%	18.2%	93.0%	3%	2%	1.6%
Zme	0	No data available											
Zsj	11	36.4%	18%	45.5%		27.3%	18%	18.2%	36.4%	90.9%	9%		
Note: 0% removed to make the table more readable													

Table 21: Summarized Major Cations: Calcium, Potassium, Magnesium and Sodium concentration ranges within aquifer units, first page.

Cations		Calcium Ca (mg/l)				Potassium K (mg/l)				Magnesium Mg (mg/l)				Sodium Na (mg/l)			
Symbol	Number of samples after manipulation	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable
Limit Ranges		80	150	300	>300	25	50	100	>100	70	100	200	>200	100	200	400	>400
Category A: Intergranular aquifers																	
Q	149	65.7%	22.6%	10.9%	0.7%	100%				67.2%	11.7%	18.2%	2.9%	64.2%	20.4%	10.9%	4.4%
Category B: Fractured aquifers																	
Trc	0	No data available															
Mw	0	No data available															
Mva	60	98.3%	1.7%			100.0%				96.6%	1.7%	1.7%		83.3%	15.0%	1.7%	
Mcl	31	100.0%				100.0%				100.0%				100.0%			
Mkr	29	96.0%	4.0%			100.0%				96.0%	4.0%			91.3%		8.7%	
Mas	186	52.8%	30.6%	13.3%	3.3%	97.2%	2.8%			81.0%	10.1%	6.1%	2.8%	39.4%	37.8%	17.8%	5.0%
Msc	2	no data				no data				no data				no data			
Mag	47	87.2%	12.8%			100.0%				92.3%	5.1%	2.6%		91.3%	4.3%	2.2%	2.2%
Ms	54	93.2%	2.3%	4.5%		100.0%				97.7%		2.3%		97.7%	2.3%		
Vpg	23	80.0%	20.0%			100.0%				85.0%	15.0%			95.0%	5.0%		
Vry	2		100.0%			100.0%				100.0%				100.0%			
Vsk	0	No data available															
Vsi	0	No data available															
Vdp	0	No data available															
Vti	2	100.0%				100.0%						100.0%		100.0%			
Vkp	4	25.0%	25.0%	50.0%		100.0%				25.0%		75.0%		25.0%	50.0%	25.0%	
Vpe	0	No data available															
Rvz	36	67.6%	32.4%			100.0%				67.6%	23.5%	5.9%	2.9%	76.5%	20.6%	2.9%	
Vkw	0	No data available															
Vsc	2	100.0%				100.0%				50.0%			50.0%	100.0%			

Note: 0% removed to make the table more readable

Table 22: Summarized Major Cations: Calcium, Potassium, Magnesium and Sodium concentration ranges within aquifer units, second page.

Cations		Calcium Ca (mg/l)				Potassium K (mg/l)				Magnesium Mg (mg/l)				Sodium Na (mg/l)			
Symbol	Number of samples after manipulation	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable
Limit Ranges		80	150	300	>300	25	50	100	>100	70	100	200	>200	100	200	400	>400
Category C: Karst aquifers																	
Vds	5	33.3%	33.3%	33.3%		100.0%					33.3%	66.7%		75.0%	25.0%		
Vma	39	42.3%	38.5%	15.4%	3.8%	100.0%				53.8%	30.8%	7.7%	7.7%	100.0%			
Category D: Intergranular and Fractured aquifers																	
P-Tr	2	100.0%				100.0%				100.0%				100.0%			
Ppe	0	No data available															
Mn	88	59.0%	28.9%	12.0%		100.0%				81.9%	10.8%	6.0%	1.2%	66.3%	18.1%	10.8%	4.8%
Mr	1	100.0%				100.0%				100.0%				100.0%			
N-Za	51	80.0%	16.0%	4.0%		98.0%	2.0%			78.0%	14.0%	8.0%		74.0%	14.0%	10.0%	2.0%
Vrs	58	66.7%	26.3%	5.3%	1.8%	96.5%	3.5%			29.8%	14.0%	49.1%	7.0%	72.4%	19.0%	8.6%	
Vco	20	50.0%	35.0%	15.0%		100.0%				40.0%	15.0%	45.0%		30.0%	50.0%	20.0%	
Zga	1		100.0%			100.0%				100.0%				100.0%			
Zjt	200	65.8%	25.0%	7.1%	2.2%	98.4%	1.6%			42.9%	27.2%	26.6%	3.3%	57.6%	23.4%	15.2%	3.8%
Zme	0	No data available															
Zsj	11	100.0%				100.0%				63.6%	9.1%	27.3%		27.3%	36.4%	27.3%	9.1%
Note: 0% removed to make the table more readable.																	

Table 23: Summarized Electrical Conductivity, pH, and Fluoride concentration ranges within aquifer units, first page.

Physical properties & F		Conductivity (mS/m)				pH (pH units)				Fluoride F (mg/l)			
Symbol	**Number of samples after manipulation**	**Class 0 (Ideal)**	**Class I (Acceptable)**	**Class II (Maximum Allowable)**	**Un-acceptable**	**Acceptable Acidic**	**Ideal**	**Acceptable Alkali**	**Un-acceptable**	**Class 0 (Ideal)**	**Class I (Acceptable)**	**Class II (Maximum Allowable)**	**Un-acceptable**
Limits Ranges		**70**	**150**	**370**	**>370**	**4.0 -5.9**	**6.0-9.0**	**9.1 - 10.0**	**>10 & <4**	**0.7**	**1**	**1.5**	**>1.5**
Category A: Intergranular aquifers													
Q	149	22.1%	50.3%	24.8%	2.7%		98.6%	0.7%	0.7%	51.8%	26.3%	13.9%	8.0%
Category B: Fractured aquifers													
Trc	0	No data available											
Mw	0	No data available											
Mva	60	80.0%	18.3%	1.7%		3.3%	96.7%			85.0%	1.7%	3.3%	10.0%
Mcl	31	96.7%	3.3%				100.0%			90.3%	3.2%	3.2%	3.2%
Mkr	29	79.3%	13.8%	6.9%		17.2%	82.8%			100.0%			
Mas	186	13.4%	45.2%	32.8%	8.6%	1.1%	97.8%	1.1%		38.3%	22.8%	17.8%	21.1%
Msc	2	50.0%	50.0%				100.0%			no data			
Mag	47	72.3%	21.3%	6.4%		2.1%	97.9%			65.2%	6.5%	15.2%	13.0%
Ms	54	92.6%	3.7%	3.7%		7.4%	90.7%		1.9%	81.1%	3.8%	5.7%	9.4%
Vpg	23	71.4%	28.6%				100.0%			66.7%	20.0%	6.7%	6.7%
Vry	2		100.0%				100.0%						100.0%
Vsk	0	No data available											
Vsi	0	No data available											
Vdp	0	No data available											
Vti	2		100.0%				100.0%			100.0%			
Vkp	4	25.0%		75.0%			100.0%			75.0%	25.0%		
Vpe	0	No data available											
Rvz	36	5.6%	80.6%	13.9%			100.0%			82.4%	14.7%	2.9%	
Vkw	0	No data available											
Vsc	2	50.0%	50.0%				100.0%			100.0%			
Note: 0% occurrences removed to make the table more readable													

Table 24: Summarized Electrical Conductivity, pH, and Fluoride concentration ranges within aquifer units, second page.

Physical properties & F		Conductivity (mS/m)				pH (pH units)				Fluoride F (mg/l)			
Symbol	Number of samples after manipulation	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Un-acceptable	Acceptable Acidic	Ideal	Acceptable Alkali	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Un-acceptable
Limits Ranges		70	150	370	>370	4.0 -5.9	6.0-9.0	9.1 - 10.0	>10 & <4	0.7	1	1.5	>1.5
Category C: Karst aquifers													
Vds	5	25.0%	50.0%	25.0%			100.0%			100.0%			
Vma	39	10.5%	76.3%	13.2%			100.0%			96.2%			3.8%
Category D: Intergranular and Fractured aquifers													
P-Tr	2	100.0%					100%			50.0%		50%	
Ppe	0	No data available											
Mn	88	16.5%	58%	23.5%	2.4%		100%			30.1%	23%	20%	26.5%
Mr	1	100.0%					100%						100.0%
N-Za	51	22.0%	62%	14.0%	2.0%		100%			46.9%	20%	8%	24.5%
Vrs	58	6.9%	59%	31.0%	3.4%		100%			90.4%	6%	4%	
Vco	20	5.0%	35%	60.0%			100%			45.0%	20%	25%	10.0%
Zga	1		100%				100%			100.0%			
Zjt	200	6.1%	59%	30.8%	4.5%	0.5%	98%	1.0%		49.7%	17%	18%	14.6%
Zme	0	No data available											
Zsj	11	27.3%	27%	45.5%			100%			54.5%	27%	9%	9.1%
Note: 0% removed to make the table more readable. Two periods of Diabase intrusions are shown on the Thabazimbi geological map sheet, Zwazian and Mokolian													

6.2 Aquifer Units

The lithostratigraphy of the hydrogeological map sheet is based on the existing 1:250 000 geological map sheet 2426 Thabazimbi, that was used to sub-divide the map sheet area into hydrogeological relevant lithological units (referenced as aquifer units), which possess some degree of lithological homogeneity and similarities in rock properties. However, lithological homogeneity and similarities in rock properties were not the only consideration. Where geological formations were large enough, they were regarded as separate units, despite lithological homogeneity and similarities in rock properties with adjacent formations or lithologies.

The aquifer units are grouped together based on the interpreted groundwater occurrence namely: Intergranular (a), Fractured (b), Karst (c) and Intergranular and Fractured (d).

In total 34 aquifer units were identified, characterized, and discussed in terms of areal extent, general geology and statistics on yield and water quality. The unit dolerite Jdo was included although no dolerite sills or dykes was identified on the map. Additional aspects that were covered in some of the units are groundwater targets, proven geophysical methods and references to findings in previous groundwater reports. The methodology used for the characterization of each unit is similar throughout the report and is based on the same methodology used for the 1:500 000 hydrogeological map series.

The Intergranular aquifer consists of a single unit with an aerial extent of 485.2km² (2.8%); the Fractured aquifers consist of 20 units with an aerial extent of 7254.5km² (42.1%); the Karst aquifer consists of 2 units with an aerial extent of 1274.3km² (10.3%) and the Intergranular and Fractured aquifers consists of 10 units with an aerial extent of 7595.5km² (44.8%) of the map area. The total map area in South Africa covers an area of 17 254.4km². The total map area including Botswana is 24 910km². Surface water bodies cover an area that is less than 19.6km² (0.1%) of the map area.

Table 25: Basic information for the aquifer units and areal extent, first page.

Unit symbol	Lithostratigraphy	Geochronology	Geological time period	Geological description	Areal extent (km²)	% of map area
Botswana (The areal extent is 7655,578 km² but is not included in the % of map calculations. The areal extent of the South African units is 16735,686 km²					7655.578	not taken in account
				Surface water bodies	19.600	0.1%
Category A: Intergranular aquifers						
Q	Alluvium	Tertiary Quaternary	Tertiary Quaternary	Alluvium	485.237	2.8%
				Total for Alluvium aquifers	485.237	2.8%
Category B: Fractured aquifers						
Trc	Clarens Formation	Karoo Supergroup	Triassic	Fine-grained cream coloured sandstone sandstone with marl and shale at base	126.073	0.73%
Mw	Undifferentiated Waterberg Group	Waterberg Supergroup	Mokolian	Sandstone, conglomerate, mudrock, lava	3.975	0.02%
Mva	Vaalwater Formation	Waterberg Supergroup	Mokolian	Felspathic sandstone, arkose, siltstone, shale	260.046	1.51%
Mcl	Cleremont Formation	Waterberg Supergroup	Mokolian	Very coarse-grained, white sandstone with fine-grained, purple, micaceous sandstone at the base	267.304	1.55%
Mkr	Kransberg Subgroup (Integrated Sandriviersberg & Mogalakwena Formations)	Waterberg Supergroup	Mokolian	Sandstone, subordinate conglomerate, siltstone and shale	1654.273	9.59%
Mas	Aasvoëlkop Formation	Waterberg Supergroup	Mokolian	Siltstone, mudrock, sandstone	1056.748	6.12%
Msc	Schilpadkop Formation	Waterberg Supergroup	Mokolian	Sandstone, conglomerate	308.691	1.79%
Mag	Alma Formation	Waterberg Supergroup	Mokolian	Felspathic and lithic sandstone, subordinate conglomerate and mudrock (mainly siltstone)	433.475	2.51%
Ms	Swaershoek Formation	Waterberg Supergroup	Mokolian	Medium- to coarse-grained sandstone (pebbly in places), conglomerate, trachytic lava, quartz porphyry	1.284	0.01%
Vpg	Undifferentiated Pretoria Group	Transvaal Supergroup	Vaalian	Andesitic lava, subordinate pyroclastic rocks, minor quartzite, shale and conglomerate	918.975	5.33%
Vry	Rayton Formation	Transvaal Supergroup	Vaalian	Quartzite, shale, subordinate subgreywacke	327.720	1.90%
Vsk	Undifferentiated Smelterskop Formation	Transvaal Supergroup	Vaalian	Felspathic quartzite, andesitic lava with interbedded shale and grit, shaly quartzite. The Smelterskop Formation is not developed in the western portion of the basin.	71.946	0.42%
Vsi	Silverton Formation	Transvaal Supergroup	Vaalian	Shale, minor limestone/dolomite, basalt and tuff	339.598	1.97%
Vdp	Daspoort Formation	Transvaal Supergroup	Vaalian	Shale (partly ferruginous and carbonaceous, hornfels locally with quartzite and calcareous hornfels, marl, and dolomitic limestone, andesitic lava locally with quartzite and conglomerate, ferruginous, shale and hornfels.	233.245	1.35%
Vti	Timeball Hill Formation	Transvaal Supergroup	Vaalian	Quartzite ,shale (ferruginous), and hornfels locally with conglomerate, and quartzite near base and higher up	334.345	1.94%
Vkp	Klapperkop Quartzite Member	Transvaal Supergroup	Vaalian	Quartzite (ferruginous in places), wacke, siltstone, shale, magnetic ironstone	56.697	0.33%
Vpe	Penge Formation	Transvaal Supergroup	Vaalian	Iron-formation,	18.052	0.10%
Rvz	Undifferentiated/unnamed Ventersdorp Supergroup	Ventersdorp Supergroup		Acid lava (quartz porphyry, felsite and rhyolite) agglomerate, tuff with interbedded quartzite, grit, conglomerate, breccia and shale	646.693	3.75%
Vkw	Kwaggasnek Formation	Transvaal Supergroup	Vaalian	Massive, generally red, porphyritic felsite, minor pyroclastic rocks and sandstone/quartzite	2.520	0.01%
Vsc	Schrikkloof Formation	Transvaal Supergroup	Vaalian	Fine-grained, flow-banded, porphyritic and spherulitic felsite	192.849	1.12%
				Total for Fractured aquifers	7254.507	42.04%

Table 26: Basic information for the aquifer units and areal extent, second page.

Unit symbol	Lithostratigraphy	Geochronology	Geological time period	Geological description	Areal extent (km²)	% of map area
Category C: Karst aquifers						
Vds	Malmani Integrated with Pilanesberg dykes	Transvaal Supergroup	Vaalian			2.9%
Vma	Malmani Subgroup	Transvaal Supergroup	Vaalian	Dolomite, subordinate chert, minor carbonaceous shale, limestone and quartzite	1274.262	7.4%
				Total for Karst aquifers	1274.262	10.3%
Category D: Intergranular and Fractured aquifers						
P-Tr	Irrigasie Formation	Karoo Supergroup	Triassic	Predominantly red mudstone containing one or more sandstone units towards the base.	63.036	0.37%
Ppe	ECCA Group	Karoo Supergroup	Permian	Shale, with sandstone-rich units present towards the basin margins in the south, west and northeast and coal seams in the northeast	63.144	0.37%
Mn	Nebo Granite	Bushveld Igneous Complex	Mokolian	Granite, Granophyric, porphyric, pegmatitic or aplitic	1169.614	6.78%
Mr	Rashoop Granophyre	Bushveld Igneous Complex	Mokolian	Graniodiorite	14.410	0.08%
N-Za	Diabase Intrusions	Intrusive	Vaalian	Diabase Intrusions	848.812	4.92%
Vrs	Undifferentiated Rustenburg Layered Suite	Bushveld Igneous Complex	Vaalian	Includes Molendraai magnetite gabbro and Mapela Formation.	865.686	5.02%
Vco	Crocodile River Fragment	Transvaal Supergroup	Vaalian	Stratigraphy, structure, and tectonic evolution of the Crocodile River Fragment	79.350	0.46%
Zga	Gaborone Granite	Intrusive	Vaalian	Granite-aplo granite, Quartzsite. The granite is intrusive into basic and ultrabasic rocks, "old granite" and hyperite along the Marico river and into the Kanye Volcanic Group and Modipe gabbro in Botswana.	195.003	1.13%
Zjt	Granite and granite gneiss. Western Transvaal belt	Archaean Complex	Swazian	Undifferentiated Granite and granite gneiss. Western Transvaal belt of Metamorphism and mobilizaion	4026.223	23.33%
Zme	Modipe Gabbro Complex	Archaean Complex	Swazian	Basic (and ultrabasic?) intrusive rocks (gabbro, etc.)	230.569	1.34%
Zsj	Basement rocks of the area correlated with Archaean Complex + Jamestown Complex	Archaean Complex	Swazian	Gneiss, granulite, schist, quartsite, arkose.Basement rocks of the area correlate with the Archaean Complex. The oldest formations, i.e. Swaziland System & metamorphic- to ultrabasic rocks are correlated with Jamestown Igneous Complex. Amygdaloidal lava	39.672	0.95%
				Total for Intergranular and Fractured aquifers	7595.520	44.74%
				Total areal extent of map area, South Africa	**17254.4**	
				Total areal extent of map area including Botswana	**24910.0**	

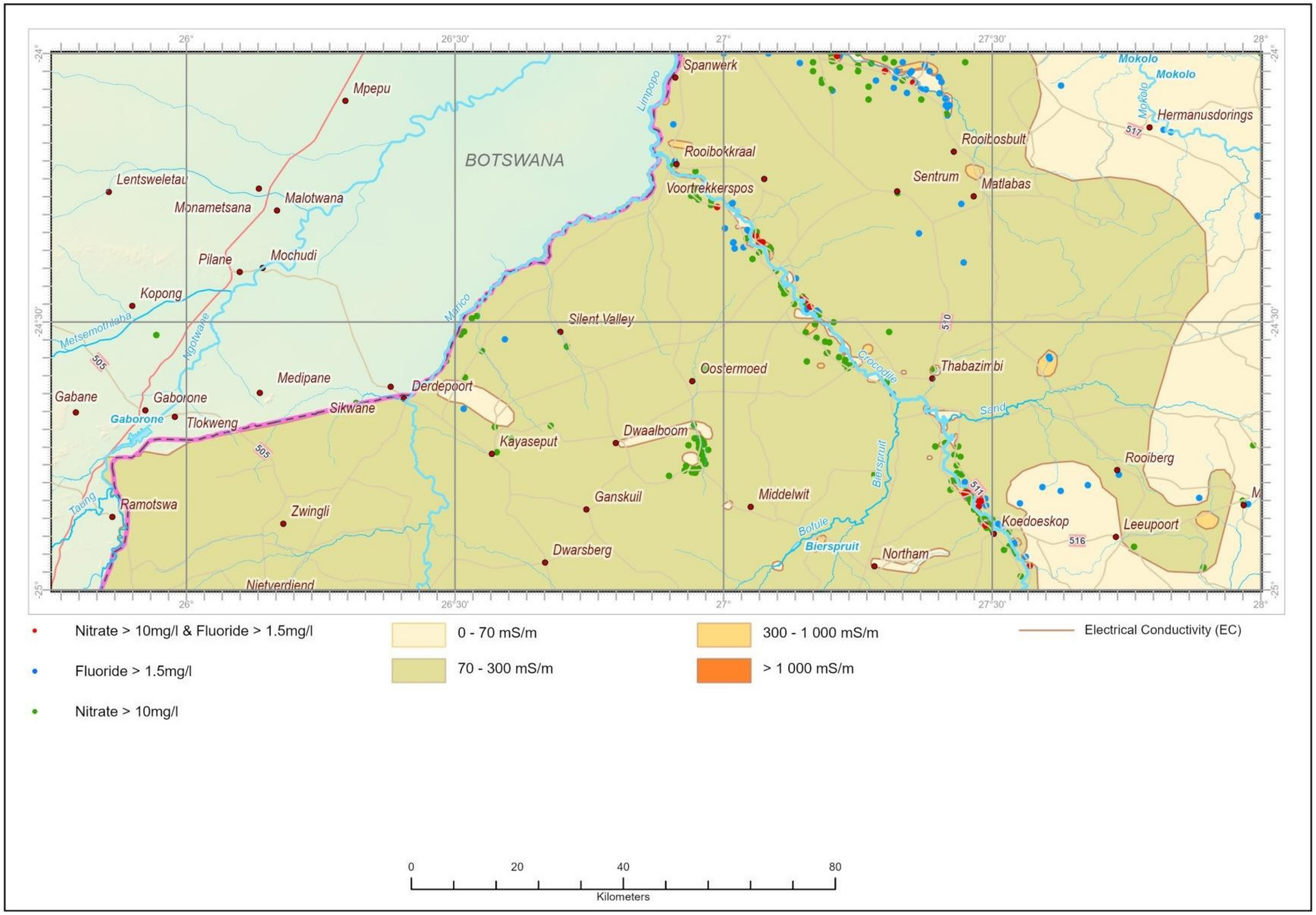


Figure 8: Distribution of Electrical conductivity (EC) and boreholes with Nitrate and Fluoride values exceeding the acceptable levels for human consumption.

7. HYDROGEOLOGY OF THE VARIOUS GEOLOGICAL GROUPS AND FORMATIONS

In this chapter the hydrogeology of the various geological groups and formations is briefly described in terms of its geographical location, occurrence, general use, and quality. Hydrogeology is supported by a statistical analysis of the borehole data available for each group or formation. For yield data, the results are portrayed as borehole yield frequency diagrams and for hydrochemistry as stiff diagrams. Table 27 shows the percentage boreholes in each yield range as obtained from the yield frequency diagrams.

Table 27: Summary of borehole yield distributions.

Aquifer Unit	Total number dry boreholes	Total number wet boreholes	Total boreholes with no information	0-0.01 (ℓ/s)	0.1-0.5 (ℓ/s)	0.5-2 (ℓ/s)	2-5 (ℓ/s)	5-10 (ℓ/s)	>10 (ℓ/s)
Category A: Intergranular aquifers									
Q	19	74	152	13.5%	13.5%	27.0%	9.5%	9.5%	27.0%
Category B: Fractured aquifers									
Trc	No data available								
Mw	0	2	6		50.0%	50.0%			
Mva	16	415	21	17.1%	21.7%	31.8%	20.5%	7.0%	1.9%
Mcl	20	224	29	21.0%	25.0%	25.0%	16.1%	8.0%	4.9%
Mkr	76	368	13	14.9%	19.6%	43.2%	17.4%	3.3%	1.6%
Mas	88	254	268	20.1%	18.5%	35.4%	18.1%	5.9%	2.0%
Msc	43	122	22	18.0%	23.8%	38.5%	14.8%	4.1%	0.8%
Mag	56	463	15	13.4%	23.8%	36.7%	16.2%	6.5%	3.5%
Ms	47	97	3				72.2%	19.6%	8.2%
Vpg	66	115	59	14.8%	24.3%	40.0%	12.2%	7.8%	0.9%
Vry	4	5	8		40.0%	40.0%	20.0%		
Vsk	0	15	30		26.7%	33.3%	20.0%	20.0%	
Vsi	17	32	17	25.0%	25.0%	25.0%	15.6%	9.4%	
Vdp	7	28	11	28.6%	14.3%	28.6%	28.6%		
Vti	11	66	75	16.7%	28.8%	31.8%	15.2%	6.1%	1.5%
Vkp	14	18	10	16.7%	16.7%	44.4%	22.2%		
Vpe	2	2	2			100.0%			
Rvz	63	122	175	40.2%	20.5%	16.4%	10.7%	6.6%	5.7%
Vkw	No data available								
Vsc	9	10	5	30.0%	20.0%	40.0%	10.0%		
Category C: Karst aquifers									
Vds	24	44	30	36.4%	20.5%	22.7%	11.4%	2.3%	6.8%
Vma	66	124	111	18.5%	18.5%	25.8%	17.7%	13.7%	5.6%
Category D: Intergranular and Fractured aquifers									
P-Tr	0	3	4	33.3%		33.3%	33.3%		
Ppe	1	4	1			75.0%		25.0%	
Mn	72	101	81	17.8%	21.8%	32.7%	21.8%	5.0%	1.0%
Mr	11	12	3	8.3%	25.0%	50.0%	8.3%	8.3%	
N-Za	56	117	92	16.2%	15.4%	35.0%	24.8%	4.3%	4.3%
Vrs	151	142	108	26.8%	21.8%	31.7%	9.9%	2.8%	7.0%
Vco	5	9	15	33.3%		55.6%	11.1%		
Zga	115	101	58	34.7%	24.8%	23.8%	9.9%	5.0%	2.0%
Zjt	649	640	398	28.6%	20.2%	31.7%	12.5%	4.4%	2.7%
Zme	31	40	31	30.0%	12.5%	37.5%	17.5%	2.5%	
Zsj	60	71	11	62.0%	12.7%	16.9%	7.0%	1.4%	
Note: Cross boundary units are Mcl, Msg, Mva, Mas, Mag, Mkr. The total number of boreholes within the Thabazimbi map sheet boundary is 5906 thus 1450 less than shown in this list.									

7.1 PRIMARY AQUIFERS

7.1.1 CATEGORY A: INTERGRANULAR AQUIFERS

Within the map sheet intergranular aquifers are restricted to the alluvium deposits within and in the immediate flood planes or palaeo channels near the Limpopo River and its Tributaries, (Figure 9). It covers approximately 2.8% of the map area; the calculations do not include the theoretical total map area inclusive of Botswana.

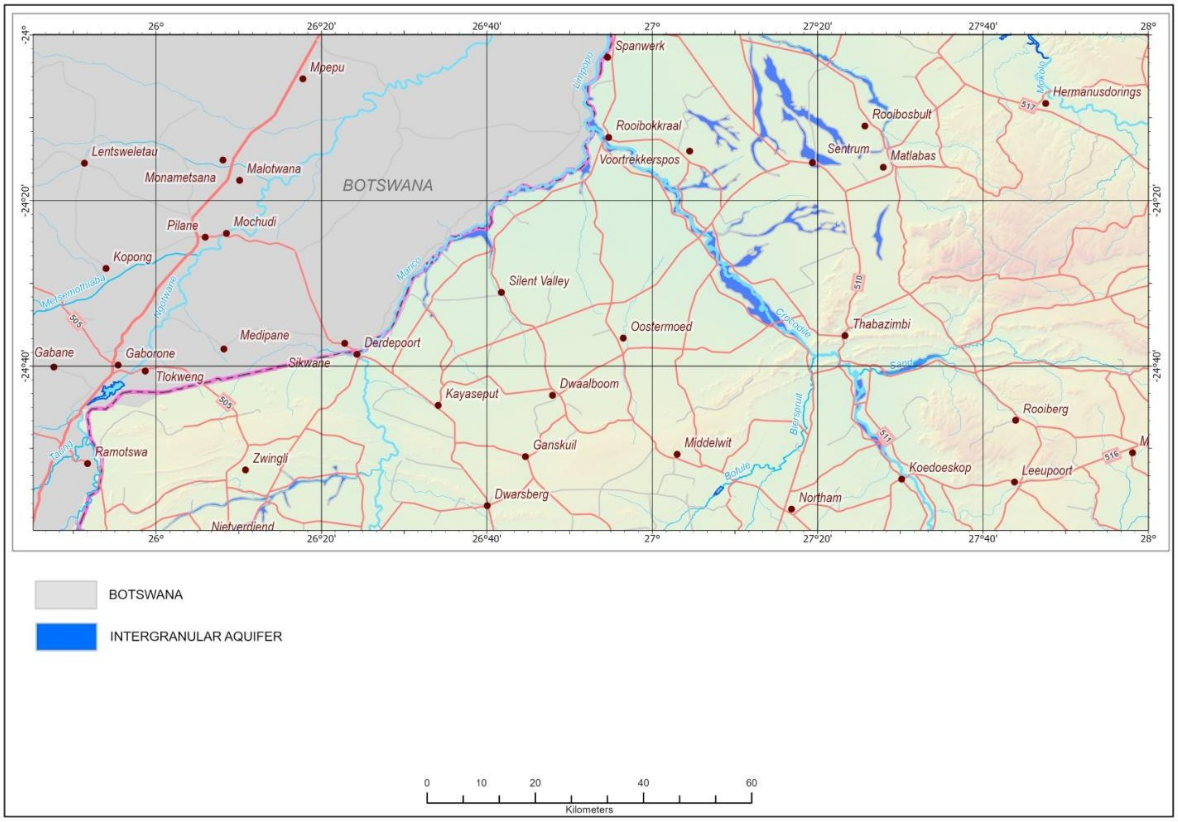


Figure 9: Geographical distribution of the Intergranular Aquifers (Q) and the associated groundwater sampling points.

7.1.1.1 TERTIARY-QUATERNARY ALLUVIUM DEPOSITS (Q)

Groundwater occurs in tertiary-quaternary alluvium deposits within floodplains and river terraces of the Limpopo River and its tributaries. The major Tributaries for the Limpopo River in the map area are the Ngotwane, Marico, Crocodile, Matlabas and Mokolo Rivers, (Figure 10).

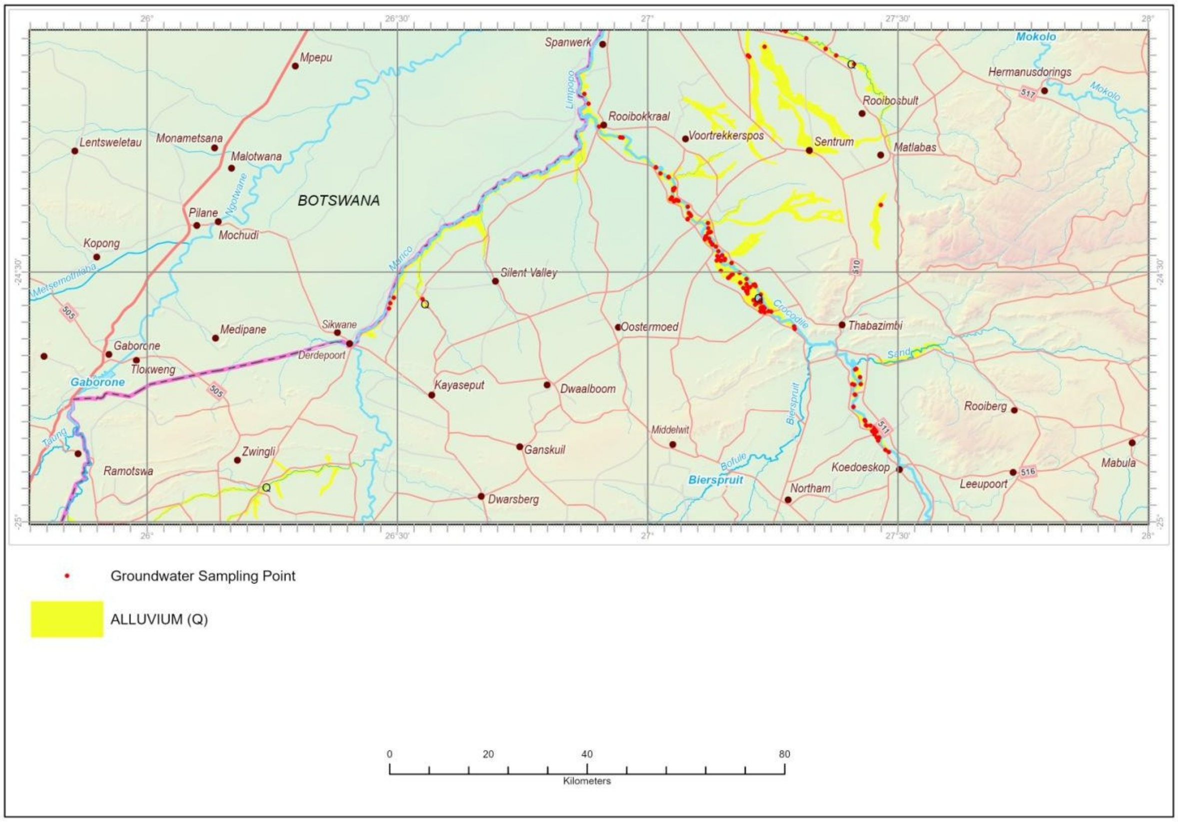


Figure 10: Geographical distribution of the Tertiary-quaternary alluvium deposits (Q) and the associated groundwater sampling points.

Understanding the upstream-downstream linkages in hydrological processes is essential for water resources planning in river basins (Nepal et al., 2014). The hydrological processes can be divided into three broadly classified zones (headwaters zone, transitional zone, and depositional zone). The focus of Basement Management is the 'yield' of the basin as it defines its ability to support socio-economic development. A basin profile is a descriptive set of data portraying factors that include but are not limited to physical characteristics (e.g., soils, geology, vegetation, etc.), hydro climate (i.e., rainfall, runoff, recharge, etc.), land use, common resource area, resource concerns, and social information, (Kapangaziwiri et al., 2021).

To characterize and quantify alluvial deposits in the rivers the above characteristics and many other factors need to be considered. The following is from various studies, and it may not include all the factors to consider.

- Delineate the lateral extent of alluvial aquifers using tools such as remote sensing techniques; this was extensively done in the study by Kapangaziwiri et al., (2021). Other methods employed include photo-geological interpretation, resistivity surveys, field mapping and exploration drilling, Hobbs et al. (1987).
- Use all available information such as previous studies, Groundwater data and geological maps, satellite imagery etc.
- Delineate the depth of the alluvial deposits; this can be done using geophysical methods, drilling logs, previous studies and local knowledge.
- Evaluate large scale irrigation along the rivers and investigate the percentages of conjunctive use of surface and water within the alluvial or even the fractured zones underlying the alluvial deposits.

- Characterize the alluvial in terms of grain size, composition, primary storage and permeability. This will be a function of the upstream rock types, Karst deposits (Marico & Crocodile Rivers), distance of mobilization, flow characteristics, topography and gradient.
- River flow, period of flow, non-natural factors such as water releases in dry periods (e.g. Mokolo Dam), weirs, upstream usage, anthropogenic processes, inter basin transfers, surface groundwater interaction, relief, slope etc.
- In a study of the Mokolo River the following were used to divide the river into sections to quantify and characterize the alluvial deposits. The factors used were topography, underlying geology, typical thickness, and transmissivity of the alluvium, (Rivers for Africa eFlows Consulting, 2010).
- The hydrological cycle that will have an influence on surface and groundwater within the alluvial namely, precipitation, evaporation, storage, and runoff (Nepal et al., 2014).
- The anticipated changes to natural conditions, climate and rainfall patterns. Long term monitor data is essential.

The Limpopo River Basin was divided into various Sub-basins in a study by Kapangaziwiri et al., (2021). Within the map sheet it includes the names assigned by the study as well as new names for the purpose of this brochure. The names used to describe the alluvial deposits are Marico Sub-basin, Crocodile Sub-Basin-South, Crocodile Sub-Basin-North, Ngotwane Sub-Basin, Matlabas Sub-Basin, Mokolo Sub-Basin and the Limpopo River section that falls within the map sheet. Some details are given for the Limpopo River sections that falls on adjacent hydrogeological map sheets.

For the brochure the findings of the study are included, but for each of the division's additional available information on alluvial deposits is included. Google imagery was used to comment on large scale irrigation along the sections of each river. The use of active centre pivots is indicative of the availability of large volumes of water that can either be from surface, deep groundwater sources and groundwater associated with the alluvial deposits. The assumption used is that farmers will only maintain large scale irrigation along rivers if the surface and groundwater associated with alluvium is available for long periods after rainfall; (other factors such as soil, topography and the ability to plough is ignored). In addition to the above the alluvial deposits indicated on the geological map sheet are discussed as well as any other available information sourced from existing reports and data.

The Marico Sub-basin:

The Great Marico River is fed by a number of springs that drain the Groot Marico dolomitic aquifer compartment. The most important of these is the Marico Eye (Marico Oog) near the town of Groot Marico; the estimated flow was reported as 18.25Mm³/a, Hatch (1904).

Alluvial deposits in the Marico Sub-basin occur along the lower reaches of the Marico River, measuring an approximate length of 10.15 km and covering an area of 4.14 km², (Kapangaziwiri et al., 2021). Remote sensing techniques were used for the delineation of alluvial deposits. These deposits are described as sandy clay loam and sandy loam, with coarse sandy soils within the river channel (DWAF, 2004; RHP, 2005). The groundwater system in this sub-basin is rather complex, as alluvial deposits often overlay dolomitic aquifers that contribute to the groundwater supply and therefore recorded borehole yields can range from 5ℓ/s to 20ℓ/s in a particular region, (DWA, 2004). Irrigation farming is generally practised along Great Marico and its tributaries, (DWAF, 2004).

The above assessment of 4.14km² implies an average width of 408m over the 10.15km length identified using remote sensing techniques. The groundwater records used for the Thabazimbi brochure do not list the high yielding boreholes referenced by DWS in 2004 as 5ℓ/s to 20ℓ/s; the highest reported yield available on the records used for the brochure is only 3.5ℓ/s. Large scale irrigation occurs in a 17km section along the river; the alluvial identified with the study by Kapangaziwiri et al., 2021 is most likely occurring along this section.

The total length of the Marico River covered with alluvium as indicated on the geological map sheet is approximately 72km measured in a straight line; if the meandering is included, the GIS measured length is approximately 102km. It is therefore assumed that the study did not include sections of the river where the width of the alluvial deposits is limited.

Although not included in the Marico Sub-basin, notable alluvium is indicated on the geological map sheet along the Brakfonteinspruit and some of its tributaries. The Brakfonteinspruit is within the south-western section of the map sheet and flows easterly to north-easterly into the Molatedi Dam. The underlying geology is rocks of the Rustenburg Layered Suite; the alluvium covers 37.43km². From available information 4 boreholes are reported with data on yield; the highest yield is 3.3ℓ/s. No large-scale irrigation occurs in this unit or in the nearby vicinity; the area is mostly used for game and livestock farming. The Brakfonteinspruit and tributaries are listed as non-perennial, and the assessment will thus be that the alluvial aquifer will most likely fail in prolonged dry periods with large scale abstraction. No further information is available regarding the characteristics of this occurrence.

Crocodile Sub-basin-South: (section of the river between Thabazimbi to the south up to the boundary of the map sheet (latitude 23ºS).

In the Thabazimbi map sheet large scale irrigation occurs along the Crocodile River, Alluvial deposits play a crucial role in maintaining this activity. Farmers use groundwater and surface water to maintain irrigation in a vast alluvial plain around the river.

The Crocodile River rises on the Highveld Ecoregion that includes the Witwatersrand. It has a perennial drainage, with flows supplemented by substantial discharges of treated domestic and industrial effluent as well as water imported from the Vaal River system. Rainfall is strongly seasonal, with most rainfall occurring as thunderstorms during the summer period of October to April. Mean annual rainfall ranges from 1000mm on the Witwatersrand to 400mm at the confluence with the Limpopo River, (Kapangaziwiri et al., 2021).

In the Crocodile sub-basin, alluvial channel deposits occur along the lower reaches of the Crocodile River, measuring an approximate length of 43.23km and covering an area of 2.69 km². The Crocodile River has an average slope of 0.5m/km along its length and features such as, cut- off meanders and flood plains indicate that the river has reached maturity, (Kapangaziwiri et al., 2021). The average width is calculated as 62.2m when using the above 2.69km² and a length of 43.23km.

According to Hobbs et al. (1987), the alluvial aquifer typifies a water-course aquifer traversed by a hydraulically connected stream. The deposits comprise dense and clay-rich sandy loam soil floodplain deposits and aquiferous sand, gravel, and coarser riverine deposits (Hobbs et al., 1987; RHP, 2005). A limited zone of weathered bedrock, generally less than 2m thick, underlies the alluvial deposits and the depth to bedrock seldom exceeds 16 m. Hydraulic properties of the alluvial aquifer were recorded by Hobbs et al. (1987) as follows: transmissivity ranges from 130m²/day to 3100m²/day and storativity ranges from 0.5% to 13%.

The following findings and comments are drawn from the investigation by Bredenkamp and Porszasz (1967) into the groundwater potential of the farms Buffelshoek 351 and Wachteenbietjesdraai 356. This study was undertaken to assess the viability of groundwater supply to the town of Thabazimbi. The investigated area is situated approximately 10 km south of Thabazimbi.

- Within the investigated section, the average depth of the alluvial deposits was determined to be approximately 18 meters. The river zone in this area is predominantly underlain by dolomite, rocks of the Pretoria Group, and numerous easterly to north-easterly trending diabase dykes and sills that locally outcrop.
- Parallel ridges transecting the river such as quartzite ridges and geological contacts presumably divide the alluvial basin into five compartments,
- A certain degree of leakage through the outer boundaries is possible, but since these formations are much more impermeable than the alluvial sediments, this leakage is regarded as negligible. The compartments are thus not water tight as leakage through the alluvial will occur.
- The lateral extent of the alluvium as mapped by Boardman (1947) represents the outer boundaries of the alluvial aquifer,
- Bedrock (shale, quartzite, banded ironstone and dolomite) underlying the alluvial aquifer is mostly weathered or broken, this contributes to high yields along the river,
- Seismographic and borehole data reveal evidence of sinkholes in the underlying dolomite. This was also derived from areas where the alluvial deposits were deeper than average,
- The Crocodile drainage system with the Elands and Pienaars River as the main tributaries constitutes the main source of recharge of groundwater supplies. A reasonable annual flood is essential to maintain recharge and subsequent pumping from alluvial beds.
- During the period 1962 to 1966, severe drought conditions were experienced and this adversely affected run-off and recharge of groundwater,
- After wet seasons such as 1966/7 a certain amount of base flow occurs emanating as return seepage from the alluvial beds,
- An investigation at the time to the yields of boreholes indicated that 50% of all boreholes yield between 6.3ℓ/s to 25.3ℓ/s; the maximum tested yield was 34ℓ/s. The average water strikes were 9.1mbgl to 21.3mbgl. Water strikes were found in sand layers, ranging from clayey sand, coarse sand to gravel beds (high permeability and specific yield).
- The hydraulic properties of the surface layers are poor due to the compaction of fine- grained material. This renders it rather impermeable thus vertical recharge in these areas is negligible.
- At the time Total Dissolved Salts (TDS) was averaging 330mg/l, (Ideal water quality).
- From pumping tests, the specific yield was calculated, it ranges from 8% to 16.9% with an average of 12.5%.
- The recharge was calculated as 2% of river flow, this was done using abstraction and river flow at the gauging station at Piet Groblersdrift (A2M25) during the period October 1967 to April 1969. The recharge however is a function of the rivers stage and the storage created in the alluvial aquifer. The recharge is dependent on the hydraulic gradient; the recharge could be substantially greater if a certain degree of drawdown below the normal water level could be maintained.
- Due to the variability of flood magnitude and occurrence recharge to the extent of the estimated mean annual amount, is not an annual event. Dry periods may result in negligible recharge with lowering of the static water table (decreasing storage). Exceptional floods may replenish the total storage in one event if the aquifer was almost empty.
- At the time the planned new dams Vaalkop and Klipvoor was not yet build. The theoretical estimate was that the dams will result in a 29% reduction in recharge.

Table 28: Summary of water storage in the section investigated by Bredenkamp and Porsasz (1967). Information obtained from a table on p12 of the Bredenkamp report.

Compartment number	Volume of Aquifer (m^3)	Specific Yield (%)	Water Storage (m^3)
2	242 969,34	16.9	41 046,82
3	450 467,52	8.5	38 289,74
5	784 550,36	12.2	95 711,14
4	771 269,20	12.5	96 408,65
		Total water storage:	271 456,35

Note: Figures revised from morgen feet and cubic feet as originally included in the report using the conversions: 1 cubic foot (ft^3 = 0.0283168 cubic meters (m^3) and 1 cubic meter: 1 morgen foot = 0.0283168m^3 ×10,764, (as 1 morgen is approximately 10,764 square feet). The numbers were calculated from the interpretation of pump testing data.

Another study was done by Hobbs (1982) in the section along the Crocodile River south of the area done by Bredenkamp and Porsasz (1967). This study was done after the completion of Vaalkop and Klipvoor Dams. The following is a summary of the findings. The area was divided into 4 zones each with a different character.

Sub-area A:

- The southern boundary is the farm Nooitgedacht 22JQ to Hardekoolbult / Haakdoornbult 548 & 542KQ in the north,
- The lateral extent of the alluvium is limited by extensive outcrops of dolomite and quartzite,
- The width is approximately 500m to both the left and right banks,
- Characterized by a shallow depth to bedrock along portions of the river, 3 auger drilled holes indicates depth to bedrock as 1.5m, 4m, and 9m,
- In an area 200m to 400m from the riverbank 4 boreholes show the depth to bedrock to be 16m, 16m, 13m and 13m,
- The highest yielding boreholes have maximum yields of 18ℓ/s and 20ℓ/s but the water was found in the underlying dolomite,
- It was concluded that the alluvial aquifer is generally poorly developed in this area, the average is 9m clayey soil overlying a 4m thick water bearing zone,
- A fault in the north of the area was drilled, one borehole was dry, and the other had a blow yield of 0.4ℓ/s.

Sub-area B:

- The southern boundary is the farm Hardekoolbult 548KQ & Haakdoornbult 542KQ and Kromdraai 424KQ in the north,
- The alluvial aquifer is especially well developed on the left bank, related to large cut-off meanders. On the right bank the primary aquifer is weakly developed except on farm Rietfontein,
- Characterized to numerous high yielding boreholes, (+18ℓ/s). On the farm Buffelskraal a fault is believed to result in yields of 21ℓ/s, 15ℓ/s and 19ℓ/s. Along the strike of the fault it exerts a marked influence on the water table indicative of recharge along this zone,
- It was concluded that the alluvial aquifer is generally well developed in this area, the clayey soil overburden is between 3m to 5m resulting in a thicker water bearing layer,
- One borehole seen as an exception had 10m of very clayey material overlaying a 2m thick water bearing coarse gravel. The borehole is 1700m from the river and an indication of the lateral extent of the alluvium on the farm Kromdraai.

Sub-area C:

- The southern boundary is the Kromdraai 424KQ farm and Wachteenbietjesdraai 350KQ in the north,
- The alluvial aquifer is characterized by relatively narrow alluvial deposits (left bank Middeldrift 379KQ and Elandskuil 378KQ; right bank Grootkuil 376KQ),
- Outcrops of gabbro occur over extensive areas,
- The alluvial aquifer widens out considerably on the right bank north of Grootkuil 376KQ, numerous high yielding boreholes occurs (+20ℓ/s). This portion of the aquifer underlies the farms Haakdoorndrift 373 and 374KQ. This area represents the most productive and heavily exploited aquifer. In this area the primary aquifer and underlying zone of decomposed rock attains thicknesses of up to 30m,
- The greater part of the left bank further than 300m from the river is underlain by very shallow bedrock (mainly norite and gabbro), generally less than 9m below the surface. The overburden consists mainly of decomposed bedrock and associated clay material. Nearer to the river the depth to bedrock increases up to 20m and resulted in some high yielding borehole with yields up to 15ℓ/s.

Sub-area D:

- The zone along the strike of the fault on the farm Grootkuil 376KQ. The presence of riverine deposits in this zone as determined by the drilling of an exploration borehole indicates a palaeo river channel. Numerous high yielding boreholes occur in this zone,
- Another exploration borehole revealed an aquiferous horizon consisting of coarse quartzitic gravels and rounded pebbles and boulders (>15cm) at a depth of 34m and a thickness of 4m,
- The width of this zone is less than 100m wide, boreholes drilled outside the zone failed to encounter notable groundwater strikes.

The study used water levels between the periods 1976 to 1983. It shows that the flow in the river generally influenced the static water level in the primary aquifer. Releases from the upstream dams immediately influenced groundwater levels. There is a tight relationship between flooding and the positive change in groundwater levels.

Crocodile Sub-basin-North: (section of river between Thabazimbi and Limpopo River)

The following are findings and comments from Hobbs and Chips (1987) when the groundwater resource of the lower Crocodile River was evaluated. The area investigated was the river section between Thabazimbi and the confluence with the Limpopo River. The length of this section is approximately 65km and the alluvium is mainly underlain by the hydrogeological resource unit viz. Granite and Granite Gneiss, Western Transvaal Belt (Zjt).

- Unconsolidated alluvial deposits cover an area of some 97km² adjoining the lower reaches of the Crocodile River. Of this 61% or 59km² occurs on the left bank, the aquifer is generally poorly developed on the right bank. The lateral and vertical extent of the aquifer was determined from photo-geological interpretation, field mapping of bed rock outcrop, surface resistivity surveys and exploration drilling,
- The delineation using these methods had an excellent correlation with the mapped occurrence of sandy clay to clay soil (land type maps) with the alluvial aquifer,
- These deposits represent the primary aquifer that is the major groundwater resource in the area, it is predominantly used for irrigation along the rivers. The bedrock that is mainly granite that underlays the alluvium constitutes a secondary aquifer,
- The full storage capacity of the aquifer amounts to 112 x 10^6 m³. The aquifer is replenished from surface flow in the river. The alluvium is in a direct hydraulic connection with the river,
- Flow of the Crocodile River through the area is intermitted due to large scale abstraction of surface water upstream and the tight control exercised over the upstream discharge regime

of the river from Klipvoor, Vaalkop Dams (1970) and from Roodekopjes (at the time not yet completed). In very dry periods the only flow in the river relates to surface releases,

- Rech, (1970) at the time estimated groundwater abstraction as 8.8Mm³/annum and surface water as 2.1Mm³/annum. The area under irrigation was 2000ha,
- The abstraction from groundwater in 1982 was 24.8Mm³ with 1260 ha under irrigation,
- The abstraction from groundwater in 1985 was 23.4Mm³ with 2605 ha under irrigation,
- No surface flow occurred in the river from July 1982. The date of the report is 1987,
- The thickness of the alluvium deposits was estimated by Rech: on the farms Van Wykskraal 116KQ (13m); Staankraal 117KQ (12m); Kaaldraai 321KQ (21m). The extensive use of well-point systems to abstract water from the river was mentioned,
- Cut-off meanders and a well-developed floodplain characterize the upper portion of the broad valley through which the river flows. The weakly-developed levees that enclose the 5m to 8m deep and up to 20m wide river channel further indicate the river to have reached maturity,
- The alluvial aquifer is characterized by a 6m to 10m thick sandy clay to clay overburden overlaying unconsolidated arenaceous and rudaceous deposits (sand, gravel and boulders). These deposits vary considerably in lateral extent (200m to 3000m) and thickness (5m to 30m). The basal portion of the primary aquifer consists of weathered bed- rock with a thickness of 2m to 20m,
- The average transmissivity of the primary aquifer as determined from 8 pump tests is 450m²/day. The storativity from 7 pump test was determined to vary from 1.0×10^{-2} to 4.6×10^{-4} with an average of 3.7×10^{-3}. The specific yield determined from 4 pumping tests varies from 2.3×10^{-2} to 0.17 with an average of 0.1 (10%).

Ngotwane Sub-basin

Within the Thabazimbi map area it forms the approximate 27km border (straight line) between South Africa and Botswana; using GIS the river in total is approximately 38.2km long. No alluvial deposits are indicated on the geological map sheet for this stretch of river. All the rivers in the Ngotwane basin are ephemeral, experiencing mostly brief, seasonal flow, depending on the rainfall. The Ngotwane and Taung riverbeds are dry during the dry season, and in years of drought they may be dry all year round. The area experiences flash floods.

The section of the river flowing through Botswana is approximately 218km (GIS) before joining the Limpopo River approximately 6km south of the confluence of the Matlabas River.

It covers a surface area of 48.08km² over a 197.2km stretch, (Kapangaziwiri et al., 2021), implying an average width of 243.8m. A study conducted by Schick and Shaw (1993), noted the presence of extensive terrace sequences comprising large pebbles and cobbles. Water was struck at a depth of 12.2m in the alluvial deposits of the Ngotwane River, and about 14000m³/day was obtained from a well field from this water-bearing horizon. A second supply of about 100000m³/day was obtained from a well field from the weathered junction of the dolerite and overlying alluvium at 18.3m, (Kapangaziwiri et al., 2021). This study was most likely conducted in Botswana but may give an idea what to expect in the Limpopo River alluvium with similar hydrogeological conditions. The above could not be verified.

Matlabas sub-basin

The Matlabas River has its source in the western part of the Waterberg Mountain range, within the Marakele National Park. Although it is a perennial river, the Matlabas River is highly subject to seasonal variations, meaning its runoff is highly variable. Its main tributary is the Mamba River. The sub-basin is generally dry, giving no sustainable yield from surface water, (Kapangaziwiri et al., 2021).

Within the map area the land use is mainly restricted to game and livestock farming or game reserves. Only one large scale irrigation 15ha could be identified using Google imagery. The section of the river shows some alluvium, but it is more likely that the largest portion of the water is from surface water that is stored in an off-river earth dam.

No comprehensive studies could be found on the alluvium aquifer related to the Matlabas River. Data obtained from a report by W.D. Rech, 1970 gives some detail on water use for irrigation along the tributaries of the Limpopo. For the **Matlabas River** the finding was that the alluvium associated with the river is off little significance as an aquifer. Silt and sand are mostly restricted to the riverbed with only one terrace developed along the river that consists predominantly of fine-grained material. A second higher terrace is only sporadically developed on some farms and at the confluence with the Limpopo River. Where the alluvium is not fine grained the sand points in the river were pumped at between 0.63ℓ/s to 18.9ℓ/s the water quality was very good as based on EC measurements.

Mokolo Sub-basin

The section of the river that falls within the map sheet is within the north-western part. A second section is south of the Mokolo Dam and flowing in a south-easterly direction to Vaalwater, which is outside the map area (map boundary is longitude 28º E). Within this section large scale irrigation occurs within a wide valley between the mountains. No significant alluvial deposits are indicated on the geological map sheet. Groundwater in this area is mostly from secondary aquifers such as the Bulge River Fault zone and numerous diabase intrusions.

To the south tributaries is mostly within the Waterberg Plateau; the land use in this section is predominantly a National Park and game farming with numerous lodges.

The section of the river from the Mokolo Dam to the Limpopo River falls within the Lephalale map sheet. Alluvium deposits in this section of the river are recharged by releases from the Mokolo Dam that significantly improved the abstraction from alluvial deposits for irrigation. For more information the Lephalale 1:250 000 hydrogeological map sheet and explanatory brochure can be consulted.

Limpopo section alluvium

Within the map sheet the Limpopo River section is the section of the river north of the confluence with the Marico and Crocodile Rivers. The stretch of river in a straight line is approximately 21km but using the GIS overlay that include the bends and meanders of the river the total length is 26.3km. Of this, the southern section that is approximately 13.2km long, is indicated on the geological map sheet with considerable alluvial deposits with the remaining river stretch in the north showing limited alluvial deposits. The northern boundary of the map is latitude 24º S.

No studies could be found that relate to alluvial deposits within the Limpopo River that falls within the map sheet area. The highest concentration of irrigation (centre pivots) occurs in the area where the Crocodile and Marico flows into the Limpopo River. This gives an indication of the contribution of alluvium to water supply. The sand in these areas derives from basement granites and gneisses and it will be similar to the conditions described under the section Crocodile Sub-section-North. Further to the north the alluvium is expected to be more fine-grained as the deposits mitigate from fine grained rocks of the Aasvoëlkop Formation.

In other sections of the river that fall outside the area some of the alluvium deposits consist of silt, clay and coarse sand that are developed on the flood plains along the Limpopo River and within the riverbed. In areas to the north-west the maximum thickness of the alluvium is 15m to 20m thick. On the farm Sannandale 9LQ that is outside the map area (Lephalale map sheet) the alluvium is 15m thick, (Brandl, 1996). This farm is 24km north-east along the river from the confluence of the Mahalapye River (Mhalatswe & Taupye) flowing from Botswana.

The increase in irrigation (centre pivots), east of the Mokolo River confluence (Lephalale map sheet) gives an indication of the contribution of alluvium to water supply as well as the influence of surface water releases from the Mokolo Dam. The sand in these areas is derived from basement gneisses thus the conditions will be similar as found in the Messina Well Field that was developed downstream of Beit Bridge.

Downstream from Beit Bridge (1:500 000 Musina map sheet) water is abstracted from boreholes within and along the river that abstract water from fractured basement rock overlain by thick alluvial deposits 6m to 18m. The alluvial acts as storage (porosity estimated between 20 and 30%) while the fractured basement rock act as the conduit of water. At the confluence of the Shashe River from Botswana (Musina hydrogeological map sheet area), the Weipe farming area is known for abstracting large quantities of water from alluvial sand.

Within the section of the Limpopo River (Lephalale map sheet) underlain by Karoo sediments and the Aasvoëlkop Formation, records indicates that the average borehole yields are less within and along the river; this may be attributed to finer grained sand within the river. More studies need to be done to evaluate the potential of the alluvium in that section of the river.

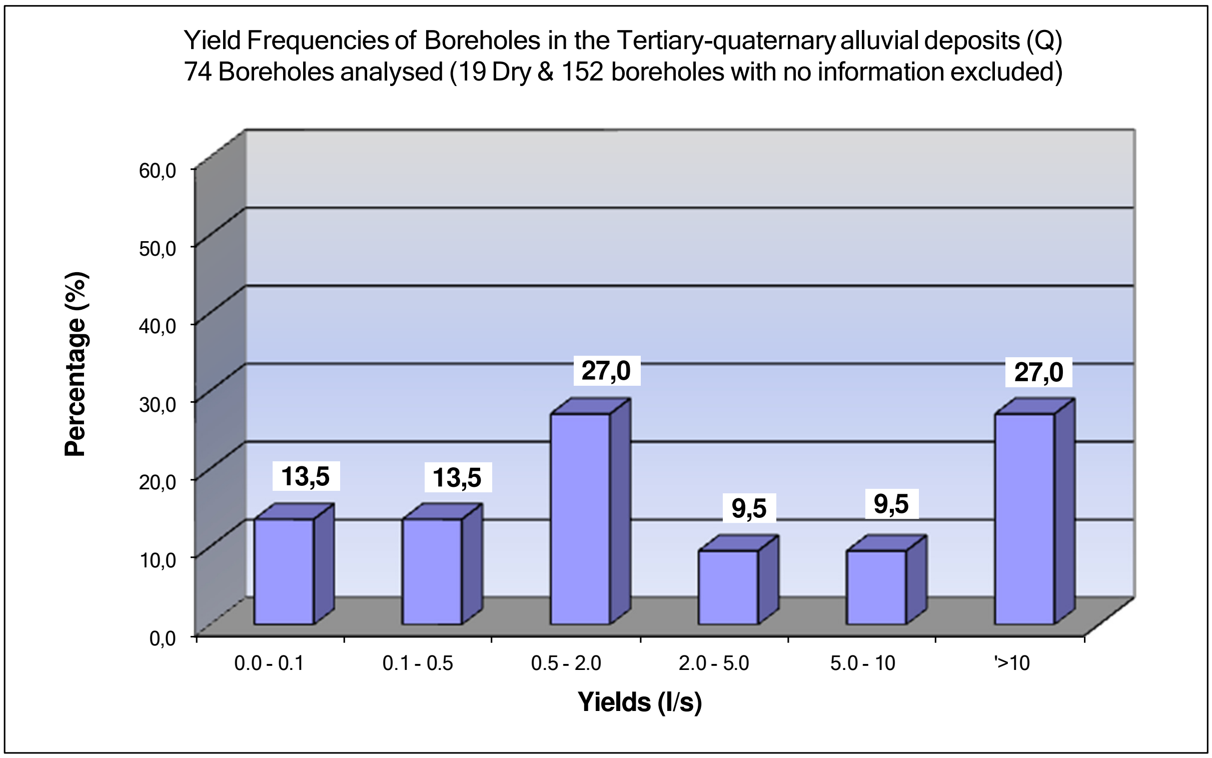


Figure 11: Yield frequency for the intergranular Tertiary-Quaternary alluvial (Q) aquifers.

Figure 11 is a representative yield frequency diagram of yields within the alluvial aquifers. The diagram shows that 54% of the existing boreholes yield between 0.1ℓ/s and 2ℓ/s. A further 19% of boreholes yield between 2ℓ/s and 10ℓ/s, while 27% yield more than 10ℓ/s.

The static water level ranges from ground level or equal to the top level of the alluvial with no surface water in the river to 60.96 meters below ground level (mbgl), with a median of 9.1mbgl and an average static water level of 13.31mbgl, (based on 77 points). The maximum depth recorded is 110m, with an average of 50m and a median depth of 50m, (44 points). The deep boreholes were drilled through the alluvium into the basement rocks underlying the alluvium. The minimal installation depth is 12m that may correspond to the depth of the alluvium in the Limpopo River. The maximum installation depth is 24m and the average is 18.6m, (17 data points).

From the statistics on the installation depths and borehole depths, the statistics include many boreholes that targeted deeper fractured zones overlain by alluvium. The maximum recommended daily abstraction on record is 604.8 cubic meters per day (m^3/day) and the average is 429.6m^3/day. The total number of boreholes subjected to pump testing within this groundwater resource unit on record is 19.

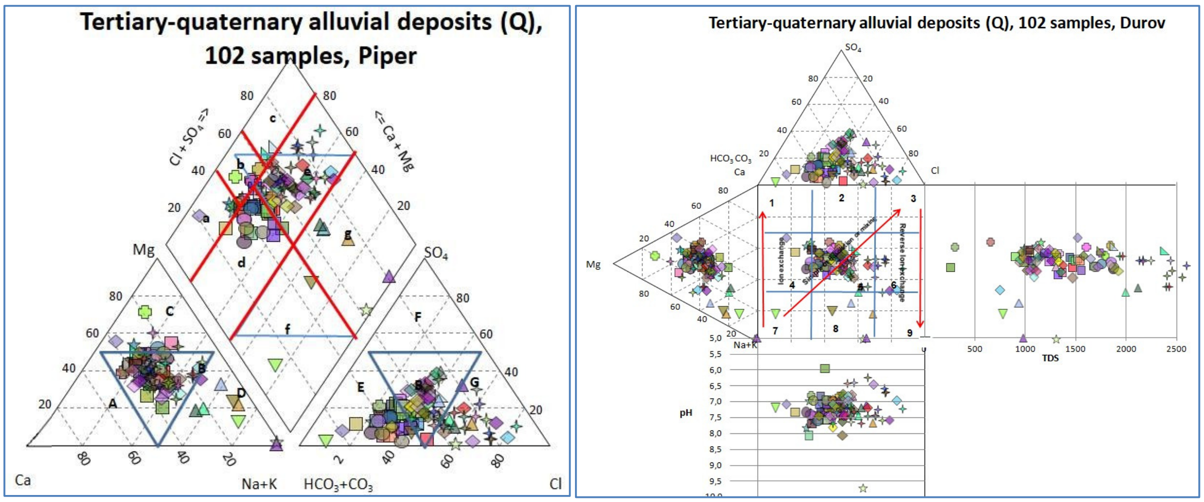


Figure 12: Trilinear diagrams, Piper and Durov for the Tertiary-quaternary alluvial deposits (Q).

The trilinear Piper diagram, (Figure 12) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on dominance is as follows: Alkali earths > Alkali (92.2%), Weak acidic anions > Strong acidic anions (35.8%); Alkali >Alkali earths (7.8%); Strong acids > Weak acids (64.2%).

The type of water within this unit is a function of the geology within the upper catchment area, the time of year (river dry or with water), the depth of the borehole (only within alluvial or deeper fractures) the layering of the deposit (layered permeability-clay/sand) and the timing of the sampling (after longer pumping, water from the underlying fractured zones may dominate).

From the available data and ignoring the above influences in this groundwater resource unit, the water classifies as:

- Mixed Calcium-Magnesium-Bicarbonate type (27.5%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride with prevailing Sulphate type (24.5%);
- Mixed Calcium-Magnesium-Chloride (19.6%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride with prevailing Sodium and Sulphate type (10%);
- Mixed Calcium-Magnesium-Bicarbonate with prevailing Chloride and Sulphate type (4.9%);
- Sodium-Bicarbonate-Chloride with prevailing Sulphate type (3.9%);
- Magnesium-Bicarbonate type (2.9%);
- Sodium-Chloride type (2.9%);
- Magnesium-Bicarbonate with prevailing Chloride and Sulphate type (1.9%);
- Sodium-Bicarbonate type (1.9%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- No dominant anion or cation indicates fresh recent recharge water exhibiting simple dissolution or mixing (74.5%), points plot along the dissolution or mixing line,
- Anion discriminates and Na is dominant, probable mixing, or uncommon dissolution influences (9.8%),
- Anion discriminates and Ca or SO_4 dominant, mixed water or water exhibiting simple dissolution (8.8%),
- Cl dominant anion and Na dominant cation reverse ion exchange of Na-Cl waters (5.9%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (1%),

-The high TDS in some of the samples may be indicative of long residence times in the aquifer allowing reactions to be complete. These samples may relate to the underlying geology, thus deeper fractures contributing more to the supply than from the alluvium. In another study on a section of the Limpopo River, high TDS values were found in the sand aquifer after a very high local rainfall event. The section of the river affected was downstream from the inflow point of a local tributary i.e. Soutsloot. The high TDS was contradictive to the expectation. It was concluded that local rainfall events in the surrounding arid environment mobilized build up salts to wash into the Limpopo River.

Table 29: Chemical statistics for the Tertiary-quaternary alluvial deposits (Q).

Element / Parameter	Statistics Drawn from a population of 149 data points for the Tertiary-quaternary alluvial deposits (Q)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	147	3,87	9,74	7,60	7,64	7,19	7,70	8,08	0,51	6,7%
Electrical Conductivity (mS/m EC)	149	7,6	904,0	88,9	142,4	62,3	104,0	307,6	122,5	86,0%
Total Dissolved Salts (mg/l TDS)	137	99,0	5904,0	649,6	1011,6	433,4	761,0	2137,4	834,2	82,5%
Calcium (mg/l Ca)	137	0,94	313,00	28,53	82,26	36,96	59,80	187,00	60,73	73,8%
Magnesium (mg/l Mg)	137	0,50	347,30	21,40	68,36	25,30	51,40	153,00	54,83	80,2%
Sodium (mg/l Na)	137	1,46	1677,00	45,22	125,03	33,02	70,40	227,80	184,23	147,4%
Potassium (mg/l K)	137	0,57	24,52	2,51	3,77	1,40	2,90	5,99	3,17	84,1%
Chloride (mg/l Cl)	136	2,13	2519,90	58,20	225,76	45,05	103,85	646,90	352,83	156,3%
Sulphate (mg/l SO_4)	137	2,00	1251,00	28,31	77,44	13,28	56,20	125,64	118,71	153,3%
Total Alkalinity (mg/l) $CaCO_3$)	142	2,00	1990,00	131,29	321,31	160,70	280,15	560,77	198,30	61,7%
Nitrate (mg/l N)	148	0,02	59,19	0,23	6,25	0,09	2,28	17,76	10,13	162,0%
Fluoride (mg/l F)	137	0,01	15,03	0,38	0,95	0,38	0,69	1,40	1,55	163,7%
Silicon as Si	114	0,55	42,05	10,40	20,41	6,87	20,57	35,00	10,86	53,2%
Iron (Fe)	17	0,000	0,370	0,001	0,100	0,003	0,013	0,370	0,16	154,8%
Manganese (Mn)	22	0,000	0,812	0,002	0,116	0,001	0,009	0,457	0,23	197,1%
Ortho Phosphate as Phosphorus as PO4	114	0,003	0,162	0,005	0,014	0,003	0,005	0,024	0,03	195,5%
ZAR	137	0,13	40,50	1,34	2,86	0,80	1,67	4,08	4,89	171,0%
LSI	129	Langelier Saturation Index (LSI)			Slightly Scaling		**49,6%**	Highly Scaling		**0,0%**
		Highly corrosive		**2,3%**	Slightly corrosive		**3,9%**	Balanced Corrosion		**44,2%**

Table 29 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality for the unit in terms of Electrical conductivity (EC) is ideal to good in 72.5% of the analysis, of a moderate quality in 24.8% and unacceptable only in 2.7% (values above 370mS/m).

The Total Dissolved Solids (TDS) is acceptable in 75.9% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions of 149 samples show that elevated concentrations of Chloride (Cl > 600mg/l) in 12.5%; Fluoride (F >1.5mg/l) in 8%; Nitrate (N >10mg/l) in 7.4%; Sodium (Na > 400mg/l) in 4.4%; Magnesium (Mg > 200mg/l) in 2.9%; Calcium (Ca > 300) in 0.7% and Sulphate (SO4 >600mg/l) in 0.7% of the analysis. The pH value exceeds the maximum allowable limit in one sample; it is acidic.

The Langelier Saturation Index (LSI) indicates that the water is highly too slightly corrosive (6.2%); slightly scaling (49.6%) and 44.2% balanced. The ZAR index indicates that 81.8% of the water is of a fair quality for irrigation (ZAR < 3).

Due to the shallow nature of the aquifer micro bacteriologic risks will always be a factor to consider when using it for domestic purposes.

7.2 SECONDARY AQUIFERS

Consolidated hard rocks cover a large section of the map area (± 97.1%). The map area does not include the section within Botswana. The rock mass was formed over a period of 3800 million years which almost spans the whole length of the South African geological history. Processes of tectonic deformation (folding, faulting) aided by weathering, dissolution (carbonate rocks) and unloading through erosion generated and/or enhanced fractures, interstices, and solution cavities in the hard rocks of the map area, eventually contributed to the present groundwater environment prevailing in the different groups and formations. Therefore, the aquifer types used for Hydrogeological map sheets for secondary aquifers are Karst, fractured, and intergranular & fractured.

7.2.1 CATEGORY B: FRACTURED AQUIFERS

- Clarens Formation (Trc)
- Undifferentiated Waterberg Supergroup (Mw)
- Vaalwater Formation (Mva)
- Claremont Formation (Mcl)
- Kransberg Subgroup (Mkr) (Sandriviersberg & Mogalakwena Formations)
- Aasvoëlkop Formation (Mas)
- Schilpadkop Formation (Msc)
- Alma Formation (Mag)
- Swaershoek Formation (Ms)
- Undifferentiated Pretoria Group (Vpg)
    - Magaliesburg Formation (Grouped with undifferentiated Vpg)
    - Black Reef Formation (Grouped with undifferentiated Vpg)
- Rayten Formation (Vry)
- Undifferentiated Smelterskop Formation (Vsk)
- Silverton Formation (Vsi)
- Daspoort Formation (Vdp)
- Timeball Hill Formation (Vti)
- Klapperkop Member (Vkp)
- Penge Formation (Vpe)
- Undiffentiated / unnamed Ventersdorp Group (Rvz)
- Kwaggasnek Formation (Vkw)
- Schrikkloof Formation (Vsc)

The geographical distribution of the fractured rock aquifers is shown as Figure 13.

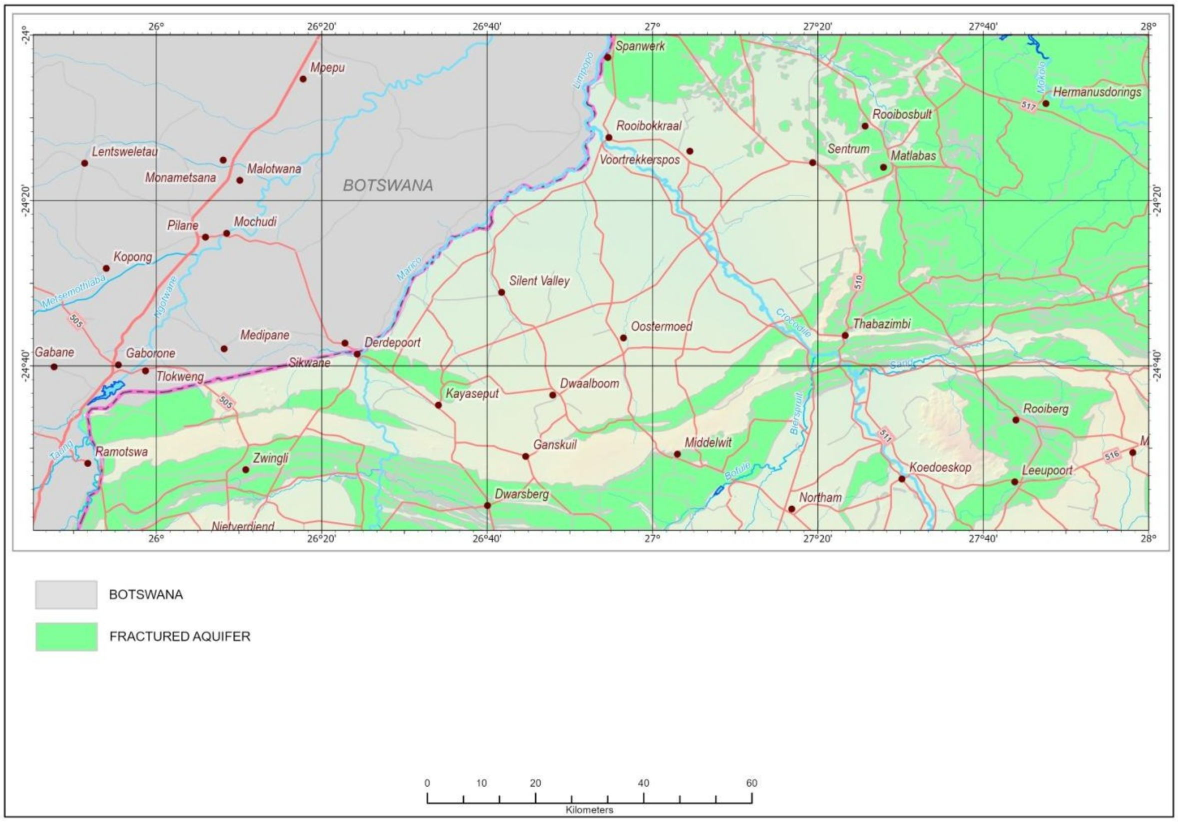


Figure 13: Geographical distribution of the fractured rock aquifers.

7.2.1.1 CLARENS FORMATION (Trc)

This Clarens Formation occurs extensively on the Springbok Flats, which is predominantly falling within the Modimolle map sheet. Within the Thabazimbi map sheet the occurrence is limited to the south-eastern section of the map sheet, (Figure 14). It covers approximately 0.73% of the total map area. The formation consists essentially of fine-grained, aeolian deposited sandstone.

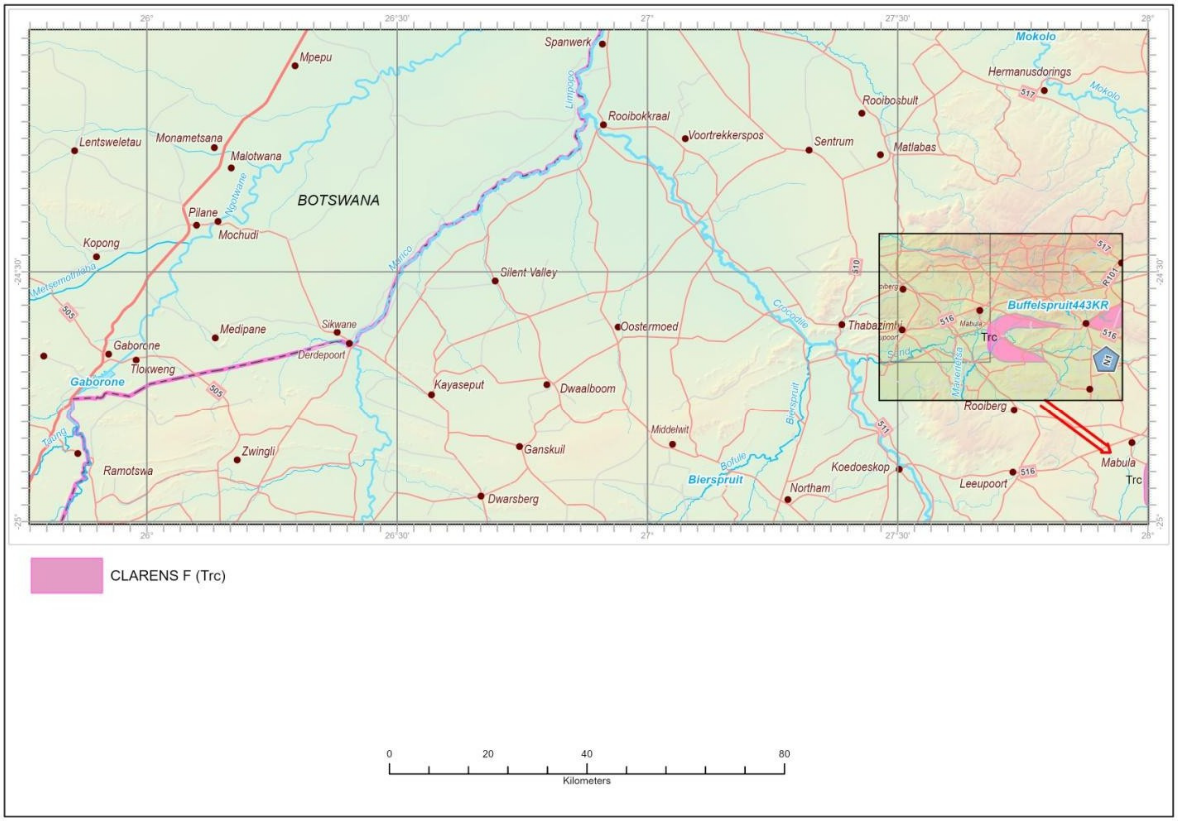


Figure 14: Geographical distribution of the Clarens Formation (Trc) and the associated groundwater sampling points.

There is no information available on borehole yields, chemical analysis, depths, water strike depths or abstraction for this groundwater resource unit. For more information on the groundwater resource unit the Modimolle map sheet and brochure will provide more detail on the characteristics of the unit.

7.2.1.2 UNDIFFERENTIATED WATERBERG SUPERGROUP (Mw)

The Undifferentiated Waterberg Supergroup unit occurs in a small section in the south-western section of the map sheet near the Botswana border, (Figure 15). It covers approximately 0.02% of the total map area and consists of Sandstone, grit, conglomerate and breccia.

There is not sufficient data available on the maximum yield, water quality, depth, static water level or abstraction for characterization.

Groundwater from the unit is abstracted for livestock and domestic use for rural villages.

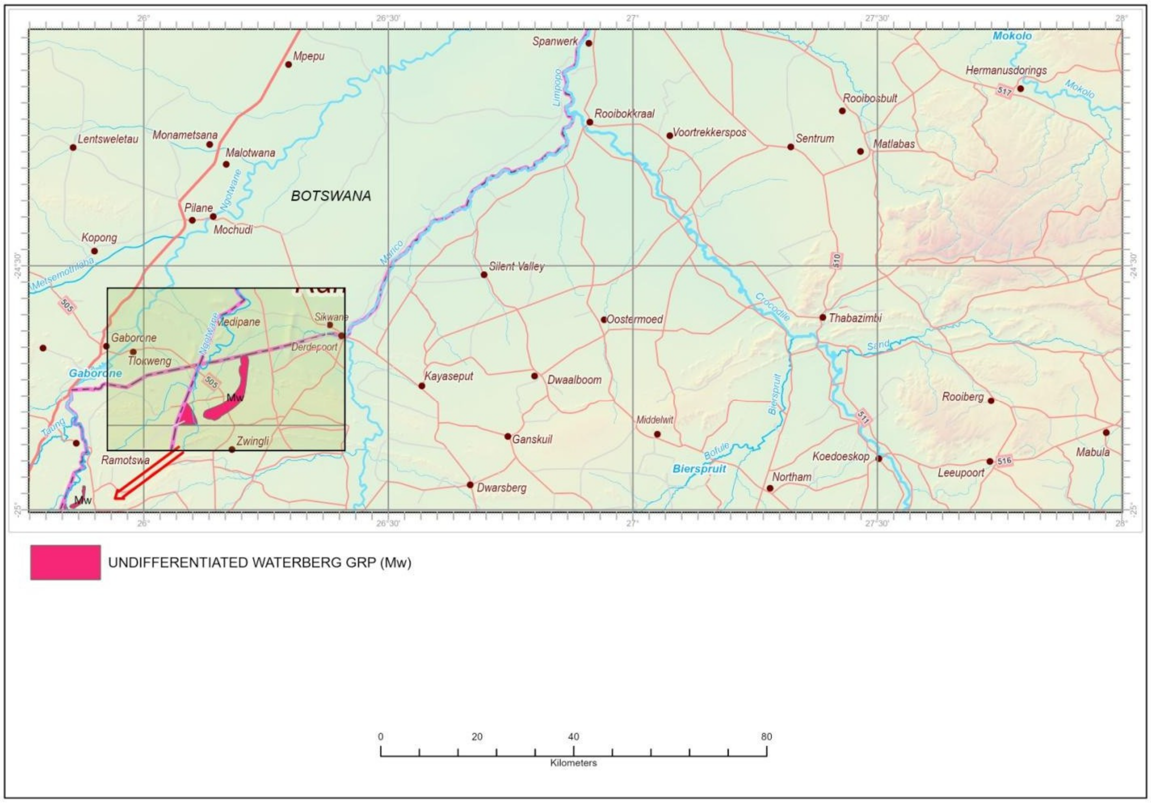


Figure 15: Geographical distribution of the Undifferentiated Waterberg Supergroup (Mw).

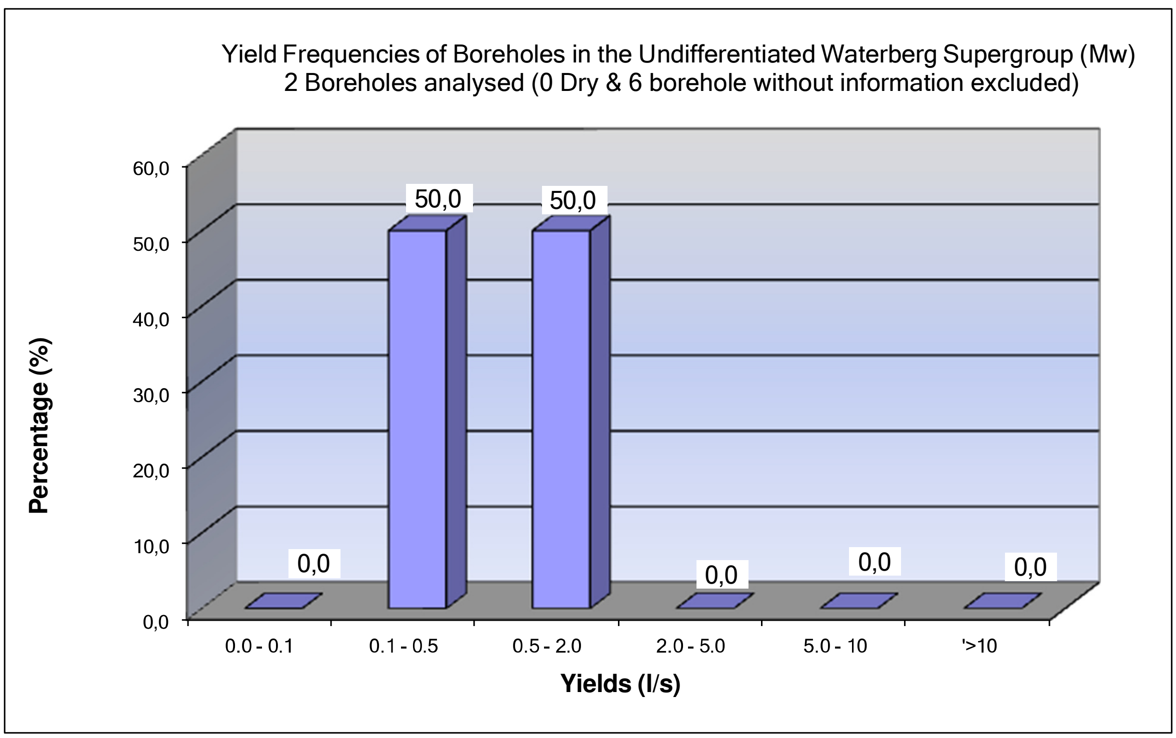


Figure 16: Yield frequency for the fractured aquifers of the Undifferentiated Waterberg Supergroup (Mw)

7.2.1.3 VAALWATER FORMATION (Mva)

The Vaalwater Formation is described as a separate groundwater resource unit, although it forms part of the Kransberg Subgroup of the Waterberg Supergroup. Structurally, the Kransberg Subgroup lies within the Nylstroom Syncline, a large, shallow synclinal fold (a trough-shaped fold where the youngest rocks are preserved in the core).

As with most of the Formations in the Waterberg Supergroup, the Vaalwater Formation appears on the map as a fractured aquifer. On the Thabazimbi map sheet the unit occurs within the north-eastern section of the map sheet and extends eastward as part of a larger outcrop that predominantly falls within the Modimolle map sheet, (inset map Figure 17). The southern boundary of the groundwater resource unit is delineated by the north-west-trending Bulge River fault zone, a distinctive geological feature in the area. During dry periods, the fault zone is visible as a linear green belt due to denser vegetation along the mountainside (particularly near the Bulge River settlement, from which the name is derived). The higher-lying area to the south is underlain by the lower formations of the Kransberg Subgroup. The fault zone has caused localized deformation and fracturing in the sedimentary rocks, influencing their porosity and permeability, and some high yielding (up to 10ℓ/s) boreholes are reported near the fault zone. Other high-yielding boreholes, (up to 17ℓ/s) occur near the Mokolo River.

The Vaalwater Formation consists of fine-grained feldspathic sandstone, as well as micaceous sandstone, arkose, siltstone, and shale. Cross-bedding and ripple marks are abundantly developed. It forms the roof or uppermost layer of the Kransberg Subgroup (Council for Geoscience).

The section of the Vaalwater Formation within the Thabazimbi map sheet covers approximately 1.51% of the total area. The unit occurs across the boundary between the Thabazimbi and Modimolle map sheets; this cross-boundary occurrence is continuous and shares the same hydrogeological setting. Therefore, information from both maps was used for the characterization of this unit.

The Vaalwater Formation has been intruded extensively by sills and dykes of predominantly diabasic composition. These diabase intrusions (N-Za) play a major role in the occurrence of groundwater. If dykes and sills are ignored, the groundwater potential of the Waterberg Group is generally low. The yield diagram indicates that 70.6% of the yields are less than 2ℓ/s, (Figure 18).

In terms of water chemistry, in 10% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anion of concern is Fluoride.

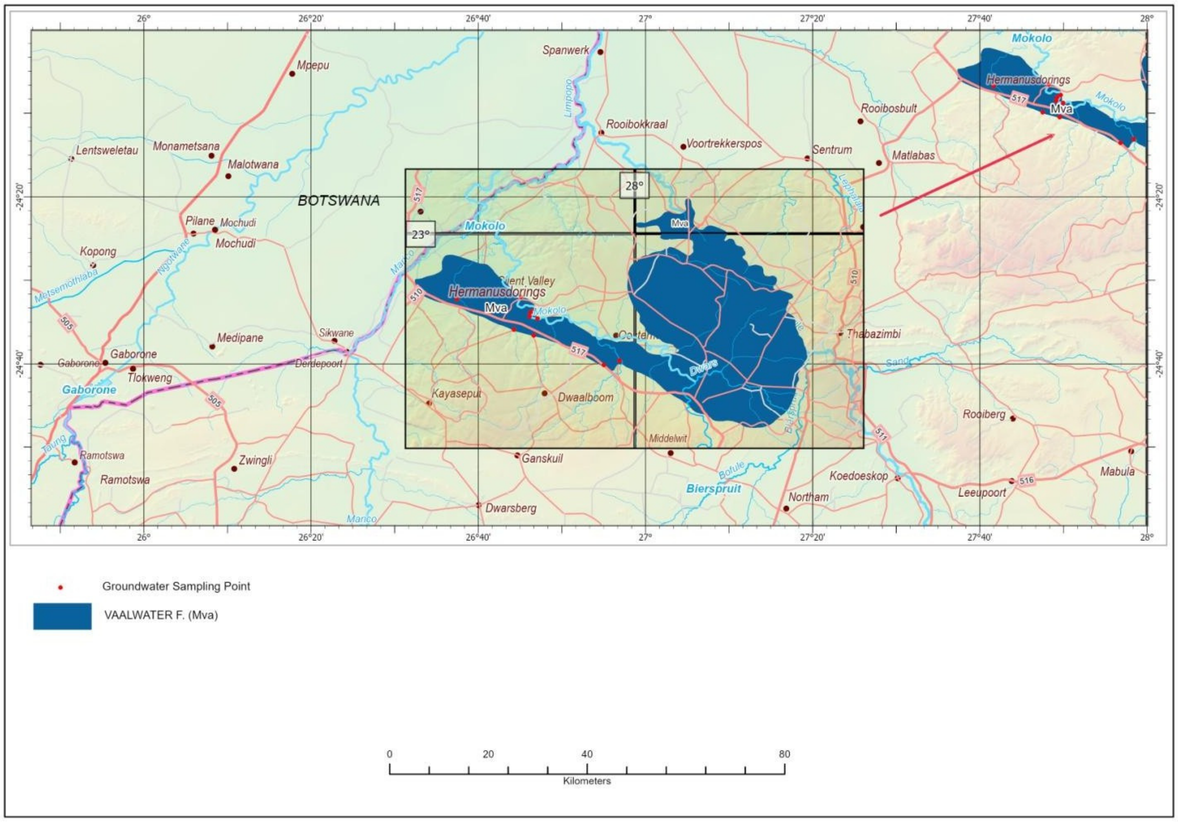


Figure 17: Geographical distribution of the Vaalwater Formation (Mva) and the associated groundwater sampling points.

As in most of the Formations in the Waterberg Group, groundwater occurs mainly in fault zones, sill/dyke contacts, fracture zones, and fractures related to anticlines and bedding planes. Deep drilling (up to 250m) has confirmed that fractures do occur at these depths and can therefore be targeted when searching for groundwater sources. However, it remains difficult to trace these deeply seated fractures using geophysical methods.

Diabase sills, dykes, and the Bulge River fault zone are major targets for good groundwater yields and can often be identified on aerial photographs. Diabase is less resistant to weathering than the surrounding sandstone, which may lead to the formation of surface depressions. Weathering of the diabase may also result in the development of fertile soils, promoting dense vegetation growth along the dykes. This dense vegetation can sometimes be traced for many kilometers. Where sills are weathered and fractured to extended depths below the water table, good water strikes can be found, (See also the chapter on the Diabase Intrusive groundwater resource unit for more detail, chapter 7.2.3.5).

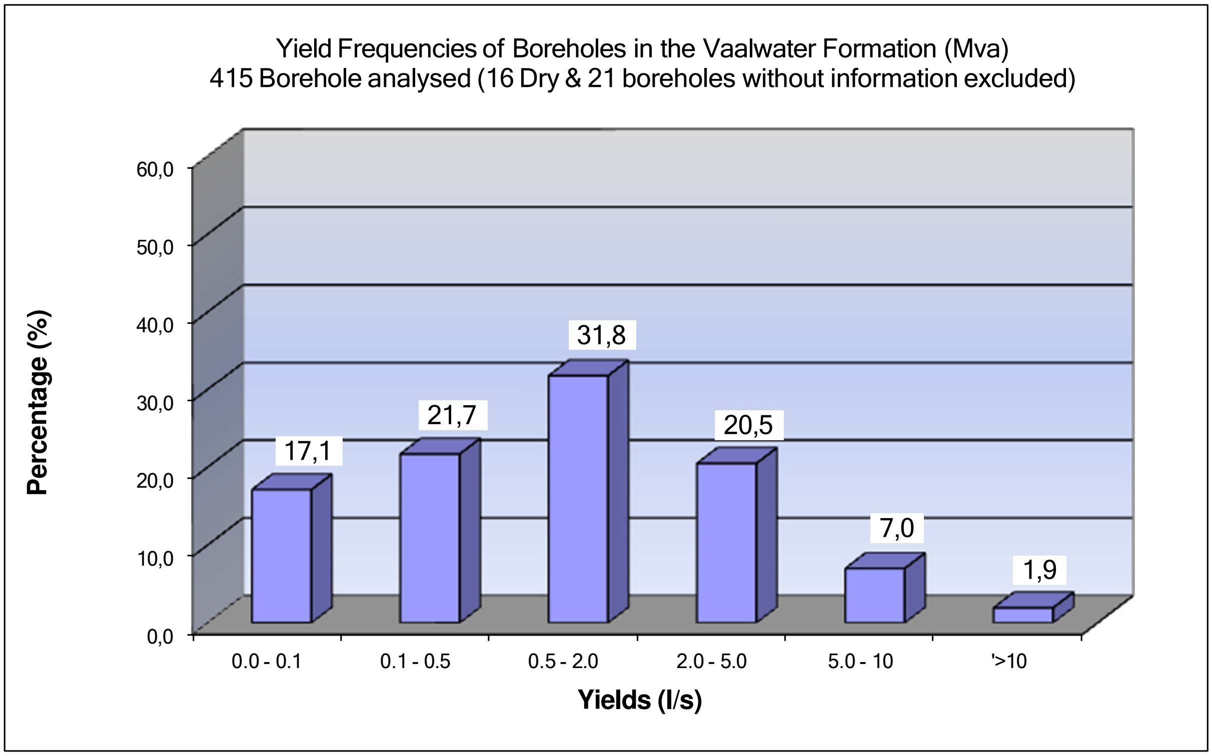


Figure 18: Yield frequency for the fractured aquifers of the Vaalwater Formation (Mva), data used from 2 map sheet, (cross boundary occurrence).

The groundwater resource unit occurs on both sides of the map boundaries (Thabazimbi and Modimolle). For the yield data 369 data points fall on the Modimolle map sheet and 46 data points on the Thabazimbi map sheet.

Analysis of 415 borehole records indicates that 38.8% of the maximum yields are suitable for small households (>0.1ℓ/s to 0.5ℓ/s). A further 31.8% of the boreholes yield between 0.5ℓ/s and 2ℓ/s, while 20.5% of the boreholes yield between 2ℓ/s and 5ℓ/s. Only 8.9% of the records indicate maximum yields exceeding 5ℓ/s.

For the 46 data points falling on the Thabazimbi map sheet, the static water level ranges from artesian (one data point) to 58.52 meters below ground level (mbgl), with a median of 11.76mbgl and an average static water level of 15.35mbgl, (based on 50 data points). The maximum depth recorded is 195.1m, with an average depth of 107.5m and a median depth of 98.3m, (10 data points). The minimal installation depth is 30m; the maximum installation depth is 66m and the average installation depth is 46.9m, (8 data points). The maximum recommended daily abstraction on record is 432m³/day and the average is 224.6m³/day. The total number of boreholes subjected to pump testing within this unit on record is 8.

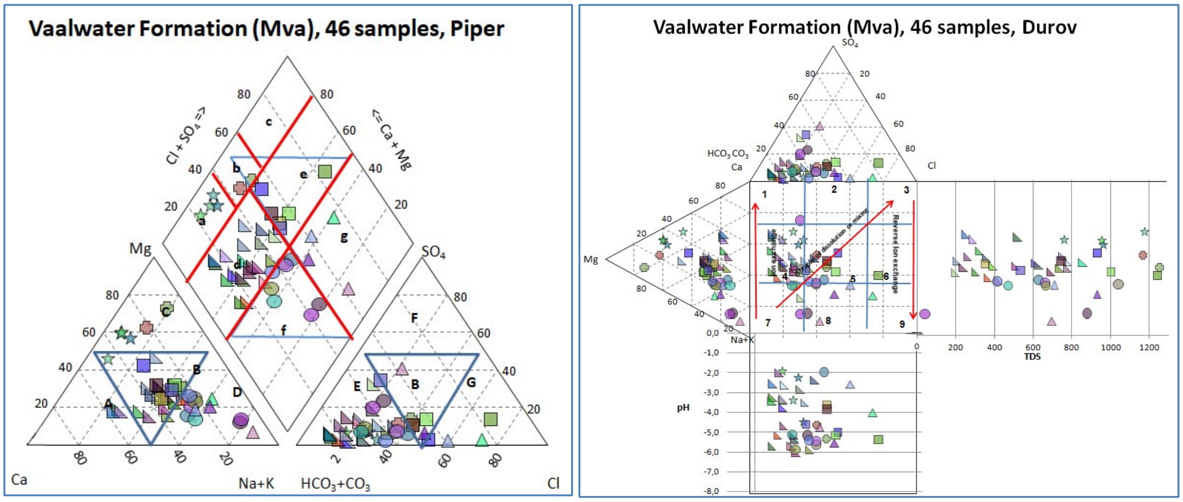


Figure 19: Trilinear diagrams, Piper and Durov for the Vaalwater Formation (Mva).

The groundwater resource unit occurs on both sides of the map boundaries (Thabazimbi and Modimolle). In total 38 data points with chemical analyses fall on the Modimolle map sheet and 22 on the Thabazimbi map sheet. The accuracy of the chemical analysis was checked by the plausibility of the Electrical Conductivity (EC) and Electro Neutrality (E.N). Only 46 analyses could be used as 14 analyses were not considered accurate

The trilinear Piper diagram, (Figure 19) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (73.9%), Weak acidic anions > Strong acidic anions (76.1%); Alkali >Alkali earths (26.1%); Strong acids > Weak acids (23.9%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate with prevailing Sodium type (45.7%);
- Sodium-Chloride type (21.7%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride with prevailing Sodium type (8.7%);
- Calcium-Bicarbonate type (6.5%);
- Magnesium-Bicarbonate-Chloride type (4.3%);
- Magnesium-Bicarbonate type (4.3%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with increased Sodium and Sulphate (2.2%);
- Mixed Calcium-Magnesium-Chloride with prevailing Sodium type (2.2%);
- Sodium-Bicarbonate-Chloride type (2.2%);
- Sodium-Bicarbonate with prevailing Chloride and Sulphate type (2.2%);

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (47.8%),
- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (30.4%), plot along the dissolution or mixing line,
- Cl dominant anion and Na dominant cation reverse ion exchange of Na-Cl waters (8.7%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (6.5%),
- Anion discriminates and Na dominant, probable mixing or uncommon dissolution influences (2.2%),
- Cl and Na dominant, is frequently indicative of end-point gradient waters through Dissolution (2.2%),

- HCO_3 and Ca dominant, indication of recharge in sandstone (2.2%),
- The high TDS is some of the samples that may be indicative of long residence times in the aquifer allowing reactions to be fairly complete.

Table 30: Chemical statistics for the Vaalwater Formation (Mva).

Element / Parameter	Statistics Drawn from a population of 60 data points for the Vaalwater Formation (Mva), 22 data points from the Thabazimbi map area, the rest from Modimolle map area									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	60	5,30	8,60	7,85	7,92	7,45	8,18	8,44	0,68	8,6%
Electrical Conductivity (mS/m EC)	60	2,5	189,8	29,1	53,1	19,4	52,0	82,2	30,6	57,7%
Total Dissolved Salts (mg/l TDS)	60	26,0	1278,0	227,1	378,0	147,1	370,0	623,2	217,5	57,5%
Calcium (mg/l Ca)	59	0,50	91,70	10,49	30,23	8,66	28,16	51,50	17,65	58,4%
Magnesium (mg/l Mg)	59	0,50	100,20	7,51	20,33	5,39	12,00	49,18	19,76	97,2%
Sodium (mg/l Na)	60	5,00	253,80	27,13	52,96	12,30	43,09	111,84	43,02	81,2%
Potassium (mg/l K)	59	0,50	15,09	1,44	2,49	0,82	1,58	5,66	2,78	111,5%
Chloride (mg/l Cl)	60	1,50	402,80	13,32	41,00	5,69	25,01	87,36	62,16	151,6%
Sulphate (mg/l SO_4)	60	2,00	95,70	6,93	20,92	3,19	11,28	50,48	23,29	111,3%
Total Alkalinity (mg/l) $CaCO_3$)	46	12,40	403,00	129,72	201,31	103,78	190,30	339,55	92,61	46,0%
Nitrate (mg/l N)	58	0,02	13,00	0,16	1,86	0,05	1,09	4,11	2,40	129,0%
Fluoride (mg/l F)	60	0,10	4,00	0,29	0,72	0,16	0,36	1,70	1,11	153,8%
Silicon as Si	57	4,00	29,22	12,06	13,87	10,08	12,80	20,24	4,71	34,0%
Iron (Fe)	27	0,005	0,370	0,021	0,072	0,008	0,050	0,167	0,10	134,2%
Manganese (Mn)	27	0,001	0,070	0,006	0,032	0,002	0,050	0,050	0,02	71,1%
Ortho Phosphate as Phosphorus as PO4	50	0,006	0,800	0,020	0,166	0,009	0,022	0,800	0,28	169,3%
ZAR	59	0,25	7,79	1,16	2,11	0,64	1,58	5,80	1,83	86,9%
LSI	44	Langelier Saturation Index (LSI)			Slightly Scaling		**40,9%**	Highly Scaling		**0,0%**
		Highly corrosive		**4,5%**	Slightly corrosive		**4,5%**	Balanced Corrosion		**50,0%**

This unit occurs on both sides of the map boundaries (Thabazimbi and Modimolle), for the chemical data 22 data points fall within the Thabazimbi map sheet and 38 on the Modimolle map sheet.

Table 30 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality in terms of the Electrical conductivity (EC) is ideal to good (98.3%) and marginal in 1.7% of the analysis (EC < 370mS/m). The values range from 2.5mS/m to 189.8mS/m, the 90th percentile is 82.2mS/m.

The Total Dissolved Solids (TDS) is acceptable in 98.3% of the samples (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 60 samples show elevated concentrations of Fluoride (F >1.5mg/l) in 10% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly too highly corrosive in 9% of the samples; slightly scaling in (40.9%) and predominantly balanced (50%). The ZAR index indicates that 84.8% of the water is of a fair quality for irrigation (ZAR < 3).

The water is abstracted for livestock, game watering, domestic purposes and irrigation. Two rivers cut through the area, namely, the Bulge River flowing into the Malmanies River and the Mokolo River. The irrigated fields are along the Bulge River fault zone and along the rivers and the contribution between surface and groundwater to irrigation is not known.

7.2.1.4 CLEREMONT FORMATION (Mcl)

The Cleremont Formation is described as a separate groundwater resource unit, although it forms part of the Kransberg Subgroup of the Waterberg Supergroup. Structurally, the Kransberg Subgroup lies within the Nylstroom Syncline, a large, shallow synclinal fold (a trough-shaped fold where the youngest rocks are preserved in the core).

Within the Thabazimbi map sheet, the Cleremont Formation occurs within the north-eastern section of the map sheet, with the Vaalwater Formation outcrop forming its southern boundary and the lower Sandriviersberg and Makgabeng Formations (included in the report as the Kransberg Subgroup unit), forming the northern boundary. The unit extends eastwards into the Modimolle map sheet as part of a larger outcrop that appears to form a ring around the Vaalwater Formation.

The Cleremont Formation comprises sandstone with minor shale and forms a thin cover over the Mogalakwena Formation. It reaches a maximum thickness of approximately 60m within the map area, (Weinert, 1955; Neetling, 1956). The sandstone is medium to coarse-grained, well-sorted, and contains a high percentage of quartz. It is locally gritty and whitish in colour. Rare occurrences of light-pink or light red coloured sedimentary rock are noted and are apparently restricted to the base of the formation, (Callaghan, 1987; Callaghan and Brandl, 1991).

The section of the unit within the Thabazimbi map sheet covers approximately 1.6% of its total areal extent. The groundwater resource unit occurs across four adjacent map sheets (Modimolle, Lephalale, Polokwane, and Thabazimbi). The cross-boundary occurrences are predominantly connected and share the same hydrogeological setting. Therefore, information from all four maps was used for the characterization of this unit, (see Figure 20 with the inset map).

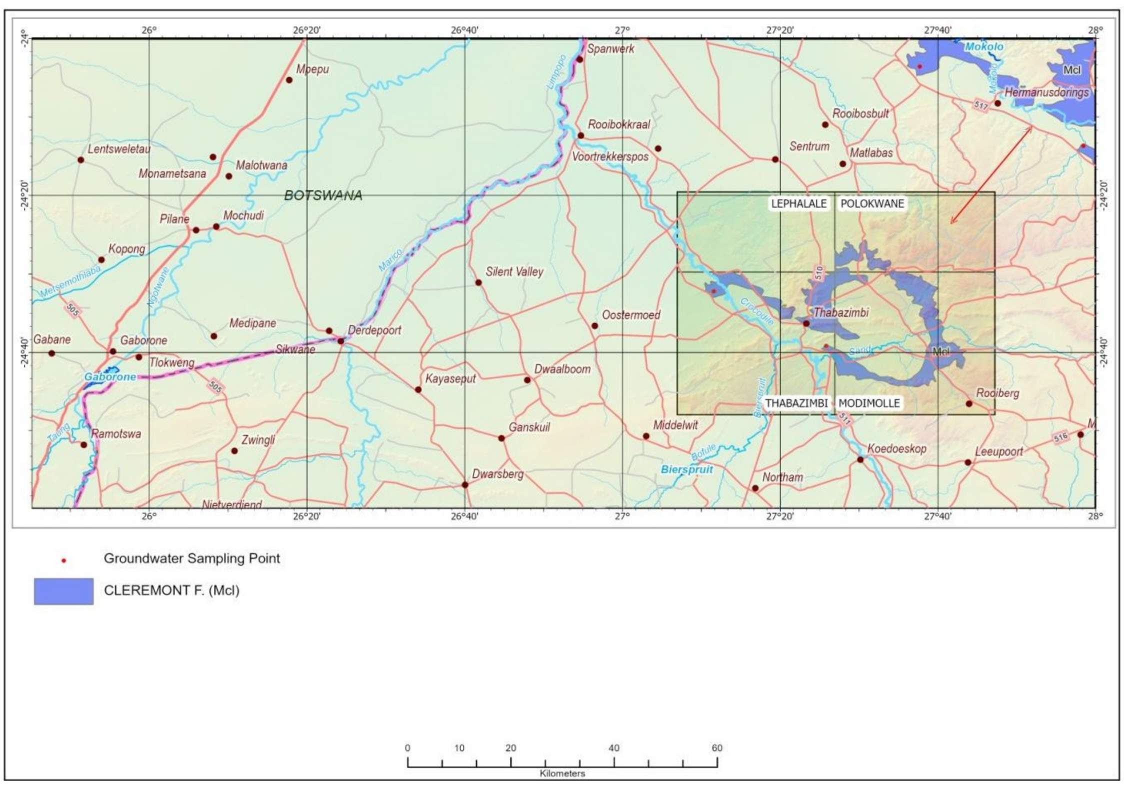


Figure 20: Geographical distribution of the Cleremont Formation (Mcl) and the associated groundwater sampling points.

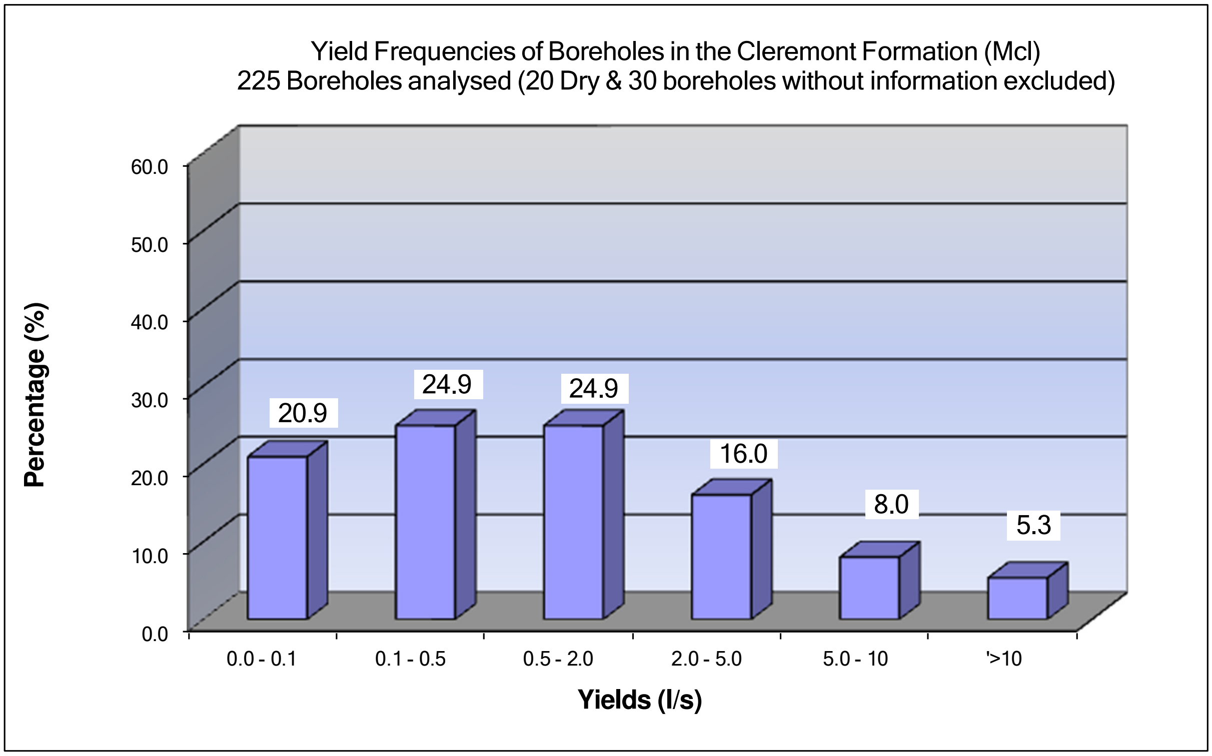


Figure 21: Yield frequency for fractured aquifers of the Cleremont Formation (Mcl).

The groundwater resource unit occurs across four adjacent map sheets (Modimolle, Lephalale, Polokwane, and Thabazimbi). For the yield data 136 data points fall on the Modimolle map sheet, 41 on the Lephalale map sheet, 2 on the Polokwane map sheet and 47 data points on the Thabazimbi map sheet.

The analysis of 225 borehole records indicates that 45.8% of the maximum yields are suitable for small households (>0.001ℓ/s to 0.5ℓ/s). A further 24.9% of the boreholes yield between 0.5ℓ/s and 2ℓ/s, while 16% yield between 2ℓ/s and 5ℓ/s, and 13.3% have yields exceeding 5ℓ/s.

The analysis of 47 borehole records from the Thabazimbi map indicates that the static water level ranges from 5.18 meters below ground level to 58mbgl, with a median of 18.29mbgl and an average static water level of 21.85mbgl, (40 data points excluding a single borehole with a water level of 113mbgl). Only borehole resource is reported with a depth of 175.9m. No information is available on water strikes or pump testing data.

Similar in characteristics to the Mogalakwena Formation, groundwater occurs mainly in fault zones, sill/dyke contacts, fracture zones and fractures related to anticlines and bedding planes. No information is available to determine if the underlying contact with the Mogalakwena Formation will result in water strikes.

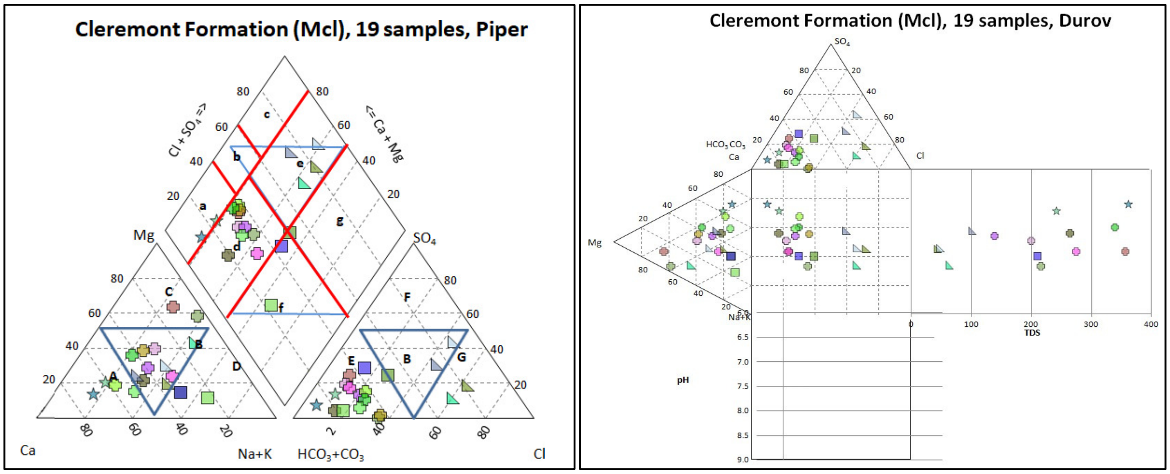


Figure 22: Trilinear diagrams, Piper and Durov for the Cleremont Formation (Mcl).

The groundwater resource unit occurs on the boundaries of four adjacent map sheets namely Modimolle, Lephalale, Thabazimbi and Polokwane. For the chemical data 28 data points fall on the Modimolle map sheet, 2 on the Lephalale map sheet, 1 on the Thabazimbi map sheet and 0 data points on the Polokwane map sheet. The accuracy of the chemical analysis was checked by the plausibility of the Electrical Conductivity (EC) and Electro Neutrality (E.N). Only 19 analyses could be used as 12 analyses were not considered accurate.

Figure 22 facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions in order to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (84.2%), Weak acidic anions > Strong acidic anions (78.9%); Alkali >Alkali earths (15.8%); Strong acids > Weak acids (21.1%).

The second evaluation was on the water type: mixed

- Calcium-Magnesium-Bicarbonate type (42.1%);
- Calcium-Bicarbonate type (21.1%).
- Sodium-Bicarbonate type (15.8%);
- Mixed Calcium-Magnesium-Chloride type with prevailing Sodium and Sulfate (10.5%);
- Mixed Calcium-Magnesium-Chloride type (10.5%);

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (42.9%),
- No dominant anion or cation indicates fresh recent recharged water exhibiting simple dissolution or mixing (28.6%), plots along the dissolution or mixing line,
- HCO_3 and Ca dominant, indication of recharge in sandstone (14.3%),
- HCO_3 and Ca dominant, with prevailing Na, an important ion exchange is presumed (4.8%),
- Anion discriminates and Na is dominant, probable mixing or uncommon dissolution influences (4.8%),
- HCO_3 and Na dominant, indication of ion exchanged water (4.8%),

Table 31: Chemical statistics for the Cleremont Formation (Mcl).

Element / Parameter	Statistics Drawn from a population of 31 data points for the Cleremont Formation (Mcl), 28 data points from the Modimolle map sheet, 1 from the Thabazimbi map sheet and 2 data points from the Lephalale map sheet included.									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	30	6.06	8.36	7.19	7.25	6.08	7.41	7.95	0.67	9.3%
Electrical Conductivity (mS/m EC)	30	2.5	95.9	8.9	20.8	3.4	15.1	43.2	20.4	98.1%
Total Dissolved Salts (mg/l TDS)	30	17.2	721.3	64.5	157.1	24.6	115.5	308.3	152.6	97.2%
Calcium (mg/l Ca)	26	0.67	77.70	2.77	14.85	0.82	7.92	34.11	17.81	119.9%
Magnesium (mg/l Mg)	26	0.67	45.16	2.43	6.45	1.09	3.17	14.51	9.34	144.7%
Sodium (mg/l Na)	26	1.50	59.50	5.31	12.09	2.57	7.64	24.08	13.12	108.5%
Potassium (mg/l K)	26	0.35	6.81	0.73	1.10	0.39	0.86	1.47	1.23	111.7%
Chloride (mg/l Cl)	30	2.98	62.00	6.51	11.27	3.48	6.67	26.62	12.46	110.5%
Sulphate (mg/l SO_4)	29	0.09	19.87	1.52	5.69	1.47	4.00	12.63	4.99	87.7%
Total Alkalinity (mg/l) $CaCO_3$)	27	4.00	287.27	15.26	69.66	5.51	51.05	160.70	72.30	103.8%
Nitrate (mg/l N)	30	0.02	29.53	0.20	2.59	0.08	1.06	4.44	5.44	209.6%
Fluoride (mg/l F)	31	0.05	5.15	0.14	0.38	0.09	0.15	0.43	0.92	241.1%
Silicon as Si	26	4.34	32.56	6.98	8.78	4.69	7.94	13.90	5.93	67.6%
Iron (Fe)	11	0.005	0.090	0.010	0.028	0.005	0.021	0.050	0.03	99.7%
Manganese (Mn)	6	0.009	0.082	0.030	0.049	0.030	0.050	0.066	0.02	47.7%
Ortho Phosphate as Phosphorus as PO4	29	0.005	0.800	0.017	0.130	0.010	0.019	0.800	0.27	210.2%
ZAR	26	0.21	3.11	0.49	0.68	0.32	0.50	1.11	0.57	82.8%
LSI	26	Langelier Saturation Index (LSI)			Slightly Scaling		**3.8%**	Highly Scaling		**0.0%**
		Highly corrosive		**46.2%**	Slightly corrosive		**38.5%**	Balanced Corrosion		**11.5%**

This unit occurs on four adjacent maps, (Thabazimbi, Polokwane, Lephalale and Modimolle), for the chemical data 1 data point falls within the Thabazimbi map sheet; 2 on the Lephalale map sheet, 0 on the Polokwane map sheet and 28 on the Modimolle map sheet.

Table 31 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. In terms of the electric conductivity (EC), the overall water quality is ideal; it varies between 2.5 and 95.9mS/m. The Total Dissolved Solids (TDS) is acceptable in 100% of the samples (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 31 samples show elevated concentrations of Nitrate, (N >10mg/l) in 3.3% and Fluoride (F >1.5mg/l) in 3% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be predominantly corrosive (84.7%); slightly scaling (3.8%) and only 11.5% balanced. The ZAR index indicates that 96.2% of the water is of a fair quality for irrigation (ZAR < 3).

Water is abstracted for game, livestock watering, and domestic purposes on rural farms and at lodges. South of the unit, along the Mokolo River, some large-scale irrigation occurs. Surface water for irrigation is sourced from the river, groundwater from the Bulge River fault zone (further south), and other high-yielding boreholes located within the Vaalwater Formation near the southern boundary of the unit. A large section of the unit has minimal soil cover.

7.2.1.5 KRANSBERG SUBGROUP (Mkr)

The Waterberg Supergroup has been subdivided into three subgroups, namely the Nylstroom, Matlabas, and Kransberg Subgroups. The Kransberg Subgroup consists of the Vaalwater, Cleremont, Sandriviersberg, and Mogalakwena Formations. On the Thabazimbi map sheet, the Cleremont and Vaalwater units are described as separate groundwater resource units. The groundwater resource unit listed as the Kransberg Subgroup on the Thabazimbi map sheet consists of the Sandriviersberg and Makgabeng Formations, although the latter is part of the Matlabas Subgroup.

Although the Kransberg Subgroup is discussed here and covers approximately 9.6% of the area, an overview of the Waterberg Supergroup is provided.

The Waterberg Supergroup occupies the north-eastern portion of the map area (except for the occurrence listed as the Undifferentiated Waterberg Supergroup in section 7.2.1.2). It consists of two overlapping sedimentary basins. In the deep basin (Alma trough) beds of the Swaershoek, Alma and Sterkrivier Formations were laid down. The Schilpadkop and locally the Makgabeng Formation form the base of the succession in the younger, larger, but shallower basin. The entire succession is predominately arenaceous (consists of sand), but the Aasvoëlkop and Vaalwater Formations are partly arkosic (25% feldspar content). The oldest Sub-Division (Nylstroom) of which the lower portion is the Swaershoek Formation is of late-Bushveld age and confined to proto basins of which the largest coincides approximately with the Nylstroom syncline (Council for Geosciences).

Trachytic lavas (composed mostly of alkali feldspar), are well developed and quartz porphyry occurs locally in the Swaershoek Formation. The Alma, Schilpadkop and Aasvoëlkop Formations are poorly exposed and mostly only the conglomerate beds are seen. The Alma Formation becomes less felspathic in the east. In the Sterk River area both the Swaershoek and Alma Formations decrease in thickness (Council for Geosciences). The Schilpadkop Formation wedges out to the north-east and the partly argillaceous (clayey) Aasvoëlkop Formation grades into the arenaceous Makgabeng Formation. The Sandriviersberg Formation, which occupies the southern Waterberg plateau grades to the east and north into the Makgabeng Formation, which locally contains numerous conglomerate layers (Council for Geosciences).

Sedimentary structures are well developed in the Sandriviersberg and Mogalakwena Formations (cross bedding) and the Vaalwater Formation (cross-bedding, ripple marks, convolute bedding, and lamination).

The undifferentiated Sandriviersberg and Mogalakwena Formations comprise mostly of coarse-grained sandstone, grit, and conglomerate. Groundwater occurs mainly in fault zones, sill/dyke contacts, fracture zones and fractures related to anticlines and bedding planes. Deep drilling (up to 250m) has confirmed that fractures do occur at these depths. Deep drilling can therefore be considered when developing groundwater as a water source. It is, however, difficult to trace these deeply seated fractures using geophysical methods. Diabase dykes and sills are major targets for good supplies and can easily be traced on aerial photographs. Not only is the diabase less resistant to weathering than the surrounding sandstone, generally resulting in the formation of depressions, but also produces a more fertile soil that stimulates a dense vegetation growth along the dykes. These can sometimes be traced for many kilometers. Where sills are weathered and fractured to extended depths below the water level, good supplies can be obtained from them, (See also the chapter on the diabase intrusions).

The section of the unit within the Thabazimbi map sheet covers approximately 9.88% of the total areal extent. The groundwater resource unit occurs on three adjacent map sheets viz. Modimolle, Lephalale and Thabazimbi, (Figure 23). Although not adjacent to the Thabazimbi map sheet, the unit occurs on the Polokwane map sheet where the unit crosses over to the Lephalale and Modimolle map sheet.

The cross-boundary occurrence of the unit within the Modimolle map sheet includes the same Formations (Sandriviersberg and Makgabeng) while the occurrence of the unit on the Lephalale and Polokwane Map sheets consists predominantly of the Mogalakwena Formation. It was therefore decided to use the information from the Modimolle and Thabazimbi map sheets in combination for the characterization of this unit.

In 11.1% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anion of concern is Nitrate.

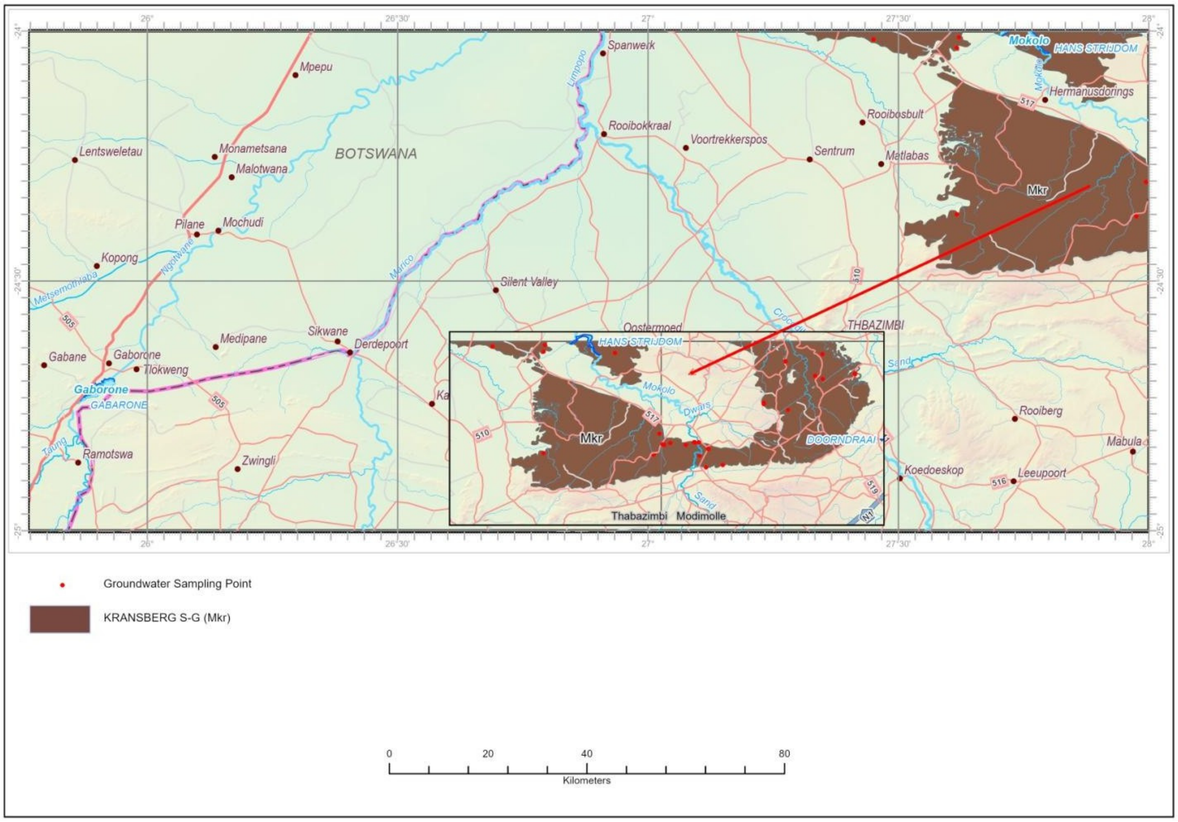


Figure 23: Geographical distribution of the Kransberg Subgroup (Mkr) and the associated groundwater sampling points.

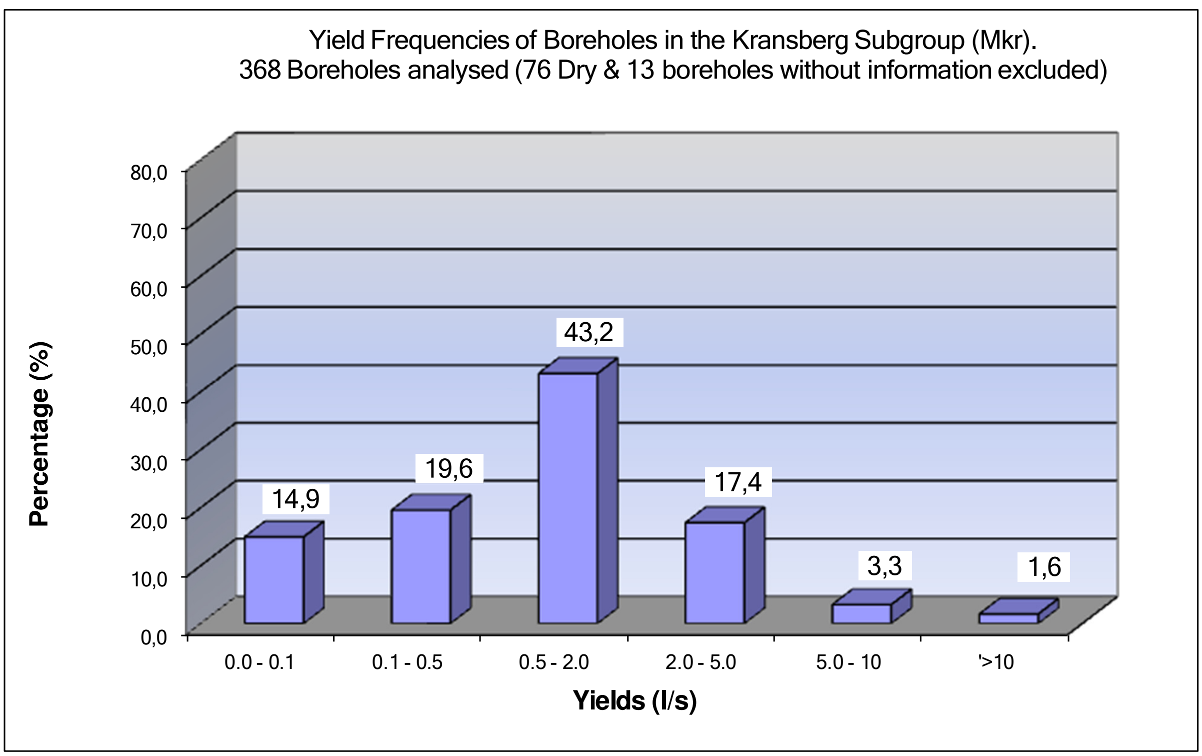


Figure 24: Yield frequency for the fractured aquifers of the Kransberg Subgroup (Mkr).

The data used for the yield frequency diagram is for the cross-boundary occurrence namely the Thabazimbi and Modimolle map sheets. For the yield data 216 data points fall on the Modimolle map sheet and 152 data points on the Thabazimbi map sheet.

The analysis of 368 borehole records indicates that 34.5% of the maximum yields are suitable for small households (>0.001ℓ/s to 0.5ℓ/s). A further 43.2% of the boreholes yield between 0.5ℓ/s and 2ℓ/s, while 17.4% yield between 2ℓ/s and 5ℓ/s. Only 4.9% of the recorded sources report maximum yields exceeding 5 ℓ/s.

The findings correlate with the 78.1% of the boreholes with yields less 2ℓ/s within the Polokwane map sheet and the 82.6% from the Lephalale map sheet for the same groundwater resource unit.

The analysis of 151 borehole records from the Thabazimbi map sheet indicates that the static water level ranges from 3 meters below ground level (mbgl) to 75mbgl, with a median of 18mbgl and an average of 22.23mbgl, (based on 74 data points). The water levels at three boreholes were ignored in the calculation; the water levels not taken in account are 91.4mbgl, 96mbgl and 154mbgl. The reason is that these water levels may have been measured during pumping. The only depth on record is 96m.

The installation depth from 4 records indicates a minimum installation depth of 52.5m, a maximum of 154m and an average depth of installation of 98.5m. The abstraction for the unit is not sufficient for a detailed analysis, only one record is available, and it is reported as 421.6 cubic meters per day (m^3/day).

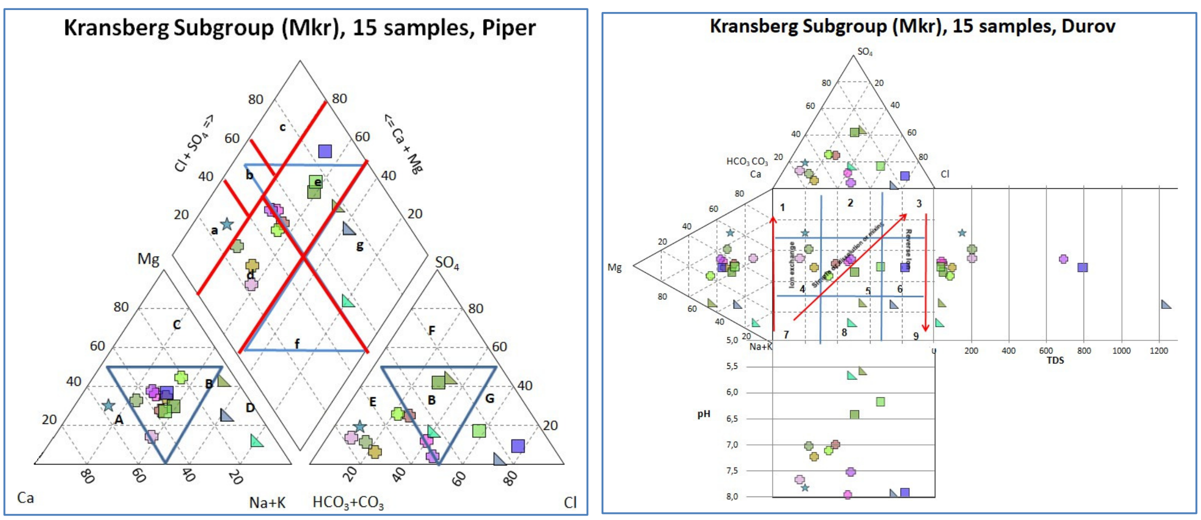


Figure 25: Trilinear diagrams, Piper, and Durov for the Kransberg Subgroup (Mkr).

The data used for the chemical analysis is sourced from the cross-boundary occurrence between the Thabazimbi and Modimolle map sheets. For the chemical dataset, 23 data points fall on the Modimolle map sheet and 6 data points on the Thabazimbi map sheet. The accuracy of the chemical analyses was verified by evaluating the plausibility of the Electrical Conductivity (EC) values and the Electro-Neutrality (E.N.) balance. Only 15 analyses could be used, as 14 analyses were not considered accurate. Although the unit also occurs within the adjacent Lephalale map sheet, the 54 available analyses from that area were not used, as they are more representative of the Mogalakwena Formation.

The trilinear Piper diagram, (Figure 25) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths >

Alkali (73.3%), Weak acidic anions > Strong acidic anions (53.3%); Alkali >Alkali earths (26.7%); Strong acids > Weak acids (46.7%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type (46.7);
- Mixed Calcium-Magnesium-Chloride type (13.3%);
- Sodium-Bicarbonate-Chloride type with prevailing Sulphate (13.3%);
- Calcium-Bicarbonate type (6.7%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with prevailing Sulphate (6.7%);
- Sodium-Chlorite type (6.7%);
- Sodium-Bicarbonate-Chloride type (6.6%),

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- No dominant anion or cation, plots along the dissolution line can be attributed to fresh resent recharge water exhibiting simple dissolution or mixing (46.7%),
- Anion discriminates and Ca or SO_4 dominant, mixed water or water exhibiting simple dissolution (20%),
- Cl dominates anion and Na dominant cation, indicates that the ground water to relate to reverse ion exchange of Na-Cl waters (13.8%),
- Anion discriminates and Na dominant, probable mixing or uncommon dissolution influences (6.7%),
- Cl and Na dominant, is frequently indicative of end-point gradient waters through dissolution (6.7%),
- HCO_3 and Ca dominant, indication of recharge in sandstone (6.7%),
- The high TDS is some of the samples that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 32: Chemical statistics for the Kransberg Subgroup (Mkr).

Element / Parameter	Statistics Drawn from a population of 29 data points for the Kransberg Subgroup (Mkr), 23 data points from the Modimolle map included.									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	29	5,05	8,17	6,85	6,97	5,78	7,07	7,91	0,88	12,6%
Electrical Conductivity (mS/m EC	29	2,20	187,70	6,37	36,33	2,49	10,70	115,68	54,48	150,0%
Total Dissolved Salts (mg/l TDS)	22	18,22	1243,00	47,84	237,77	22,79	62,26	783,60	384,35	161,7%
Calcium (mg/l Ca)	25	0,50	96,00	2,45	18,98	1,09	3,60	59,14	26,74	140,9%
Magnesium (mg/l Mg)	25	0,50	83,00	1,68	14,13	0,63	3,60	56,12	23,73	167,9%
Sodium (mg/l Na)	23	2,24	253,90	5,48	34,77	2,45	6,00	85,02	72,06	207,2%
Potassium (mg/l K)	24	0,39	15,23	0,90	3,08	0,48	1,14	8,17	4,32	140,2%
Chloride (mg/l Cl)	25	2,50	405,00	5,48	53,25	3,05	5,00	184,48	117,17	220,0%
Sulphate (mg/l SO_4)	24	0,50	43,00	2,38	8,79	1,00	4,30	20,34	11,26	128,1%
Total Alkalinity (mg/l) $CaCO_3$)	26	5,60	369,90	17,96	106,72	7,58	41,67	348,10	133,01	124,6%
Nitrate (mg/l N)	27	0,02	32,56	0,16	3,99	0,10	0,70	12,08	9,10	228,1%
Fluoride (mg/l F)	23	0,05	0,67	0,14	0,21	0,07	0,17	0,38	0,15	70,3%
Silicon as Si	24	3,82	43,93	6,95	10,78	4,37	7,96	21,98	9,68	89,7%
Iron (Fe)	6	0,018	0,750	0,029	0,149	0,020	0,025	0,40	0,29	198,6%
Manganese (Mn)	6	0,010	0,050	0,019	0,027	0,012	0,021	0,05	0,02	64,2%
Ortho Phosphate as Phosphorus as PO4	22	0,006	0,800	0,012	0,053	0,007	0,011	0,04	0,17	313,6%
ZAR	23	0,20	5,93	0,52	1,13	0,30	0,55	1,86	1,57	139,3%
LSI	19	Langelier Saturation Index (LSI)			Slightly Scaling		**10,5%**	Highly Scaling		**0,0%**
		Highly corrosive		**47,4%**	Slightly corrosive		**21,1%**	Balanced Corrosion		**21,1%**

The chemical statistics for the Kransberg Subgroup groundwater resource unit was sourced from the combined dataset for the Thabazimbi map sheet (6 data points) and from the Modimolle map sheet (23 data points). No data was used from boreholes that fall within the Lephalale and Polokwane map sheets.

Table 32 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem.

The overall water quality in terms of the Electrical conductivity (EC) is ideal to be good in 93.1% and marginal in 6.9% of the samples (EC < 370mg/l). The values range from 2.2mS/m to 187.7mS/m with 115.68mS/m representing the 90th percentile.

The Total Dissolved Solids (TDS) is acceptable in 90.9% of the samples (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 29 samples show elevated concentrations of Nitrate (N >10mg/l) in 11.1% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be predominantly highly to slightly corrosive 68.5%; slightly scaling (10.5%) and balanced 21.1%. The ZAR index indicates that 91.3% of the water is of a fair quality for irrigation (ZAR < 3).

As the unit is characterized by rugged mountainous terrain that limits the areas available for the cultivation of crops, groundwater is preliminary used for livestock, game watering and domestic purposes. No large irrigation fields occur within the unit.

7.2.1.6 AASVOËLKOP FORMATION (Mas)

The Waterberg Supergroup has been subdivided into three subgroups, namely the Nylstroom, Matlabas, and Kransberg Subgroups. The Aasvoëlkop Formation is the uppermost layer of the Matlabas Subgroup and occurs predominantly in the central-northern to north-western section of the map sheet. Outcrop is limited, as the area is flat and extensively covered with sand and soil.

The Aasvoëlkop Formation consists of a sedimentary sequence of alternating arenaceous (sand-sized particles) and argillaceous (clay-sized particles) units, with the sediment becoming coarser towards the top. The reported thickness of the unit ranges from 500 to 600 meters, (Jansen, 1982).

The section of the unit within the Thabazimbi map sheet covers approximately 6.1% of the total area. The groundwater resource unit extends across the boundary between the Lephalale and Thabazimbi map sheets; the cross-boundary occurrence exhibits the same characteristics. Therefore, information from both the Lephalale and Thabazimbi map sheets was used for the characterization of this unit. See Figure 26 for further details, especially for the inset map representing the cross-boundary occurrence.

Statistical analysis of the maximum yields indicates that 74% of the boreholes yield less than 2ℓ/s. In terms of water quality, in 21.1% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anions of concern are Fluoride followed by Nitrate and Chloride, exceeding the maximum allowable limits in 12.2% and 11.1% of the samples respectively.

In comparison the boreholes located only within the Lephalale map sheet indicates that 69.3% of the boreholes yield less than 2ℓ/s. The water chemistry shows that the anions Fluoride and Chloride exceed the maximum allowable concentration limits in 16% of the analysis.

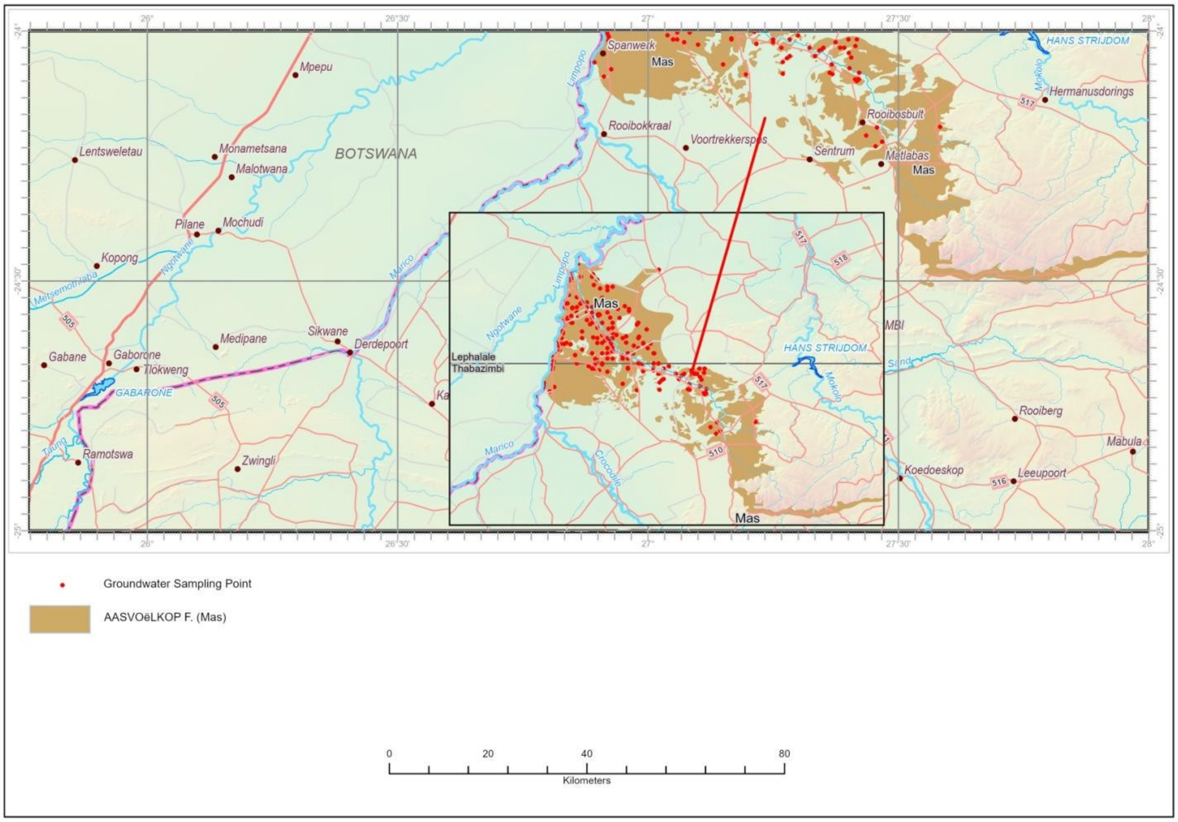


Figure 26: Geographical distribution of the Aasvoëlkop Formation (Mas) and the associated groundwater sampling points.

In general, groundwater occurrence in sedimentary rocks is controlled either by lithology, such as the contact zones between various sediments, or by secondary structures, such as fractures or joints that are locally developed along bedding planes. Geological features, such as faults, diabase dykes, and sill boundaries, can also be targeted in the exploration for groundwater. For more details on diabase intrusions, the reader can refer to the section on the diabase intrusive unit.

Within the Thabazimbi map sheet, numerous diabase sills are depicted on the geological map. This contrasts with the occurrence in the Lephalale map sheet, where diabase mainly appears in the form of scattered dykes, except for some sills south of the Matlabas River.

For the Lephalale map sheet, regional remote sensing interpretation from the DWS GRIP project (Department of Water and Sanitation Groundwater Resource Information Project) indicates that lineaments (predominantly diabase dykes), within the Mogalakwena Formation are more numerous than those within the Aasvoëlkop Formation, (Figure 7). The remote sensing interpretation was however hampered by extensive soil coverage over most of the map area, especially over the Ellisras Basin and areas underlain by rocks of the Aasvoëlkop Formation. The Mogalakwena Formation, however, forms a plateau with less soil coverage, making the lineaments more distinctly identifiable.

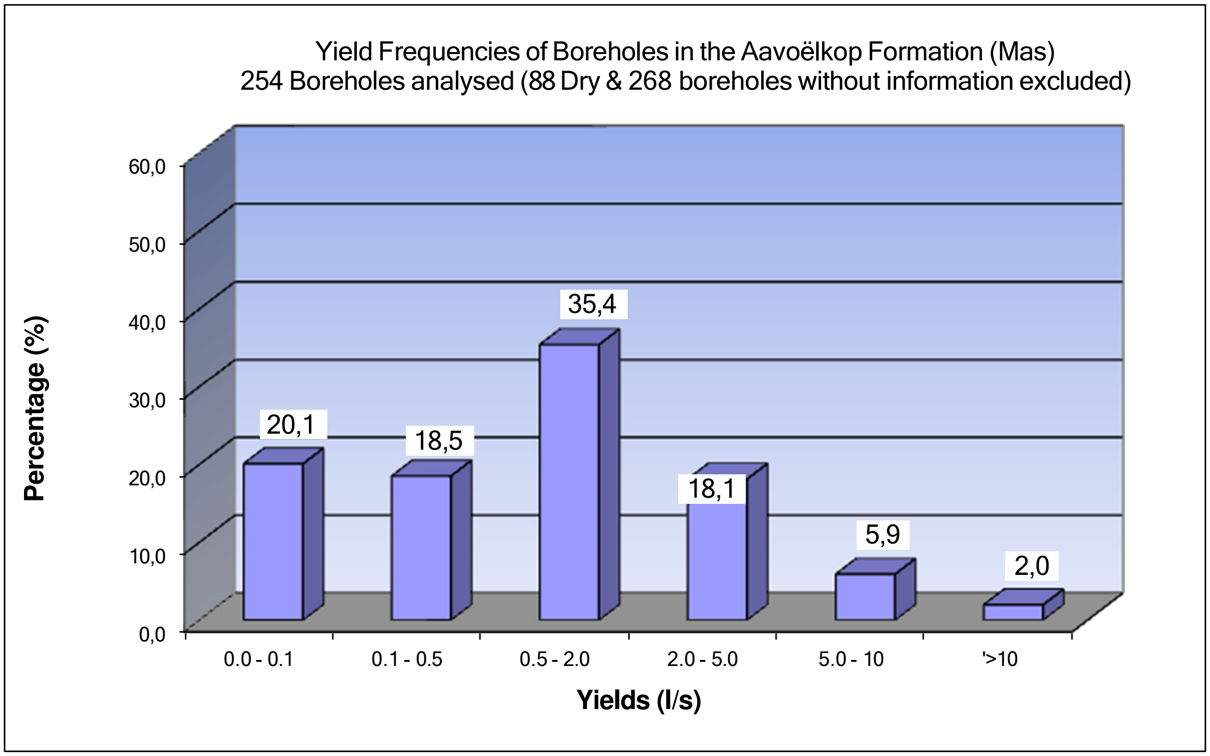


Figure 27: Yield frequency for the fractured aquifers of the Aasvoëlkop Formation (Mas).

The groundwater resource unit occurs on two adjacent maps, as it is connected the information from both sheets (Lephalale and Thabazimbi) were used. For the yield data 75 data points fall on the Lephalale map sheet and 179 data points on the Thabazimbi map sheet.

The statistical analysis of the maximum yields of 254 boreholes indicates that 48.6% of the boreholes are suitable to supply small households (>0.001ℓ/s to 0.5ℓ/s). A further 35.4% of boreholes yield between 0.5ℓ/s and 2ℓ/s, while 18.1% of the boreholes yield between 2ℓ/s and 5ℓ/s. Only 7.9% of the recorded sources report maximum yields exceeding 5ℓ/s, (Figure 27). The higher yielding boreholes tend to plot near diabase dykes and sill contacts.

The analysis of 179 borehole records from the Thabazimbi map sheet indicates that the static water level ranges from 5 meters below ground level (mbgl) to 84.12mbgl, with a median of 26.02mbgl and an average static water level of 28.22mbgl, (based on 121 data points). The reported water level for 2 data points was not used, the records indicated water levels of 108mbgl and 130mbl. These water levels were ignored as they may have been measured during pumping. Only a single record was available for borehole depth, it is 22.32m. The maximum installation depth recorded is 130m, with an average of 119m and a median depth of 108m, (2 data points). There is no pump testing data available for this unit.

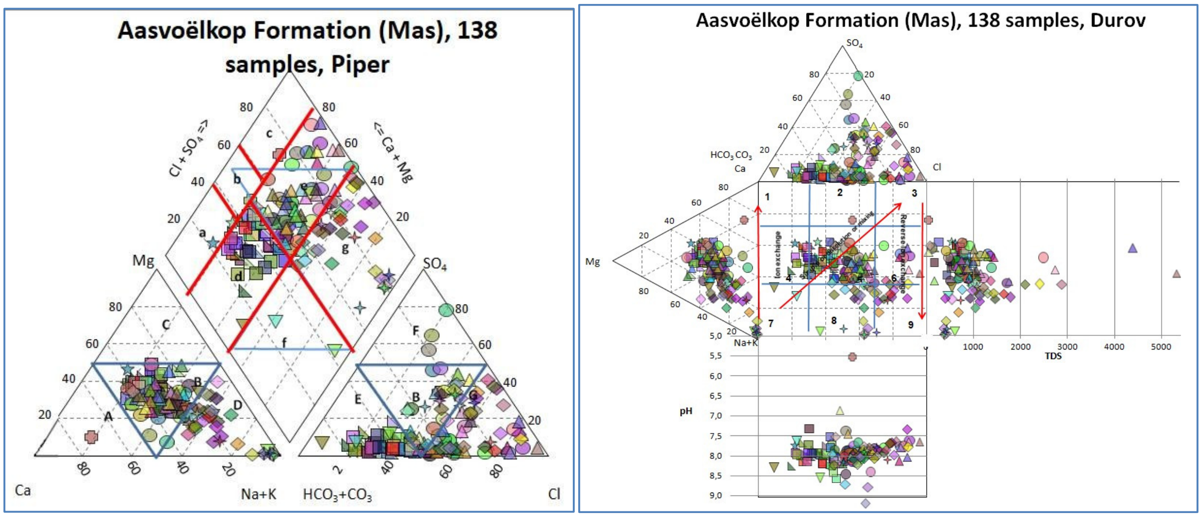


Figure 28: Trilinear diagrams, Piper, and Durov for the Aasvoëlkop Formation (Mas).

The groundwater resource unit occurs on the boundary between two map sheets namely, Lephalale and Thabazimbi. In total 127 data points had chemical analysis that falls within the Lephalale map sheet and 57 on the Thabazimbi map sheet. The accuracy of the chemical analysis was checked by the plausibility of the Electrical Conductivity (EC) and Electro Neutrality (E.N). Only 138 analyses could be used as 47 analyses were not considered accurate.

The trilinear Piper diagram, (Figure 28) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (71.5%), Weak acidic anions > Strong acidic anions (33.2%); Alkali >Alkali earths (28.5%); Strong acids > Weak acids (66.8%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type (29.2%);
- Sodium-Chloride type (26.3%);
- Mixed Calcium-Magnesium-Chloride type (25.5%);
- Mixed Calcium-Magnesium-Bicarbonate with prevailing Chloride and Sulphate type (10.2%);
- Mixed Calcium-Magnesium-Chloride (3%);
- Sodium-Bicarbonate type (2.2%).
- Mixed Calcium-Magnesium-Sulphate with prevailing Sodium type (2.2%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride with prevailing Sodium type (0.7%);
- Calcium-Bicarbonate type with prevailing Chloride and Sulphate (0.7%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- No dominant anion or cation, plots along the dissolution line can be attributed to fresh resent recharge water exhibiting simple dissolution or mixing (59.5%),
- Cl dominant anion and Na dominant cation reverse ion exchange of Na-Cl waters (10.9%),
- Anion discriminates and Ca dominant, mixed water or water exhibiting simple dissolution may be indicated (9.4%),
- Anion discriminates and Na dominant, probable mixing, or uncommon dissolution influences (9.4%),
- Cl and Na dominant, is frequently indicative of end-point gradient waters through Dissolution (8.7%),

- Cl and Na dominant, reverse ion exchange of Na-Cl waters (1.4%),
- Water type is dominated by Ca and HCO_3 ions, Na is significant, an important ion exchange is presumed (0.7%),
  - The high TDS in some of the samples may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 33: Chemical statistics for the Aasvoëlkop Formation (Mas).

Element / Parameter	Statistics Drawn from a population of 186 data points for the Aasvoëlkop Formation (Mas), 129 chemical analyses from the adjacent Lephalale map sheet are included.									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	185	4,55	9,20	7,57	7,60	7,28	7,61	7,97	0,46	6,0%
Electrical Conductivity (mS/m EC	186	1,10	1215,00	57,89	179,93	68,15	132,31	331,55	165,99	92,3%
Total Dissolved Salts (mg/l TDS)	180	22,0	6031,0	529,7	1103,6	453,5	913,8	1934,7	797,4	72,3%
Calcium (mg/l Ca)	180	1,40	726,00	31,47	99,15	16,45	76,50	189,99	94,87	95,7%
Magnesium (mg/l Mg)	179	0,50	465,20	8,48	57,86	8,98	48,60	96,46	55,33	95,6%
Sodium (mg/l Na)	180	1,00	1045,30	39,12	159,06	50,15	122,91	308,61	146,31	92,0%
Potassium (mg/l K)	180	0,66	29,00	4,19	6,80	2,16	5,33	12,75	5,25	77,2%
Chloride (mg/l Cl)	180	1,50	3425,20	56,81	273,23	40,66	133,95	624,80	416,27	152,4%
Sulphate (mg/l SO_4)	180	2,00	1320,40	16,13	100,80	6,78	26,70	246,50	185,01	183,5%
Total Alkalinity (mg/l) $CaCO_3$)	175	2,0	560,0	103,7	284,7	93,6	294,4	441,5	125,5	44,1%
Nitrate (mg/l N)	181	0,02	142,47	0,33	9,33	0,14	4,23	24,10	16,61	177,9%
Fluoride (mg/l F)	180	0,05	17,00	0,60	1,75	0,35	0,83	3,25	3,21	183,4%
Silicon as Si	172	0,60	73,68	17,38	32,12	12,36	35,01	45,47	12,61	39,3%
Iron (Fe)	11	0,0001	2,2380	0,0010	0,3484	0,0025	0,0250	1,2900	0,73	210,3%
Manganese (Mn)	11	0,0025	0,4600	0,0062	0,0789	0,0025	0,0250	0,1600	0,14	174,8%
Ortho Phosphate as Phosphorus as PO4	169	0,003	0,347	0,012	0,019	0,007	0,014	0,027	0,03	150,8%
ZAR	180	0,11	18,73	1,76	3,70	1,12	2,58	7,45	3,39	91,7%
LSI	174	Langelier Saturation Index (LSI)			Slightly Scaling		**40,8%**	Highly Scaling		**0,0%**
		Highly corrosive		**1,7%**	Slightly corrosive		**10,3%**	Balanced Corrosion		**47,1%**

The groundwater resource unit occurs as a cross-boundary unit and the adjacent map sheet namely Lephalale. The chemical data used for the characterization includes the 57 data points that fall within the Thabazimbi map sheet and 129 on the Lephalale map sheet.

Table 33 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication on the extent of the problem. The overall water quality in terms of the Electrical conductivity (EC) is ideal to good (58.6%), marginal in 32.8% and unacceptable in 8.6% of the samples. The values range from 1.1mS/m to 1215mS/m with 331.55mS/m representing the 90th percentile.

The Total Dissolved Solids (TDS) is acceptable in 70% of the samples (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 186 samples show elevated concentrations of Fluoride (F >1.5mg/l) in 21.1%; Nitrate (N >10mg/l) in 12.2%; Chloride (Cl > 600mg/l) in 11.1%; Sodium (Na > 400mg/l) in 5%; Sulphate (SO4 >600mg/l) in 3.9%; Calcium (Ca > 300) in 3.3%; and Magnesium (Mg > 200mg/l) in 2.8%;of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be slightly too highly corrosive (12%), slightly scaling (40.8%) and predominantly balanced 47.1%. The ZAR index indicates that 55.6% of the water is of a fair quality for irrigation (ZAR < 3).

Groundwater is mainly abstracted for game, livestock watering and domestic purposes. Irrigation fields do occur on the unit but are limited and seem to be dry lands. The only centre pivots occur within the southern section of the unit along the Matlabas River. It is known that the alluvial deposits along the Matlabas do not relate to high yields due to the fine-grained nature of the alluvial deposits. It is not known if groundwater contributes to irrigation or if it is predominantly surface water use.

7.2.1.7 SCHILPADKOP FORMATION (Msc)

The Schilpadkop Formation, which comprises sandstone, grit, conglomerate, and boulder conglomerate with fine-grained sandstone at the top, forms the bottom layer of the Nylstroom Subgroup. The Schilpadkop and locally the Makgabeng Formation form the base of the succession in the younger, larger, but shallower basin (Council for Geoscience). Within the Thabazimbi map sheet it outcrops in two areas with the largest occurring as a narrow rim between the Aasvoëlkop and Alma Formations south of the Waterberg Mountains. This occurrence extends eastwards into the Modimolle map sheet area; the cross-boundary occurrence relates to the same characteristics. It was therefore decided to use the information from the Modimolle and Thabazimbi map sheets for the characterization of this unit. See Figure 29 for more details as well as the inset map showing the cross-boundary occurrence.

The section of the unit within the Thabazimbi map sheet covers approximately 1.8% of the total areal extent.

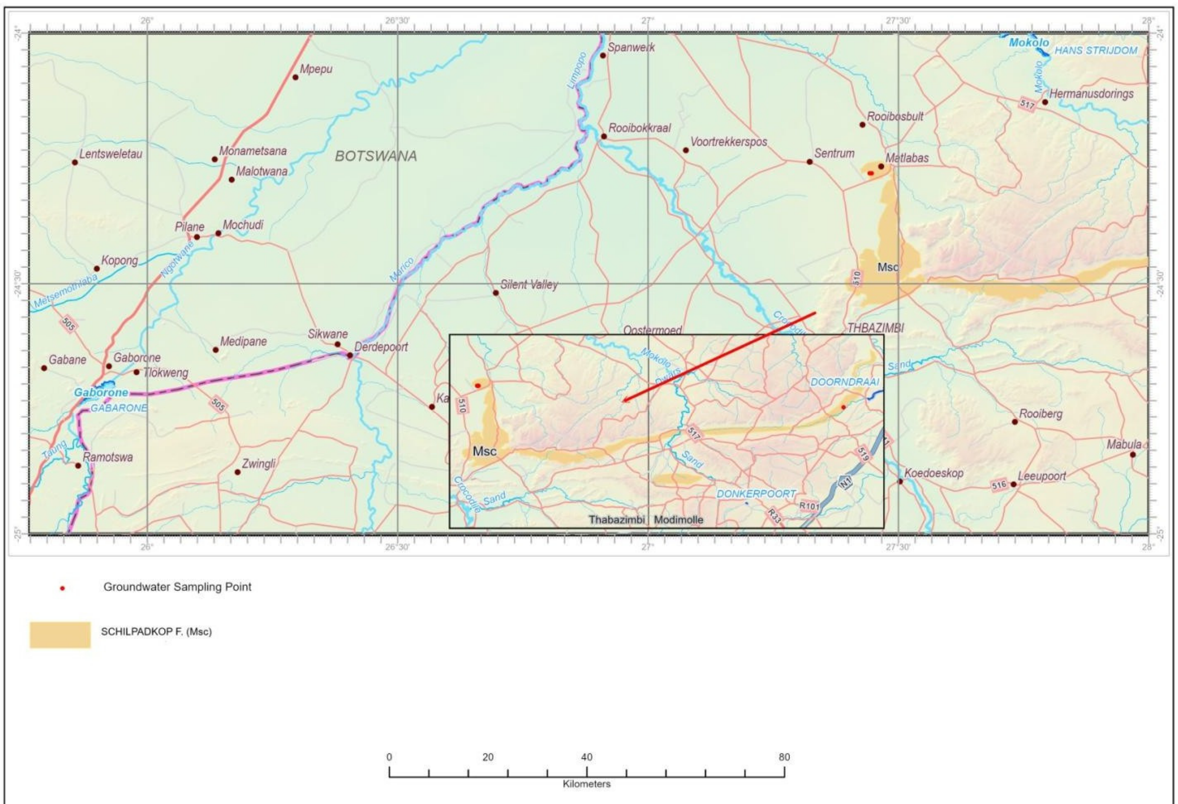


Figure 29: Geographical distribution of the Schilpadkop Formation (Msc) and the associated groundwater sampling points.

Groundwater is found in fault zones, sill/dyke contacts, fracture zones and fractures related to anticlines and bedding planes. Deep drilling (up to 250m) has indicated that fractures do occur at these depths and is thus a target for good water supply. It is, however, difficult to trace these deeply seated fractures using geophysical methods. Diabase dykes and sills are major targets for good supplies and can easily be traced on aerial photographs. The reader can refer to the section on the diabase intrusive unit for more detail.

The permeability and storage capacity of the Schilpadkop Formation are generally low. Yields tend to diminish quickly during periods of drought.

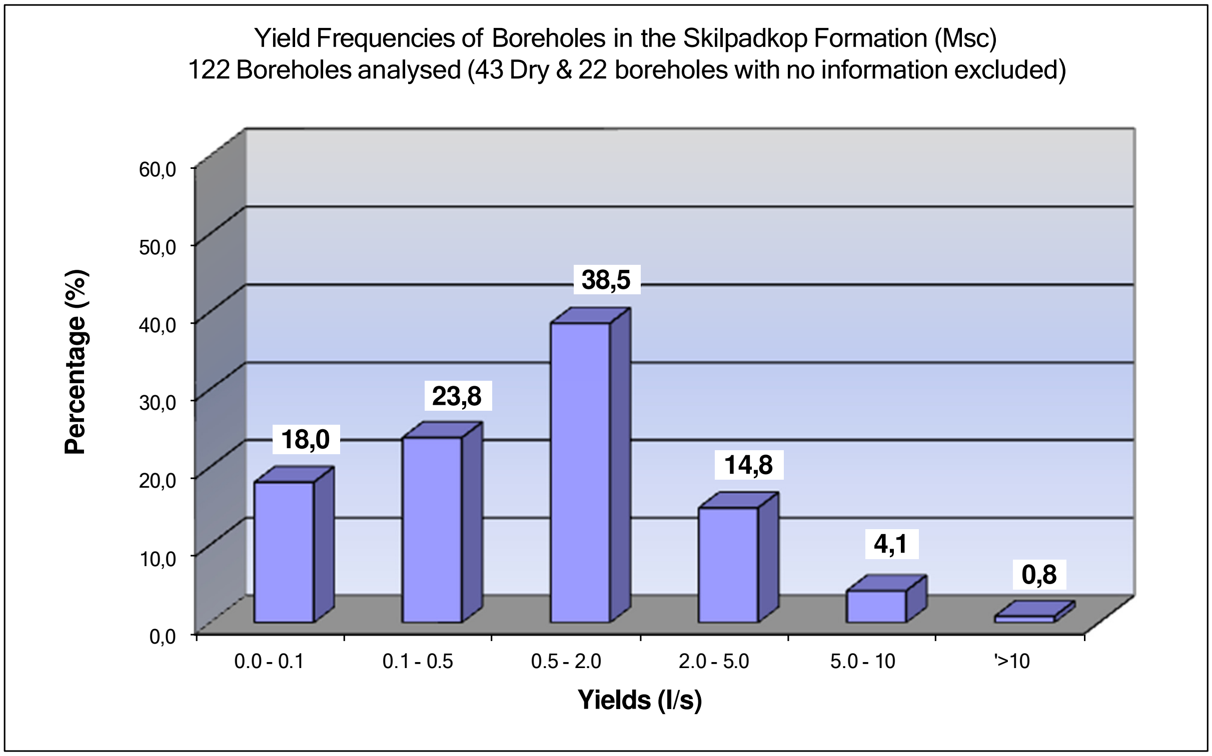


Figure 30: Yield frequency for the fractured aquifers of the Schilpadkop Formation (Msc).

The groundwater resource unit occurs on two adjacent maps, as it is connected the information from both sheets were used, (Modimolle and Thabazimbi). For the yield data 58 data points fall on the Modimolle map sheet and 64 data points on the Thabazimbi map sheet.

The statistical analysis of the maximum yields of 122 borehole records indicates that 41.8% of the successful boreholes are suitable to supply small households (>0.001ℓ/s to 0.5ℓ/s). A further 38.5% of boreholes yield between 0.5ℓ/s and 2ℓ/s, while 14.8% yield between 2ℓ/s and 5ℓ/s. Only 4.9% of the recorded sources report maximum yields exceeding 5 ℓ/s, (Figure 39),

The analysis of 179 borehole records from the Thabazimbi map sheet indicates that the static water level ranges from 8.8 meters below ground level (mbgl) to 41.22mbgl, with a median of 36mbgl and an average static water level of 29.77mbgl, (based on 7 data points). The maximum depth recorded is 111.7m, with an average depth of 103.9m and a median depth of 110m (3 data points). The maximum installation depth is 75m and the minimum is 60m, (2 data points).

The maximum recommended daily abstraction on record is 4.3 cubic meters per day (m^3/day) and an average of 3.8m^3/day. The total number of boreholes subjected to pump testing within this groundwater resource unit on record is only 2.

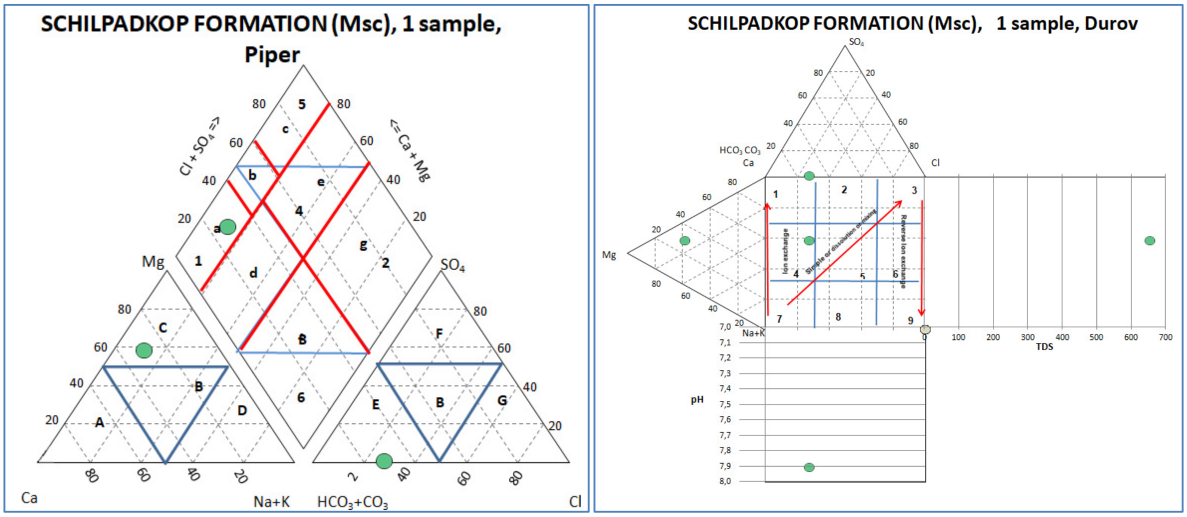


Figure 31: Trilinear diagrams, Piper and Durov for the Schilpadkop Formation (Msc).

The trilinear Piper diagram, (Figure 31) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions in order to classify the major hydrochemical facies. The first evaluation on dominance is as follows: Alkali earths > Alkali (100%), Weak acidic anions > Strong acidic anions (100%); Alkali >Alkali earths (0%); Strong acids > Weak acids (0%).

The water type identified based on minimal data is a Magnesium-Bicarbonate type. Magnesium dominant groundwater is not common especially in alkali earth's dominant water. For the sample the Ca/Mg ratio is 0.5:1. The Calcium to Magnesium ratio in most water bodies is 4:1 to 2:1 for TDS values less than 500mg/l. With increasing TDS the Magnesium ratio increases.

Table 34: Chemical statistics for the Schilpadkop Formation (Msc).

Element / Parameter	Statistics Drawn from a population of only 1 data point for the Schilpadkop Formation (Msc)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10^{th} percentile	50^{th} percentile (median)	90^{th} percentile	Standard Deviation	Coefficient of Variation
pH	1	7,90	7,90	7,90	7,90	7,90	7,90	7,90		
Electrical Conductivity (mS/m EC)	1	85,60	85,60	85,60	85,60	85,60	85,60	85,60		
Total Dissolved Salts (mg/l TDS)	0	0,00	0,00							
Calcium (mg/l Ca)	1	62,00	62,00	62,00	62,00	62,00	62,00	62,00		
Magnesium (mg/l Mg)	1	74,00	74,00	74,00	74,00	74,00	74,00	74,00		
Sodium (mg/l Na)	1	30,00	30,00	30,00	30,00	30,00	30,00	30,00		
Potassium (mg/l K)	0	0,00	0,00							
Chloride (mg/l Cl)	1	57,00	57,00	57,00	57,00	57,00	57,00	57,00		
Sulphate (mg/l SO_4)	1	2,00	2,00	2,00	2,00	2,00	2,00	2,00		
Total Alkalinity (mg/l) $CaCO_3$)	1	425,70	425,70	425,70	425,70	425,70	425,70	425,70		
Nitrate (mg/l N)	1	5,65	5,65	5,65	5,65	5,65	5,65	5,65		
Fluoride (mg/l F)	1	0,05	0,05	0,05	0,05	0,05	0,05	0,05		
Silicon as Si	0	0,00	0,00							
Iron (Fe)	0	0,00	0,00							
Manganese (Mn)	0	0,00	0,00							
Ortho Phosphate as Phosphorus as PO4	0	0,00	0,00							
ZAR	1	0,61	0,61	0,61	0,61	0,61	0,61	0,61		
LSI	0	Langelier Saturation Index (LSI)			Slightly Scaling			Highly Scaling		
		Highly corrosive			Slightly corrosive			Balanced Corrosion		

The groundwater resource unit extends into the adjacent Modimolle map sheet. The single data point with a chemical analysis falls within the outcrop that occurs within the Modimolle map sheet boundary.

Table 34 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Only one chemical analysis was available for the unit. The electric conductivity (EC) value is 85.6mS/m (ideal) and the concentration of Magnesium is 74mg/l, thus falling in the marginal range.

Groundwater is abstracted for game, livestock watering, rural domestic purposes. No irrigation fields were observed within this unit, (based on Google imagery evaluation).

7.2.1.8 ALMA FORMATION (Mag)

Of the two overlapping sedimentary basins, beds of the Swaershoek, Alma and Sterkrivier Formations were laid down in the Alma trough which is the deeper basin. The oldest Sub-Division (Nylstroom) of which the lower portion consists of the Swaershoek Formation is of late-Bushveld age and confined to proto basins of which the largest coincides approximately with the Nylstroom syncline (Council for Geosciences). The Alma Formation forms the outer rim around the Waterberg Mountains and occurs from Thabazimbi eastwards into the Modimolle map sheet area to approximately 35km west of Mokopane. The cross-boundary occurrence relates to the same characteristics. It was therefore decided to use the information from the Modimolle and Thabazimbi map sheets for the characterization of this unit. See Figure 17 for more details and the inset map for the cross-boundary occurrence.

The section of the unit within the Thabazimbi map sheet covers approximately 2.5% of the total areal extent. The Alma Formation consists of a succession of medium-to coarse-grained arkoses (sandstone with at least 25% feldspatic minerals), lithic arkoses (feldspatic sandstone with 10-25% rock fragments), feldpathic arenites (sand-sized particles 0.06mm to 2mm in diameter), sub arkoses, litharenites (sandstone with >25% lithic fragments), subordinate conglomerate and mudrock (mainly siltstone). A maximum thickness of 3000 was recorded around Alma and it decrease in thickness in all directions from that point, (Callaghan, 1987). The Formation is poorly exposed and mostly only the conglomerate beds are seen.

The Alma Formation has been intruded extensively by sills and dykes of predominantly diabasic composition. These diabase intrusions (N-Za) especially when targeting the contact zones between the diabase and the sedimentary rock, play a major role in the occurrence of groundwater. Groundwater is found in fault zones, fracture zones and fractures related to anticlines and bedding planes. Deep drilling (up to 250m) has indicated that fractures do occur at these depths and is thus a target for good supplies. It is, however, difficult to trace these deeply seated fractures using geophysical methods. As mentioned above diabase dykes and sills are major targets for good supplies and can easily be traced on aerial photographs. For more information on the diabase the reader can refer to the section on the diabase intrusive unit.

The permeability and storage capacity of the Alma Formation are generally low with 73.9% of the boreholes yielding less than 2ℓ/s, (Figure 33). Yields tend to diminish quickly during periods of drought especially if the main source is deep seated fractures.

In terms of water quality, in 13% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anion of concern is Fluoride.

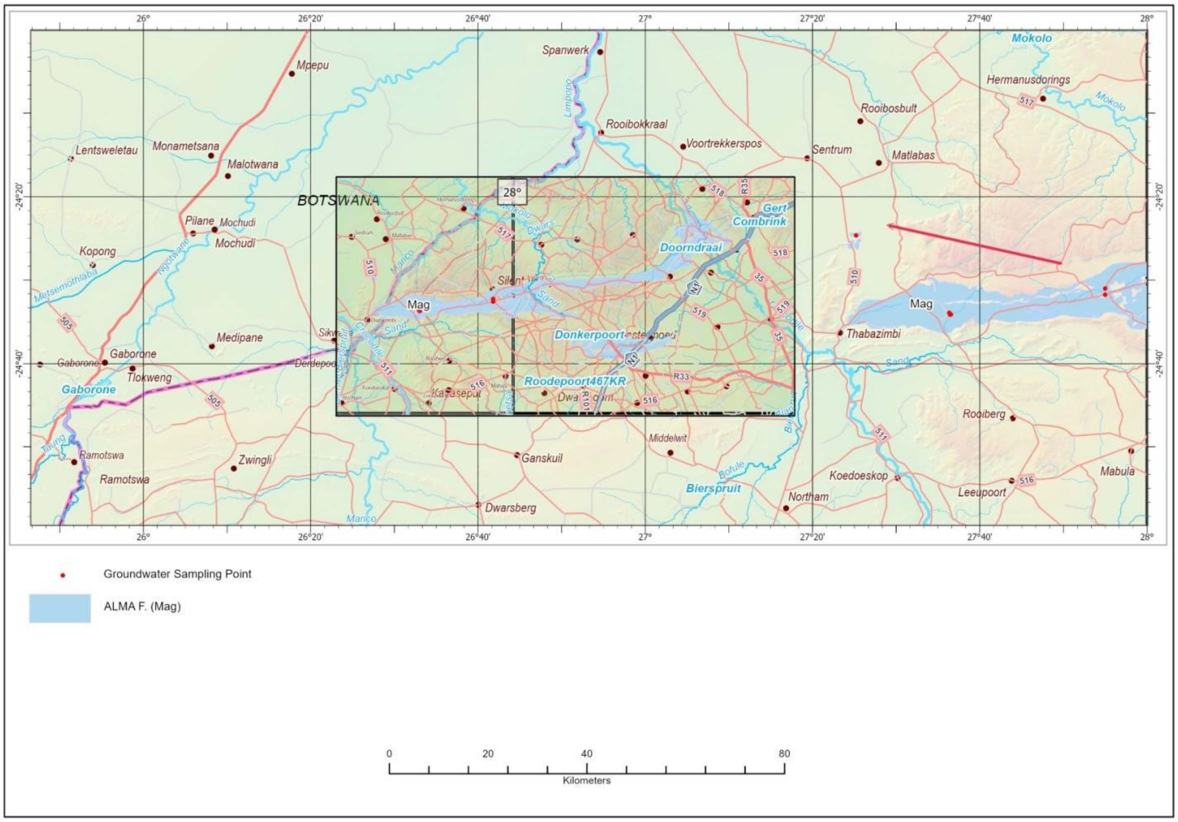


Figure 32: Geographical distribution of the Alma Formation (Mag) and the associated groundwater sampling points.

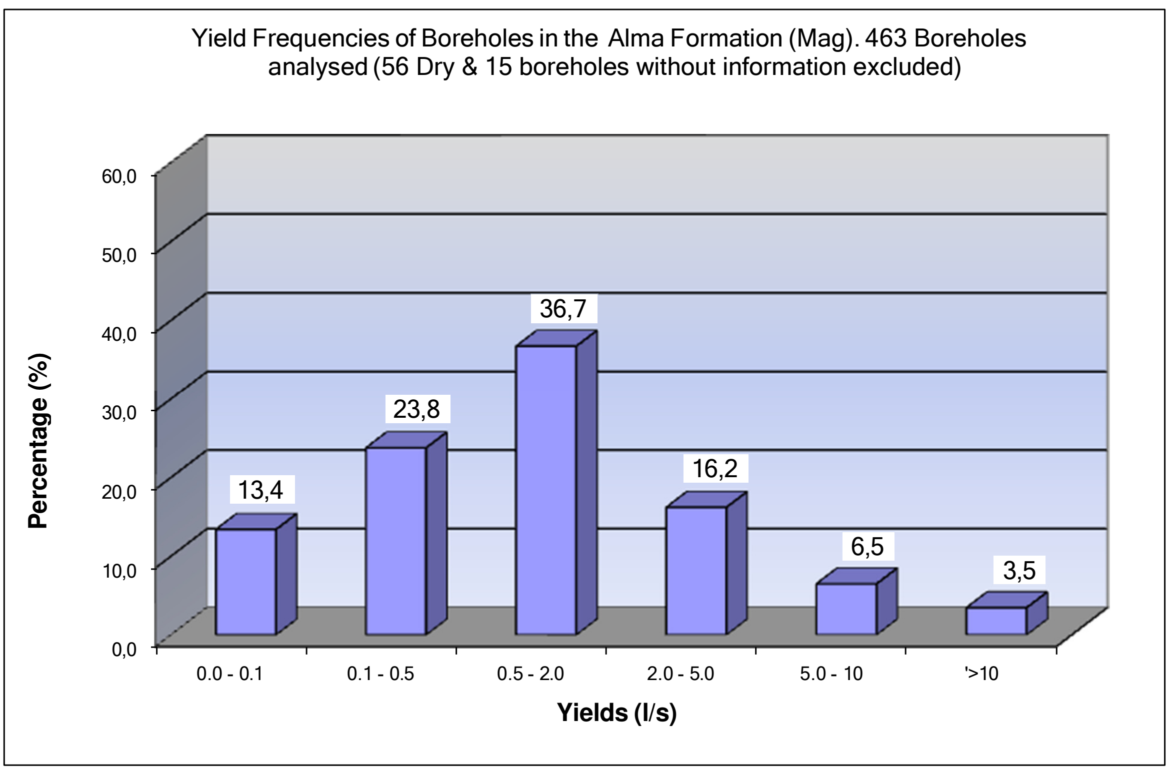


Figure 33: Yield frequency for the fractured aquifers of the Alma Formation (Mag).

The groundwater resource unit occurs on two adjacent maps, as it is connected the information from both sheets were used, (Modimolle and Thabazimbi). For the yield data 356 data points falls on the Modimolle map sheet and 107 data points on the Thabazimbi map sheet.

The statistical analysis of the maximum yields of 463 borehole records indicates that 37.2% of the successful boreholes are suitable to supply small households (>0.001ℓ/s to 0.5ℓ/s). A further 36.7% of boreholes yield between 0.5ℓ/s and 2ℓ/s, while 16.2% yield between 2ℓ/s and 5ℓ/s. Only 10% recorded sources report maximum yields exceeding 5ℓ/s, (Figure 39).

The analysis of 179 borehole records from the Thabazimbi map sheet indicates that the static water level ranges from 24.1 meters below ground level (mbgl) to 84.8mbgl, with a median of 54.45mbgl and an average static water level of 54.45mbgl, (based on 2 data points). A single record is available on borehole depth, installation depth and abstraction; the reported depth on record is 64.7m; the installation depth is 40m and the recommended abstraction is 23m³/day.

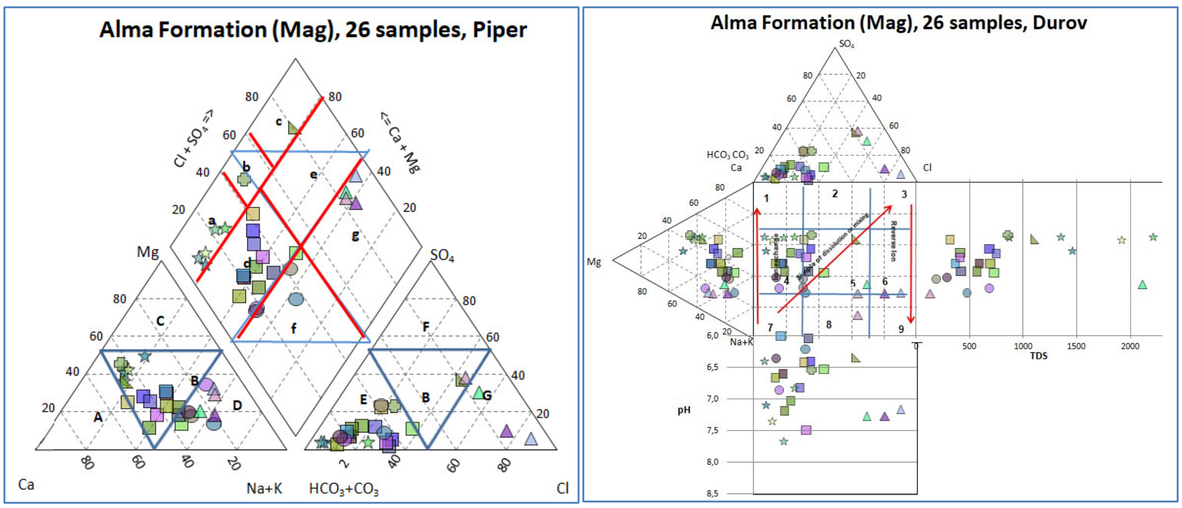


Figure 34: Trilinear diagrams, Piper and Durov for the Alma Formation (Mag).

The groundwater resource unit occurs on the boundary between two map sheets namely Modimolle and Thabazimbi. In total 40 data points had chemical analysis that falls within the Modimolle map sheet and 6 on the Thabazimbi map sheet. The accuracy of the chemical analysis was checked by the plausibility of the Electrical Conductivity (EC) and Electro Neutrality (E.N). Only 26 analyses could be used as 20 analyses were not considered accurate.

The trilinear Piper diagram, (Figure 34) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (69.2%), Weak acidic anions > Strong acidic anions (78.8%); Alkali >Alkali earths (30.8%); Strong acids > Weak acids (21.2%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type with prevailing Sodium (42.3%);
- Mixed Calcium-Magnesium-Bicarbonate type (19.2%);
- Sodium-Bicarbonate type (15.4%);
- Sodium-Chloride type (11.5%);
- Sodium-Chloride type with prevailing Sulphate (3.9%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with prevailing Sulphate (3.9%);
- Mixed Calcium-Magnesium-Chloride type with prevailing Bicarbonate and Sulphate (3.8%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (46.2%),
- No dominant anion or cation can be attributed to fresh recent recharge water exhibiting simple dissolution or mixing (38.5%), points plot along the dissolution or mixing line,
- Cl dominant anion and Na dominant cation, indicate that the water is related to reverse ion exchange of Na-Cl waters (7.7%),
- Cl dominant anion and Na dominant cation that is indicating end-point gradient water through dissolution (7.6%),
- The high TDS within two of the samples may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 35: Chemical statistics for the Alma Formation (Mag).

Element / Parameter	Statistics Drawn from a population of 47 data points for the Alma Formation (Mag), 40 data points from the adjacent Modimolle map sheet included									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	47	4,67	9,00	7,34	7,41	6,93	7,39	8,02	0,65	8,7%
Electrical Conductivity (mS/m EC)	47	6,4	351,0	28,4	61,0	14,6	39,2	117,3	65,7	107,7%
Total Dissolved Salts (mg/l TDS)	45	43,0	2335,0	188,7	386,2	101,3	251,8	739,8	404,0	104,6%
Calcium (mg/l Ca)	39	1,60	146,30	14,00	40,10	9,65	29,30	93,89	34,43	85,9%
Magnesium (mg/l Mg)	39	0,11	157,00	2,72	25,77	3,38	11,00	60,67	32,25	125,1%
Sodium (mg/l Na)	46	4,60	536,30	19,41	50,32	9,18	25,97	79,17	87,85	174,6%
Potassium (mg/l K)	38	0,49	19,16	1,34	2,60	0,79	1,30	4,43	3,50	134,8%
Chloride (mg/l Cl)	47	2,97	837,50	9,98	62,04	4,76	13,00	73,45	163,22	263,1%
Sulphate (mg/l SO_4)	47	0,78	153,90	4,78	18,83	2,00	7,20	39,69	32,00	169,9%
Total Alkalinity (mg/l) $CaCO_3$)	36	8,80	461,90	72,23	181,37	38,90	132,35	400,15	141,57	78,1%
Nitrate (mg/l N)	45	0,02	28,03	0,12	2,00	0,04	0,42	3,43	5,43	270,8%
Fluoride (mg/l F)	46	0,05	6,80	0,22	0,73	0,10	0,31	1,65	1,10	150,5%
Silicon as Si	35	1,95	33,70	9,80	16,07	5,09	14,43	28,86	9,00	56,0%
Iron (Fe)	22	0,003	1,480	0,012	0,086	0,010	0,012	0,050	0,31	361,1%
Manganese (Mn)	23	0,003	28,500	0,014	1,296	0,010	0,014	0,235	5,93	457,8%
Ortho Phosphate as Phosphorus as PO4	31	0,007	5,000	0,027	0,350	0,011	0,038	0,800	0,93	267,1%
ZAR	39	0,36	10,55	0,94	1,79	0,55	0,97	3,19	2,14	119,6%
LSI	34	Langelier Saturation Index (LSI)			Slightly Scaling		11,8%	Highly Scaling		0,0%
		Highly corrosive		8,8%	Slightly corrosive		38,2%	Balanced Corrosion		41,2%

The groundwater resource unit occurs on an adjacent map boundary namely, Thabazimbi and Modimolle. The chemical data used for the chemical statistics includes 6 data points that fall within the Thabazimbi map sheet and 41 analyses falling on the Modimolle map sheet.

Table 35 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality in terms of the Electrical conductivity (EC) is ideal to be good (93.6%) to marginal (6.4%) with values ranging between 6.4 and 351mS/m.

The Total Dissolved Solids (TDS) is acceptable in 95.6% of the samples (TDS ≤ 1200mg/l). The evaluation of the major cations and anions from 47 samples shows elevated concentrations of Fluoride (F >1.5mg/l) in 13%; Nitrate (N >10mg/l) in 4.4%; Chloride (Cl > 600mg/l) in 4.3% and Sodium (Na > 400mg/l) in 2.2% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be slightly too highly corrosive (47%); slightly scaling (11.8%) and 41.2% balanced. The ZAR index indicates that 87.2% of the water is of a fair quality for irrigation (ZAR < 3).

The water is abstracted for livestock, game watering and domestic purposes. The only irrigation fields utilizing centre pivots for irrigation are within the eastern section of the unit near Rankin's Pass. The irrigation is along Grootspruit and it is not known if conjunctive surface and groundwater is used for irrigation. Thabazimbi is partly underlain by rocks of the Alma Formation, Malmani Subgroup as well as rocks of the Undifferentiated Pretoria Group. Thabazimbi obtain 4000m³/day from groundwater and 7000m³/day from Magalies water that is pumped from Vaalkop Dam, (IDP, 2024-2025).

7.2.1.9 SWAERSHOEK FORMATION (Ms)

The oldest sub-division (Nylstroom) of which the lower portion consists of the Swaershoek Formation is of late-Bushveld age and confined to proto basins of which the largest coincides approximately with the Nylstroom syncline (Council of Geosciences). On the Thabazimbi map sheet outcrop are confined between the upper Alma Formation and the lower Schrikkloof Formation (The latter is part of the Rooiberg Group). It occurs in a thin zone from approximately 25km east of Thabazimbi eastwards into the Modimolle map sheet area where it occupies a large area around Modimolle town. The cross-boundary occurrence relates to the same characteristics. It was therefore decided to use the information from the Modimolle and Thabazimbi map sheets for the characterization of this unit. See Figure 35 for more detail and the inset map showing the cross-boundary occurrence. The section of the unit within the Thabazimbi map sheet covers approximately 0.01% of the total areal extent thereof.

Literature indicates that the Swaershoek Sandstone Formation has been informally divided into an upper and lower part. The lower part has a much smaller areal extent; it includes a quarts porphyry and has no Bushveld Granite clasts; the upper portion has a thick trachytic lava at its base and contains several other trachytic lava flows (Jansen. 1982). In the Modimolle area the lower part of the unit overlays rocks of the Rooiberg Group and Bushveld Granites conformable (Du Plessis 1972a) while in the south-western part of the basin (Thabazimbi section) the upper part of the Swaershoek Formation unconformably overlies Rooiberg Group rhyolite and where the rhyolite has been eroded away prior to deposition, it unconformably overlies Bushveld Granite (Meinster, 1975).

The Swaershoek Formation is distinguished from the overlaying Alma Formation by the presence of lava flows and by its generally non-arkosic composition as well as a higher degree of deformation in places. Most of the minor faults intersecting the unit do not continue into the Alma Formation, (Meinster, 1971). The unit is lenticular on a regional scale, showing a rapid thickness variation from 2500m in the central portion of the basin to a few hundred meters or less at the present-day edges of the basin, (De Vries, 1970).

The Swaershoek Formation has been intruded extensively by sills and dykes of predominantly diabasic composition. These diabase intrusions (N-Za) play a major role especially along dyke/sill contacts, in the occurrence of groundwater. If dykes and sills are ignored, the groundwater potential of the unit is generally low with 73% of yields <2ℓ/s, (Figure 36).

Groundwater also occurs in fault zones, fracture zones and fractures related to anticlines and bedding planes. Deep drilling in similar geological settings (up to 250m) has indicated that fractures do occur at these depths and is thus a target for good supplies. It is, however, difficult to trace these deeply seated fractures using geophysical methods. Diabase dykes and sills are major targets for good supplies and can easily be traced on aerial photographs, (See also the chapter on the Diabase Intrusive groundwater resource unit for more detail, chapter 7.2.3.5). The permeability and storage capacity of the Swaershoek Formation are generally low. The yield frequency diagram provides a reasonable indication of expected conditions.

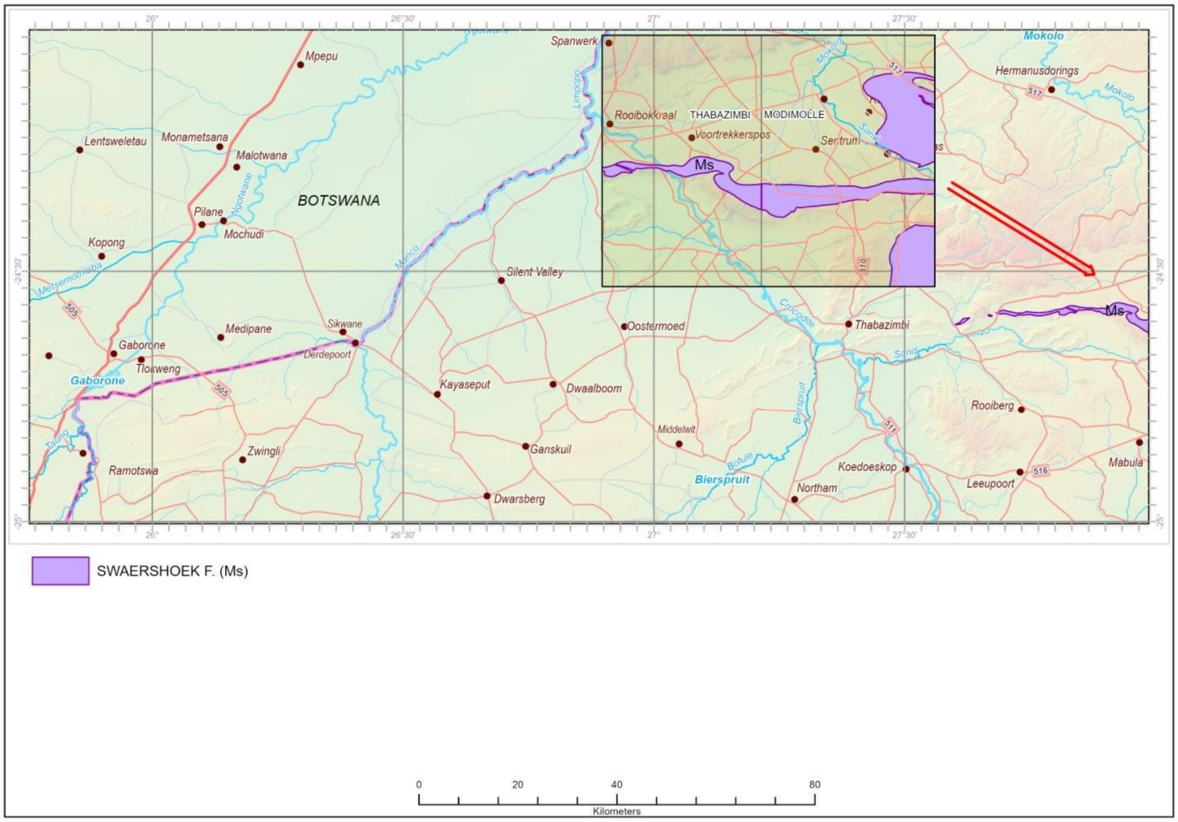


Figure 35: Geographical distribution of the Swaershoek Formation (Ms) and the associated groundwater sampling points.

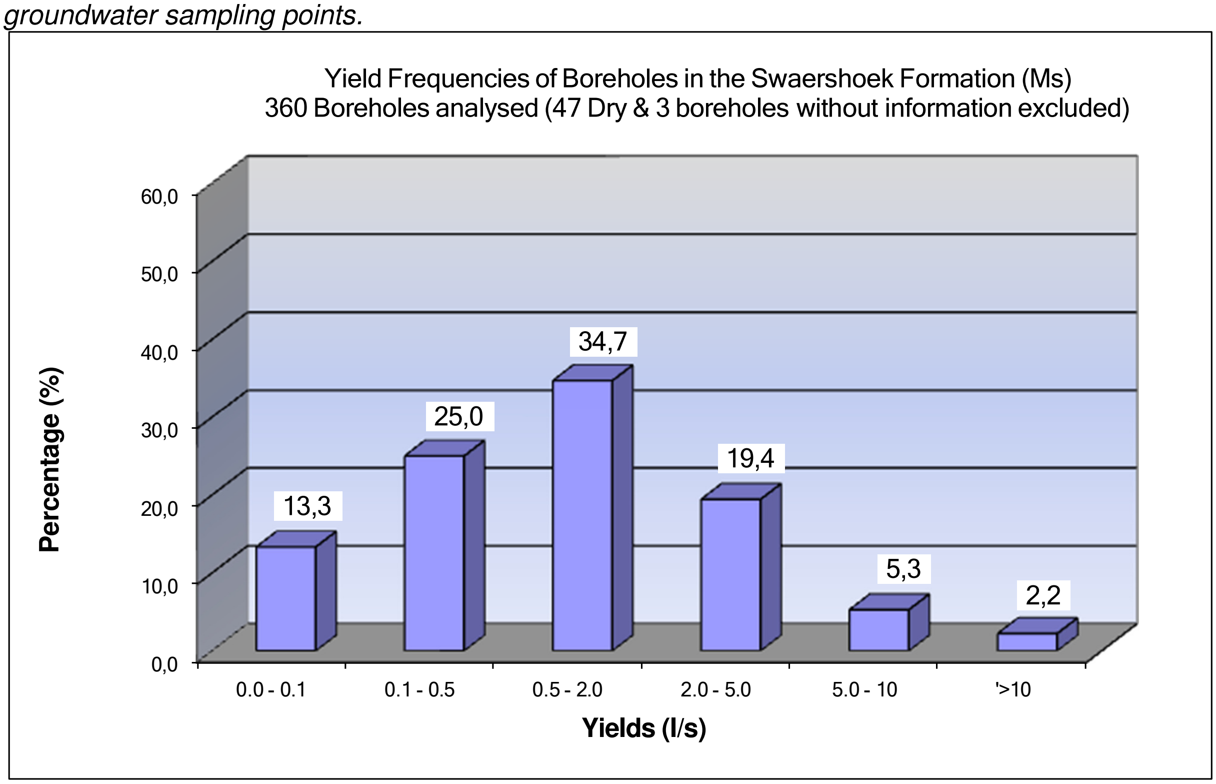


Figure 36: Yield frequency for fractured aquifers of the Swaershoek Formation (Ms).

The groundwater resource unit occurs on two adjacent maps, as it is connected the information from both sheets were used, (Modimolle and Thabazimbi). For the yield data 360 data points falls on the Modimolle map sheet and no data points falls on the Thabazimbi map sheet. Figure 36 represents a plot of maximum yields available for interpretation in the unit.

The statistical analysis of the maximum yields of 360 borehole records indicates that 38.3% of the successful boreholes are suitable to supply water to small households (>0.001ℓ/s to 0.5ℓ/s). A further 34.7% of boreholes yield between 0.5ℓ/s and 2ℓ/s, while 19.4% yield between 2ℓ/s and 5ℓ/s. Only 7.5% of the recorded sources report maximum yields exceeding 5ℓ/s.

From the data points located on the Modimolle map sheet the static water level ranges from 0.8 meters below ground level (mbgl) to 65mbgl, with a median of 18.28mbgl and an average static water level of 17.83mbgl. The maximum depth recorded is 162.2m, with an average of 86.9m and a median depth of 88m. The maximum installation depth is 85m which can be indicative of water strike depths. The maximum recommended daily abstraction on record is 229 cubic meters per day (m³/day) and the average is 51.5m³/day. The total number of boreholes subjected to pump tested within this groundwater resource unit on record is 14.

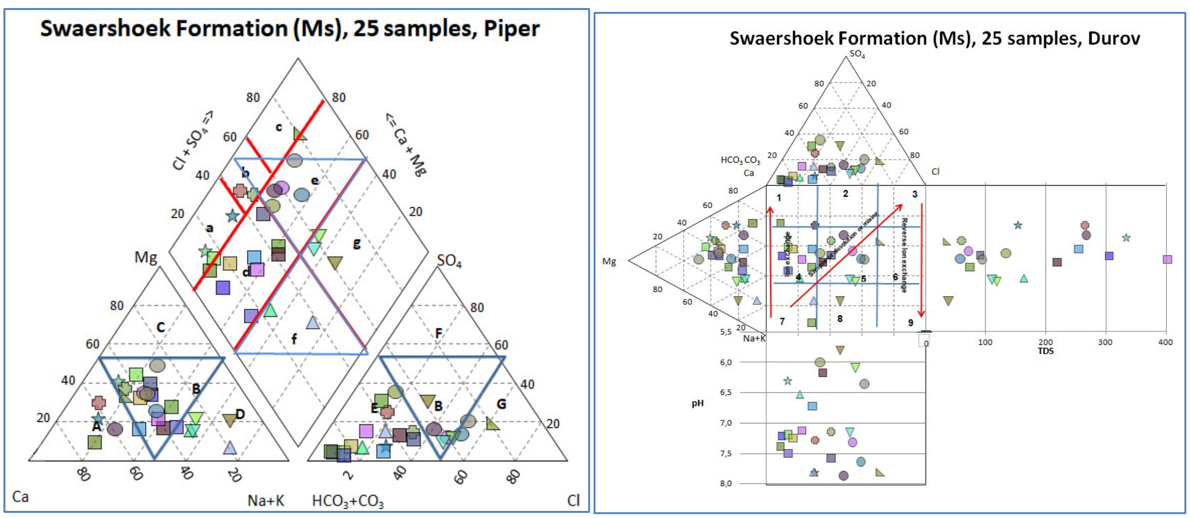


Figure 37: Trilinear diagrams, Piper and Durov for the Swaershoek Formation (Ms).

The groundwater resource unit occurs on the boundary between two map sheets namely Modimolle and Thabazimbi. In total 52 data points had chemical analysis that falls within the Modimolle map sheet and 2 on the Thabazimbi map sheet. The accuracy of the chemical analysis was checked by the plausibility of the Electrical Conductivity (EC) and Electro Neutrality (E.N). Only 25 analyses could be used, and 29 analyses were not considered accurate.

The trilinear Piper diagram, (Figure 37) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions in order to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (80%), Weak acidic anions > Strong acidic anions (60%); Alkali >Alkali earths (20%); Strong acids > Weak acids (40%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type (40%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type (28%);
- Sodium-Chloride type (12%);
- Sodium-Bicarbonate type (8%);
- Calcium-Bicarbonate type (8%);
- Mixed Calcium-Magnesium-Chloride type (4%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (40%),
- Anion discriminates and Ca dominant can be attributed to fresh recent recharged water exhibiting simple dissolution or mixing (36%), points plot along dissolution or mixing line,
- HCO_3 and Ca dominant indicates recharge in sandstone aquifer (12%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (8%),
- SO_4 dominant or anion discriminate, and Na dominant indicate probable mixing or uncommon dissolution influences (4%).

Table 36: Chemical statistics for the Swaershoek Formation (Ms).

Element / Parameter	**Statistics Drawn from a population of 54 data points for the Swaershoek Formation (Ms), only 2 samples from the Thabazimbi map area and the rest from the Modimolle map area**									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	54	1,00	8,20	6,31	6,99	6,02	7,33	7,92	1,12	16,1%
Electrical Conductivity (mS/m EC)	54	2,0	209,5	8,0	26,5	3,2	12,1	42,7	41,6	156,8%
Total Dissolved Salts (mg/l TDS)	46	12,0	1304,0	51,6	189,5	20,2	71,9	370,5	279,4	147,5%
Calcium (mg/l Ca)	44	0,50	177,70	4,12	23,54	2,32	12,17	43,60	38,37	163,0%
Magnesium (mg/l Mg)	44	0,50	134,50	2,53	10,01	1,11	3,29	22,43	21,33	213,0%
Sodium (mg/l Na)	44	1,00	135,70	4,33	17,31	2,49	7,05	35,62	26,07	150,6%
Potassium (mg/l K)	43	0,15	15,67	0,85	2,98	0,42	0,92	6,08	3,96	133,1%
Chloride (mg/l Cl)	53	1,00	441,90	4,19	34,70	1,56	5,67	77,52	88,67	255,5%
Sulphate (mg/l SO_4)	53	0,30	144,00	1,49	8,60	0,52	2,00	16,00	21,90	254,7%
Total Alkalinity (mg/l) $CaCO_3$)	43	2,00	230,90	15,46	66,25	5,32	49,80	153,14	63,29	95,5%
Nitrate (mg/l N)	49	0,02	64,10	0,17	4,35	0,06	0,60	13,84	10,74	246,8%
Fluoride (mg/l F)	53	0,05	9,60	0,14	0,83	0,05	0,18	1,24	1,97	236,2%
Silicon as Si	39	0,05	50,00	0,60	11,74	4,13	6,68	21,63	11,21	95,5%
Iron (Fe)	18	0,006	0,290	0,022	0,060	0,007	0,050	0,110	0,07	117,3%
Manganese (Mn)	15	0,017	0,510	0,056	0,116	0,050	0,050	0,310	0,15	126,8%
Ortho Phosphate as Phosphorus as PO4	37	0,005	1,100	0,017	0,248	0,006	0,024	0,800	0,36	146,9%
ZAR	44	0,12	3,96	0,40	0,72	0,20	0,60	1,29	0,69	95,4%
LSI	33	Langelier Saturation Index (LSI)			Slightly Scaling		**3,0%**	Highly Scaling		**0,0%**
		Highly corrosive		**48,5%**	Slightly corrosive		**27,3%**	Balanced Corrosion		**21,2%**

The groundwater resource unit occurs on an adjacent map boundary namely Modimolle. The chemical data used for the characterization includes 2 data points that fall within the Thabazimbi map sheet and 54 analyses falling on the Modimolle map sheet.

Table 36 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem.

In terms of the electric conductivity (EC), the overall water quality is good to marginal with values between 2 and 209.5mS/m. The Total Dissolved Solids (TDS) is acceptable in 97.8% of the samples (TDS ≤ 1200mg/l).

The evaluation of the major cations and anions in 54 samples indicates elevated concentrations of Fluoride (F >1.5mg/l) in 9.4% and Nitrate (N >10mg/l) in 4.3% of the analysis. The pH value exceeds the maximum allowable limit in one sample; it is acidic.

The Langelier Saturation Index (LSI) indicates that the water is corrosive (75.8%) to balance (21.2%) to slightly scaling in 3% of the analysis. The ZAR index indicates that 97.7% of the water is of a fair quality for irrigation (ZAR < 3).

Groundwater is abstracted for game, livestock watering and farmsteads. In 9.4% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anion of concern is Fluoride.

7.2.1.10 UNDIFFERENTIATED PRETORIA GROUP (Vpg)

The undifferentiated Pretoria Group groundwater resource unit occurs in the southern section of the map sheet in 4 areas namely, the first is in the south-west near the Limpopo River; the second occurrence is in the central-southern section of the map and east of a major north-south striking strike-slip fault trending east to north-east. This section of the groundwater unit continues east to a north-eastern direction up to Thabazimbi. The other scattered occurrences are around Thabazimbi. The unit consists of rocks of the Pretoria Group of the Transvaal Supergroup. Most of the rocks of the unit are covered by black and red soil. The underlying rocks are predominantly part of the Daspoort Formation, although rocks or remnants of the upper formations namely, Silverton and Magaliesberg as well as the lower formations namely Strubenkop, Dwaalheuwel and Timeball Hill Formations may form part of the unit. The unit covers approximately 5.3% of the total map area, (Figure 38).

The rocks listed for this unit are comprised of Andesitic lava, subordinate pyroclastic rocks, minor quartzite, banded iron stone, shale and conglomerate. The mineral iron was extensively mined in the past near Thabazimbi.

The deposition of the Pretoria Group (Transvaal Supergroup) on South Africa's Kaapvaal Craton marks a radical change in environment during the Palaeoproterozoic (Eriksson et al., 2006). The underlying Chunniespoort Group formed in a shallow inland sea (Epicontinental Sea), that resulted in the deposition of chemical sediments consisting of calcium carbonate that are formed by cyanobacteria. After a period of uplift (Eriksson et al., 2001), the chemical carbonate and banded iron stone sedimentation ended, a clastic epicontinental sea formed on the craton, into which sediments from various sources were deposited. Deposition of clastic sediment was accompanied by the extrusion of significant thicknesses of volcanic deposits.

Groundwater targets will include various fault zones, excessive intrusive of diabase and sills into the unit, fracture zones, joints and geological contacts. The yield analysis indicates that 79.1% of the maximum yields reported for the unit, is less than 2ℓ/s.

The topography related to the unit includes east-westerly and north-easterly trending mountain ranges and flat country. Around Thabazimbi borehole logs indicate difficult drilling conditions due to deep colluviums deposits (thicknesses up to 29m was reported). In terms of water quality, in 6.7% of the water samples at least one element exceeds the maximum allowed limit for domestic use. For this unit the anion of concern is Fluoride.

Plate 1: Washed colluvium, fine-grained matrix removed, predominantly consisting of fragments of lava and quartzite, the underlying grey to brown (weathered) and black formation (fresh) in the samples on the right is shale. Photo taken at Thabazimbi hospital, May 2013.

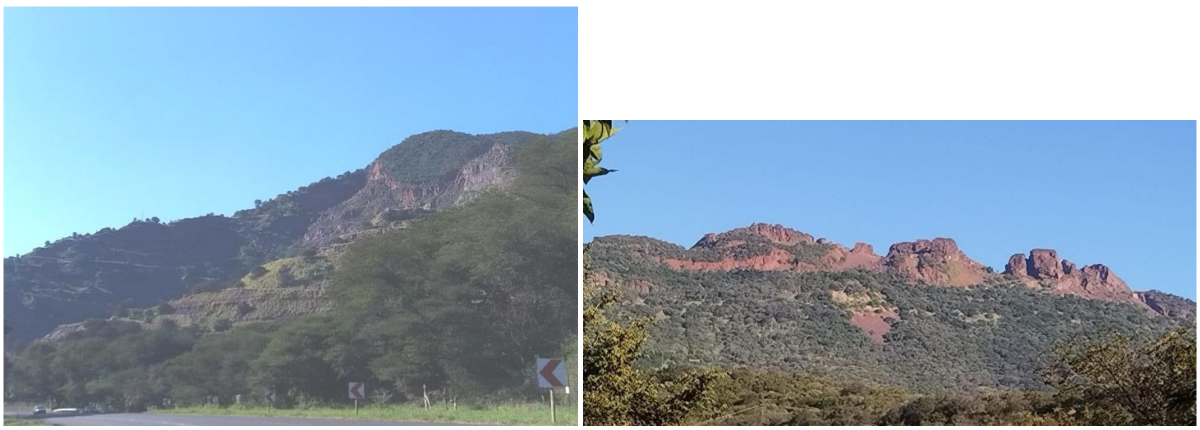


Plate 2: Old iron ore mine workings along the slopes of the mountains surrounding Thabazimbi. Photos taken at Thabazimbi, May 2025.

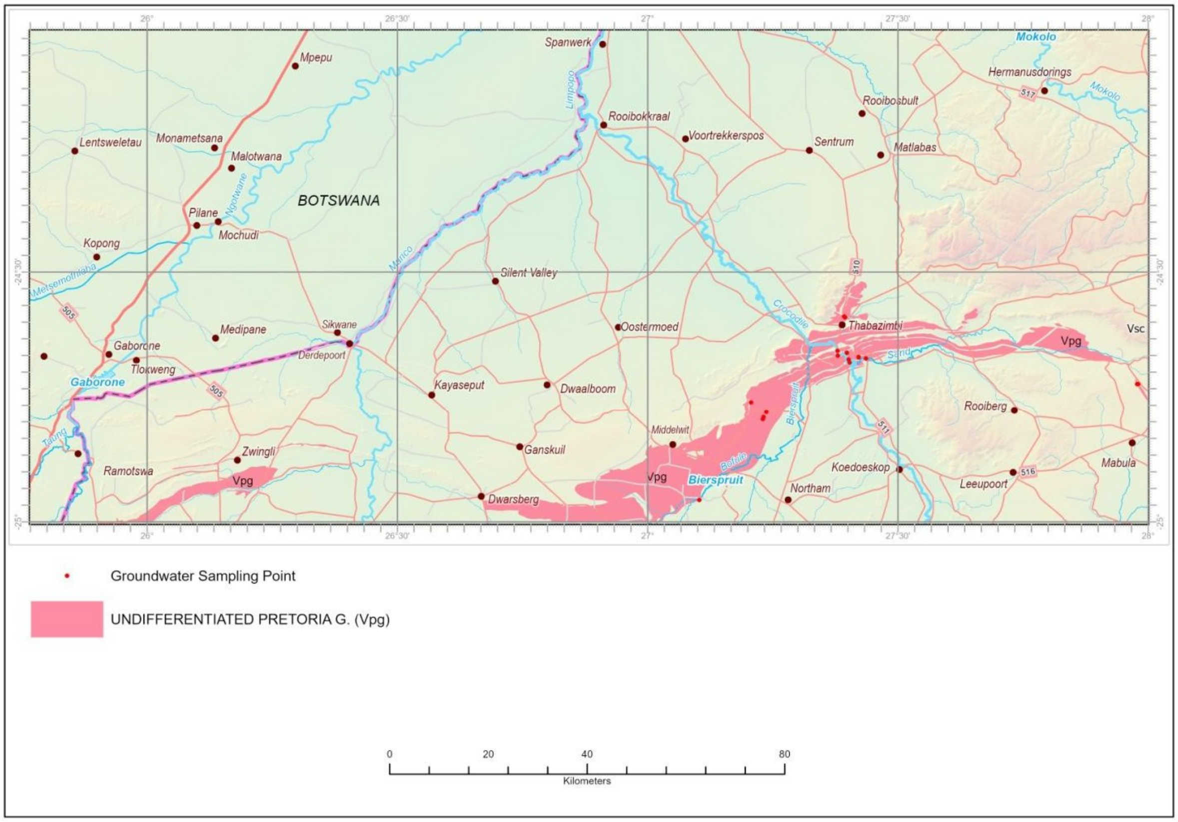


Figure 38: Geographical distribution of the Undifferentiated Pretoria Group (Vpg) and the associated groundwater sampling points.

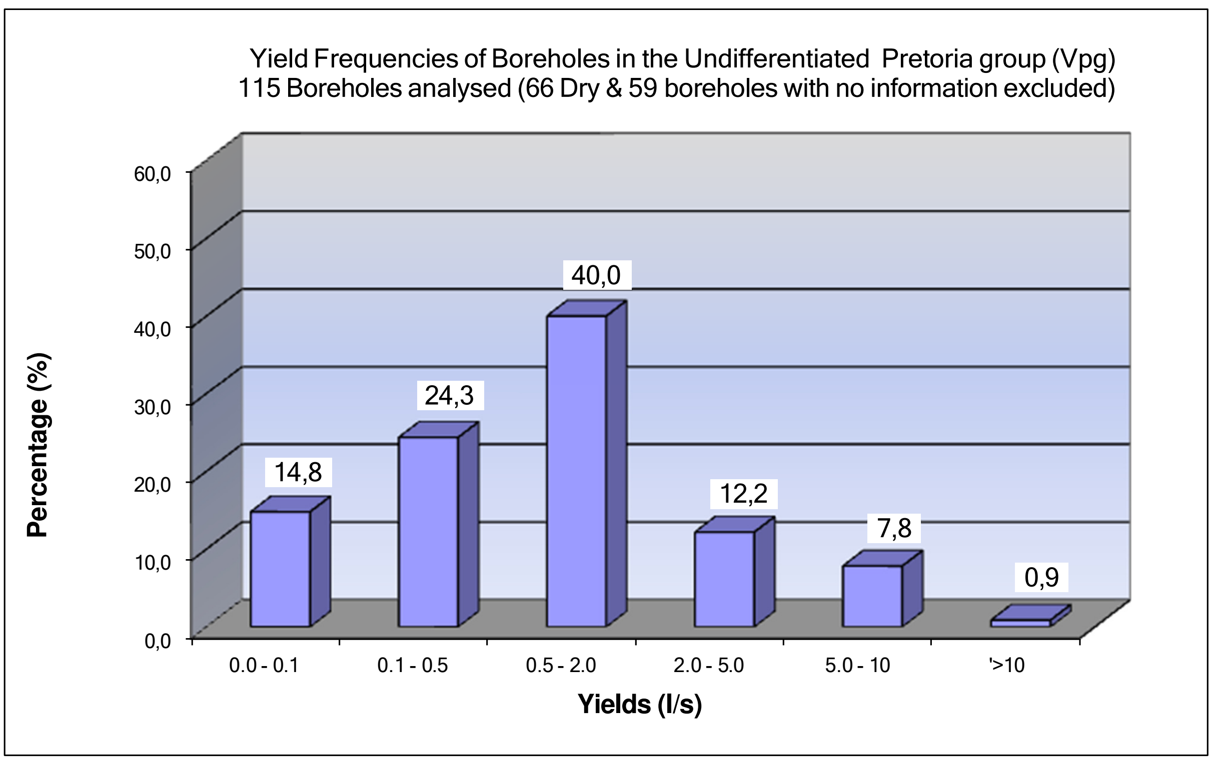


Figure 39: Yield frequency for the fractured aquifers of the Undifferentiated Pretoria Group (Vpg).

The statistical analysis of the maximum yields of 115 borehole records indicates that 40% of the boreholes yield between 0.5ℓ/s and 2ℓ/s, while 39.1% of the boreholes yield less than 0.5ℓ/s and 20.9% of the boreholes are yielding more than 2ℓ/s, (Figure 39).

The static water level ranges from 11.55 meters below ground level (mbgl) to 45.84mbgl, with a median of 18.56mbgl and an average static water level of 23.01mbgl, (based on 8 data points). The maximum depth recorded is 200m, with an average depth of 89.6m and a median depth of 81.3m, (8 data points). The average installation depth is 47.2m and the maximum is 80m, (5 data points). On record only 4 boreholes were subjected to pump testing, the maximum abstraction is 216 cubic meters per day (m^3/day) and an average daily abstraction volume of 97m^3/day.

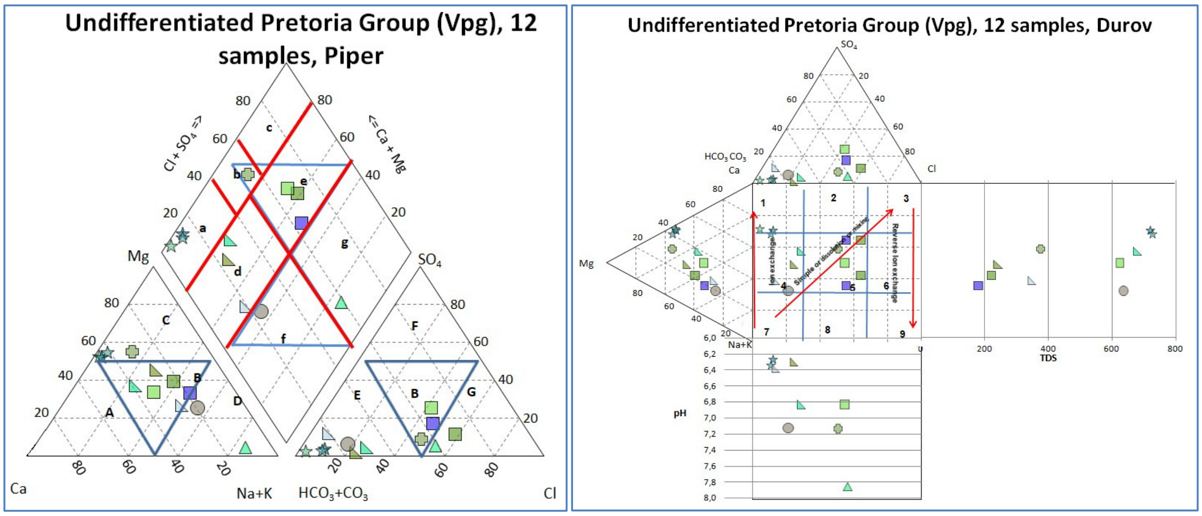


Figure 40: Trilinear diagrams, Piper, and Durov for the Undifferentiated Pretoria Group (Vpg).

The trilinear Piper diagram, (Figure 40) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (83.3%), Weak acidic anions > Strong acidic anions (62.5%); Alkali >Alkali earths (16.7%); Strong acids > Weak acids (37.5%).

The second evaluation was on the water type:

- Magnesium-Bicarbonate type (25%)
- Mixed Calcium-Magnesium-Bicarbonate Chloride type (25%).
- Mixed Calcium-Magnesium-Bicarbonate type (25%).
- Magnesium-Bicarbonate-Chloride type (8.4%)
- Sodium-Chloride type (8.3%);
- Sodium-Bicarbonate type (8.3%);

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (50%),
- HCO_3 and Ca dominant, frequently indicates recharging water in sandstone (25%),
- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (25%),

Table 37: Chemical statistics for the Undifferentiated Pretoria Group (Vpg).

Element / Parameter	Statistics Drawn from a population of 23 data points for the Undifferentiated Pretoria Group (Vpg)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	21	6,36	8,42	7,24	7,28	6,88	7,14	8,09	0,54	7,4%
Electrical Conductivity (mS/m EC)	21	21,8	83,0	43,7	52,4	29,0	51,5	78,1	21,2	40,4%
Total Dissolved Salts (mg/l TDS)	20	135,0	764,0	286,0	378,2	174,0	431,0	551,1	186,3	49,3%
Calcium (mg/l Ca)	20	7,50	91,30	22,26	39,60	12,18	25,89	88,28	29,51	74,5%
Magnesium (mg/l Mg)	20	3,63	75,50	16,41	32,89	7,93	20,10	73,34	25,32	77,0%
Sodium (mg/l Na)	20	4,00	126,73	11,72	28,68	4,30	21,40	57,47	30,50	106,3%
Potassium (mg/l K)	20	0,37	6,43	1,04	2,23	0,38	1,79	4,41	1,77	79,2%
Chloride (mg/l Cl)	20	4,60	96,20	17,35	32,64	9,13	22,35	73,34	25,53	78,2%
Sulphate (mg/l SO_4)	21	1,70	58,70	5,44	12,97	2,00	9,55	39,00	14,60	112,5%
Total Alkalinity (mg/l) $CaCO_3$)	17	50,30	485,50	150,89	228,82	87,45	183,80	451,60	142,19	62,1%
Nitrate (mg/l N)	21	0,16	24,51	0,90	2,78	0,61	1,21	3,90	5,19	186,4%
Fluoride (mg/l F)	15	0,09	5,90	0,36	0,90	0,17	0,56	1,01	1,41	156,4%
Silicon as Si	11	5,72	25,26	11,49	14,03	6,93	12,85	23,30	6,48	46,2%
Iron (Fe)	4	0,009	0,058	0,021	0,035	0,013	0,036	0,056	0,02	65,7%
Manganese (Mn)	4	0,001	0,070	0,003	0,021	0,002	0,006	0,052	0,03	158,7%
Ortho Phosphate as Phosphorus as PO4	16	0,003	0,310	0,015	0,079	0,009	0,023	0,184	0,10	121,9%
ZAR	20	0,08	7,79	0,29	1,18	0,09	0,82	1,88	1,71	145,1%
LSI	17	Langelier Saturation Index (LSI)			Slightly Scaling		**5,9%**	Highly Scaling		**0,0%**
		Highly corrosive		**11,8%**	Slightly corrosive		**41,2%**	Balanced Corrosion		**41,2%**

Table 37 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality in terms of the Electrical conductivity (EC) is ideal to good (100%); the values range between 21.8 and 83mS/m.

The Total Dissolved Solids (TDS) is acceptable in 100% of the samples (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 23 samples show elevated concentrations of Fluoride (F >1.5mg/l) in 6.7% and Nitrate (N >10mg/l) in 4.8% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly to highly corrosive (53%); slightly scaling (5.9%) and balanced (41.2%). The ZAR index indicates that 95% of the sampled water sources are of a fair quality for irrigation (ZAR < 3).

The topography related to the unit includes east-westerly and north-easterly trending mountain ranges and flat country. Groundwater use in the area includes production and monitoring boreholes for some mines such as the ARM Andalusite Mine; water supply to the hospital, commercial and residential properties in Thabazimbi. Other users include livestock, game watering and domestic purposes for lodges and farmsteads. There are approximately 3 rural villages that have water supply boreholes in the unit. Large scale irrigation is along the Crocodile River which is characterized by high yielding boreholes related to deep alluvial (10m to 25m) deposits.

There are also high yielding boreholes in this area that are related to faults. Thabazimbi obtain 4000m³/day from groundwater and 7000m³/day from Magalies Water that is pumped from Vaalkop Dam, (IDP, 2024-2025). Thabazimbi is partly underlain by rocks of the Undifferentiated Pretoria Group unit as well as the Alma Formation.

7.2.1.10.1 MAGALIESBERG FORMATION (Grouped with undifferentiated Vpg)

The Magaliesberg Formation is indicated on the 1974 Geological map sheet to occur within the area. For this brochure and hydrogeological map sheet the unit is integrated with the Undifferentiated Pretoria Group. The latest GIS digital coverage available from the Council for Geosciences that was used in compiling the hydrogeological map sheet, does not include a polygon for this formation within the Thabazimbi map coverage. Literature indicates that the formation in the western part of the country has a maximum thickness of 15m, (Visser D.J.J. 1989). The 1:500 000 hydrogeological map series, map sheet 2526 Johannesburg can be consulted for information regarding this groundwater resource unit, as it is part of the Magaliesberg Mountain range in the Pretoria area where the thickness is up to 300m.

7.2.1.10.2 BLACK REEF FORMATION (Grouped with undifferentiated Vpg)

When the Wolkberg Group is absent, the Black Reef Quartzite Formation is widely regarded as the basal unit of the Transvaal Supergroup. Depending on the location within the map sheet, it is conformably underlain by Archaean rocks belonging to the basement complex (e.g., the Gaborone Complex) or older rocks from the Witwatersrand and Ventersdorp Supergroups. It is overlain by a succession of thick carbonate rocks of the Malmani Subgroup. The contact with the overlying Malmani Subgroup is gradational in areas where the transition from a fluvial to a shallow marine depositional environment into a more extensive marine carbonate platform system occurred gradually over time. This contact is conformable, implying continuous sedimentation without significant interruption.

The Black Reef Formation, which reaches a maximum thickness of about 30m in the western part of the Transvaal Intercratonic Basin, typically comprises a succession of interbedded arenites and mudstones, with a sporadically developed basal conglomerate Unit. It is informally subdivided into a lower Conglomerate Unit and an upper Quartzite Unit, (Els et al., 1995). In their study, Els et al. concluded that the pre-Transvaal palaeosurface had a palaeorelief of up to 30m and that the palaeolandscape's topography was the dominant factor controlling early sedimentation in the basin. The pre-Transvaal palaeosurface is characterised by elongated northeast- to southwest- trending grabens and partly-eroded horst blocks (Els et al., 1995).

The palaeo depositional environments described in literature consist of braid-delta systems, shallow braided stream systems with incised valley fill (likely graben-controlled), and transgressive shallow marine conditions.

The dip of the unit is generally towards the centre of the Transvaal Intercratonic Basin. Consequently, the Black Reef Formation forms a narrow strip along the northern side (the upper part) of the Chuniespoort Group. The Chuniespoort Group forms an arch shape trending west to east from the Limpopo River, turning northward in the southern part of the map sheet (see Figure 38). The dip of the rocks in the western part of the arch is towards the south (20-37º); at the bend, the dip steepens to approximately 60º before changing to a south-easterly dip (20-30º) in the northern section of the arch. The arch splits into two branches towards the east near Thabazimbi, one to the north and one to the east, but no Black Reef rocks are indicated on the geological map within this zone.

For the hydrogeological map sheet, the Black Reef Formation was combined under the Undifferentiated Pretoria Group. For more detailed information on the hydrogeological character of the Black Reef Formation, the adjacent 1:250 000 Modimolle map sheet can be consulted.

7.2.1.11 RAYTON FORMATION (Vry)

The Rayton Formation groundwater resource unit occurs within the south-eastern sector of the map sheet (Figure 41) and covers approximately 1.9% of the total map area. Land use within the unit is predominantly dedicated to game reserves and tourism destinations, such as the Rooiberg and Leeupoort Resorts.

The upper part of the Pretoria Group of the Transvaal Supergroup consists of five sedimentary post-Magaliesberg formations in the eastern part of the Transvaal intracratonic basin, (Button, 1986). These formations are the Vermont, Nederhorst, Houtenbek, Lakenvlei, and Steenkampsberg Formations. In the central and western parts of the Transvaal Basin, the equivalents of these five formations are the Rayton Formation and the Woodlands Formation, (SACS, 1980; Key, 1986).

The Rayton Formation comprises quartzite, shale, and subordinate subgreywacke. The thickness of these formations is reported to be less than 200 m.

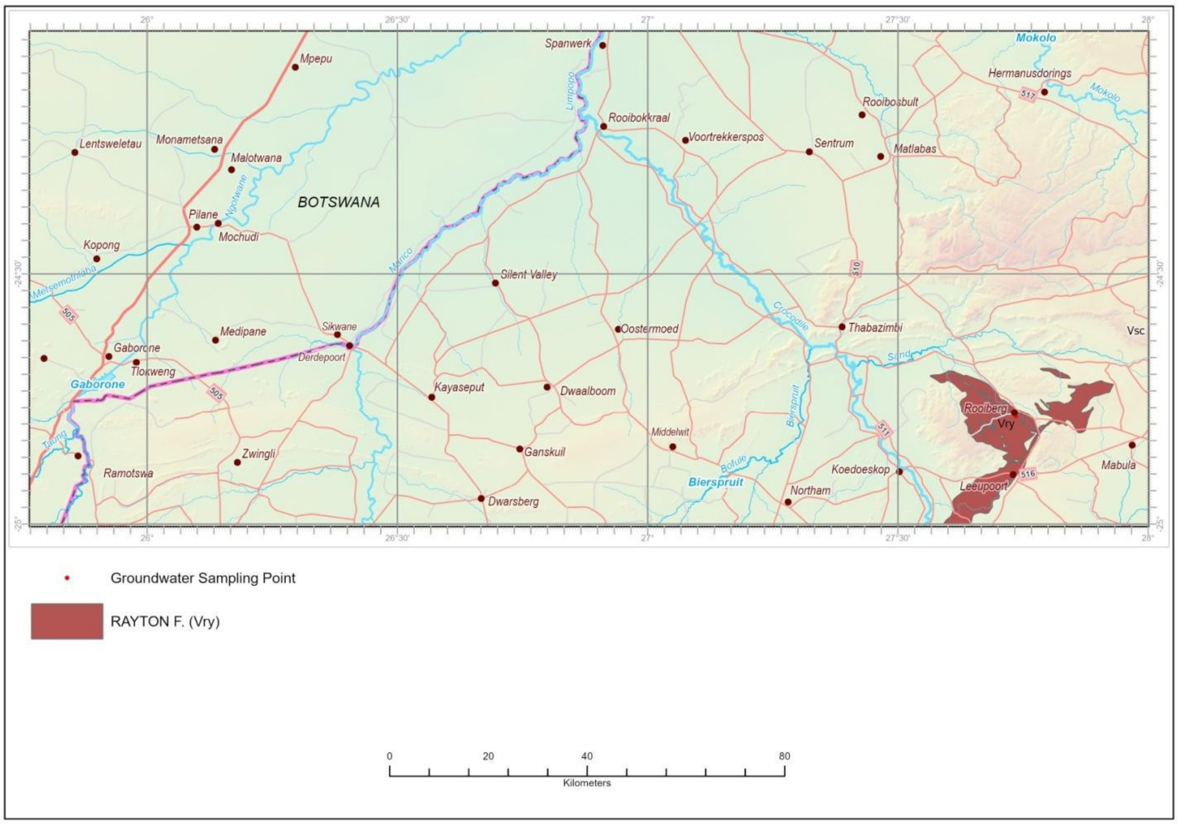


Figure 41: Geographical distribution of the Rayton Formation (Vry) and the associated groundwater sampling points.

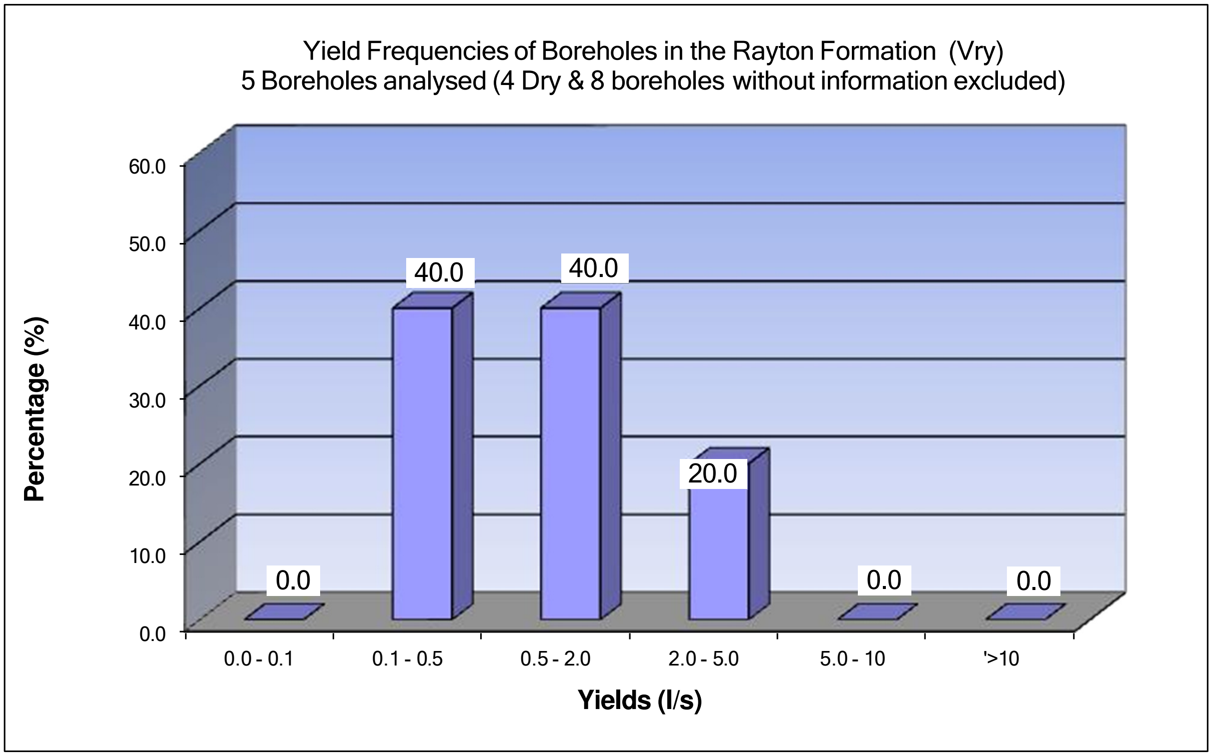


Figure 42: Yield frequency for fractured aquifers of the Rayton Formation (Vry).

The analysis of 5 borehole records in regards to the maximum yield, indicates that 40% of the boreholes can supply water to small households (>0.1ℓ/s to 0.5ℓ/s). A further 40% of the boreholes yield between 0.5ℓ/s and 2ℓ/s, while another 20% of the boreholes yield between 2ℓ/s and 5ℓ/s.

Limited data is available for the unit, the water level is 66.32 meters below ground level (mbgl) as obtained from a single record; the average depth of 4 boreholes with data is 88m, with the deepest reported as 136m. No information is available on borehole installation depths, water strikes or pump testing data.

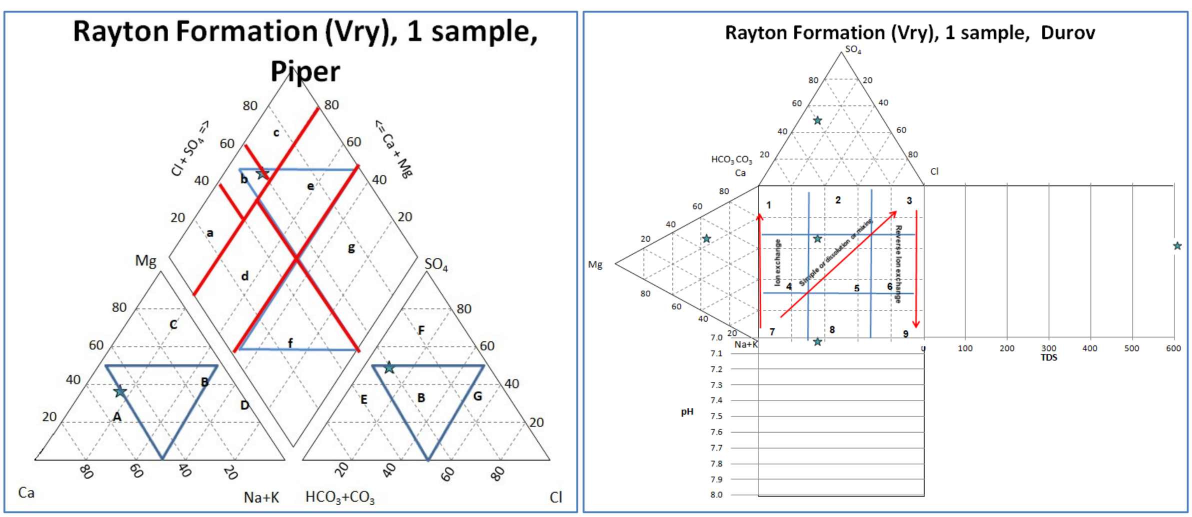


Figure 43: Trilinear diagrams, Piper and Durov for the Rayton Formation (Vry).

The trilinear Piper diagram, (Figure 43), facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions in order to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (100%), Weak acidic anions > Strong acidic anions (0%); Alkali >Alkali earths (0%); Strong acids > Weak acids (100%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate-Sulphate type (100%).

The trilinear Durov diagram defines hydrochemical processes along with the water type. The interpretation is as follows:

- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (40%), plot along the dissolution or mixing line

Table 38: Chemical statistics for the Rayton Formation (Vry).

Element / Parameter	Statistics Drawn from a population of 2 data points for the Rayton Formation (Vry)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	2	7.30	7.30	7.30	7.30	7.30	7.30	7.30		
Electrical Conductivity (mS/m EC)	2	93.7	93.7	93.7	93.7	93.7	93.7	93.7		
Total Dissolved Salts (mg/l TDS)	2	605.2	605.2	605.2	605.2	605.2	605.2	605.2		
Calcium (mg/l Ca)	2	93.98	93.98	93.98	93.98	93.98	93.98	93.98		
Magnesium (mg/l Mg)	2	43.25	43.25	43.25	43.25	43.25	43.25	43.25		
Sodium (mg/l Na)	2	33.13	33.13	33.13	33.13	33.13	33.13	33.13		
Potassium (mg/l K)	2	1.69	1.69	1.69	1.69	1.69	1.69	1.69		
Chloride (mg/l Cl)	2	25.00	25.00	25.00	25.00	25.00	25.00	25.00		
Sulphate (mg/l SO_4)	2	158.99	158.99	158.99	158.99	158.99	158.99	158.99		
Total Alkalinity (mg/l) $CaCO_3$)	2	269.00	269.00	269.00	269.00	269.00	269.00	269.00		
Nitrate (mg/l N)	2	1.40	1.40	1.40	1.40	1.40	1.40	1.40		
Fluoride (mg/l F)	2	1.90	1.90	1.90	1.90	1.90	1.90	1.90		
Silicon as Si	2	25.34	25.34	25.34	25.34	25.34	25.34	25.34		
Iron (Fe)	2	0.010	0.010	0.010	0.010	0.010	0.010	0.010		
Manganese (Mn)	2	0.010	0.010	0.010	0.010	0.010	0.010	0.010		
Ortho Phosphate as Phosphorus as PO4	0									
ZAR	2	0.71	0.71	0.71	0.71	0.71	0.71	0.71		
LSI	2	Langelier Saturation Index (LSI)			Slightly Scaling		**0.0%**	Highly Scaling		**0.0%**
		Highly corrosive		**0.0%**	Slightly corrosive		**0.0%**	Balanced Corrosion		**100.0%**

Table 36 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. In terms of the electric conductivity (EC), the overall water quality is marginal. Only 2 samples are available for characterization.

The Total Dissolved Solids (TDS) is acceptable in 100% of the samples (TDS ≤ 1200mg/l). The evaluation of the major cations and anions in 2 samples indicates elevated concentrations of Fluoride (F >1.5mg/l) in 100% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is balanced. The ZAR index indicates that 100% of the water is of a fair quality for irrigation (ZAR < 3).

The land use within the unit is predominantly game reserves with groundwater use related to these activities. The Rooiberg, Leeupoort and the Leeupoort Resort occur within the unit; these settlements are supplied by groundwater. No irrigation occurs within this unit, based on the evaluation of Google map imagery.

7.2.1.12 UNDIFFERENTIATED SMELTERSKOP FORMATION (Vsk)

The largest exposure of the Undifferentiated Smelterskop Formation groundwater unit occurs in the south-eastern quadrant of the map sheet, with additional thin, isolated east-west trending outcrops present in the central-southern and south-western sectors, (Figure 44). This unit occupies approximately 0.42% of the total map area.

Lithologically, the Smelterskop Formation is characterized by alternating sequences of brownish feldspathic quartzite, andesite lava, and tuff, with a thin, resistant quartzite layer at the top. The formation attains a cumulative thickness of approximately 300 meters, (Boardman, 1944). It is conformably overlain by volcanic rocks and subordinate sedimentary interbeds of the Rooiberg Group.

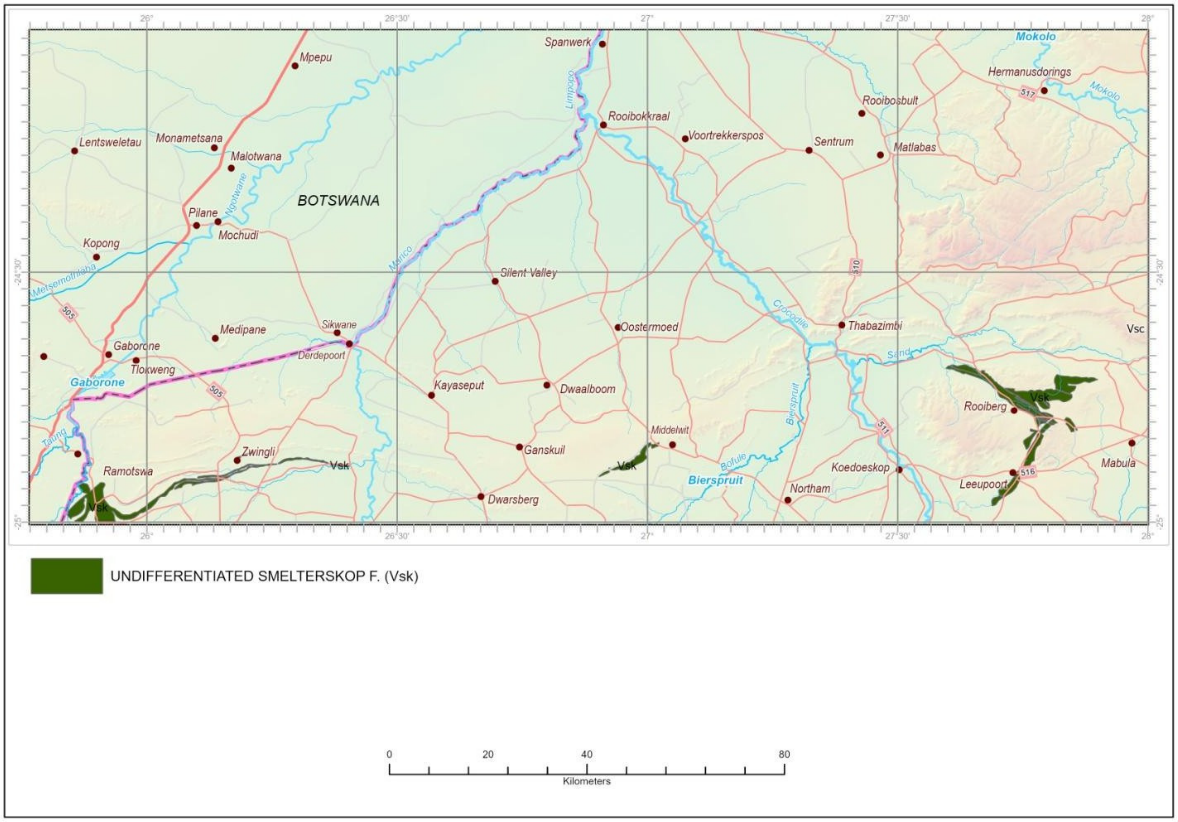


Figure 44: Geographical distribution of the Undifferentiated Smelterskop Formation (Vsk) and the associated groundwater sampling points.

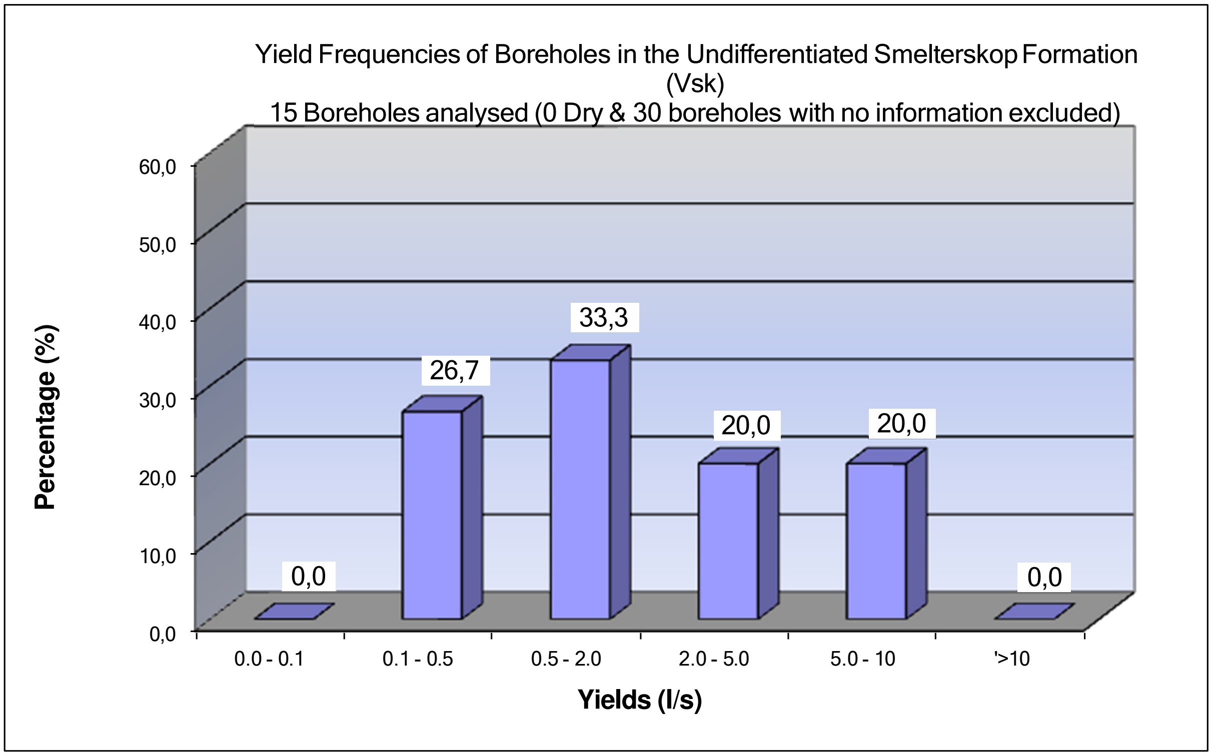


Figure 45: Yield frequency for fractured aquifers of the Undifferentiated Smelterskop Formation (Vsk).

Analysis of 15 borehole records indicates that 26.7% of the maximum yields are suitable for small household use (>0.1ℓ/s to 0.5ℓ/s). A further 33.3% of boreholes yield between 0.5ℓ/s and 2ℓ/s, while 40% yield between 2ℓ/s and 10ℓ/s.

No data is available regarding borehole depths, water strike levels, groundwater chemistry, or abstraction volumes for this groundwater resource unit.

Land use within the unit is predominantly associated with game reserves, with groundwater abstraction primarily supporting these activities. The Rooiberg and Leeupoort Resorts are located within or adjacent to the unit. No evidence of irrigation was observed within the area, based on interpretation of Google Maps imagery.

7.2.1.13 SILVERTON FORMATION (Vsi)

The Silverton Formation groundwater resource unit occurs within the south-western sector of the map sheet, covering approximately 2% of the total map area (Figure 46). The eastern boundary of the unit is defined by a major north-south striking strike-slip fault. Stratigraphically, the Silverton Formation forms part of the Pretoria Group of the Transvaal Supergroup.

The predominantly argillaceous Silverton Formation has a basin-wide extent and varies in total thickness from 2000 m in the east of the Transvaal Basin to several hundred meters in the west (Button, 1973). The formation is primarily composed of various mudrocks (approximately 80%), with locally significant volcanic rocks, (Machadodorp Member) and minor occurrences of carbonates, chert, and sandstone, (Schreiber, 1991). According to Catuneanu and Eriksson (1999), the Silverton shale represents the transgressive systems tract of an epeiric sea, deposited within a shallow to deep marine environment.

The lower contact of the Silverton Formation is gradational, with mudstones interbedded with centimeter- to decimeter-thick beds of immature sandstone, resting atop the arenaceous Daspoort Formation. The upper contact with the overlying arenaceous Magaliesberg Formation is also gradational, exhibiting an upward-coarsening sequence, (Button, 1973; Schreiber, 1991; van der Neut, 1990).

Topographically, the unit is characterized by extensive and broad valleys. In the Western Transvaal Basin, the shale is graphitic and is extensively altered to hornfels due to multiple intrusions of diabase sills, (Visser, 1989).

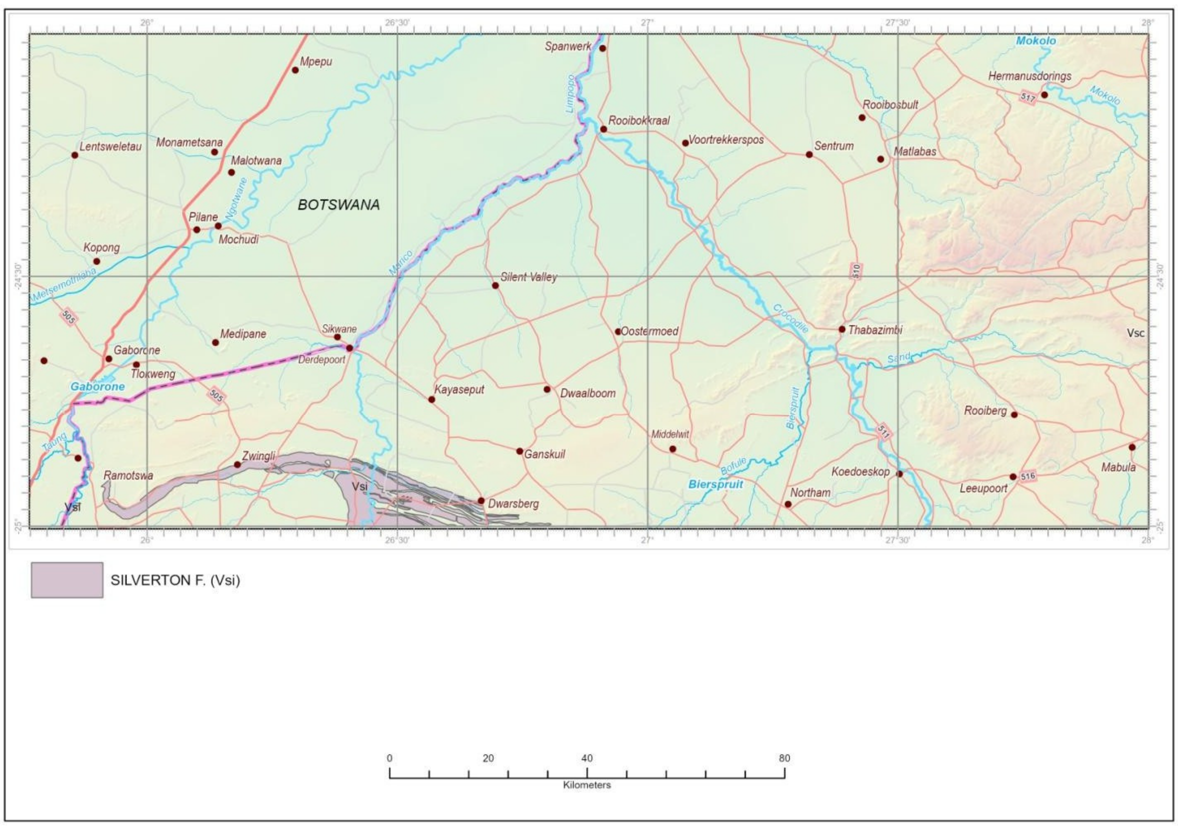


Figure 46: Geographical distribution of the Silverton Formation (Vsi) and the associated groundwater sampling points.

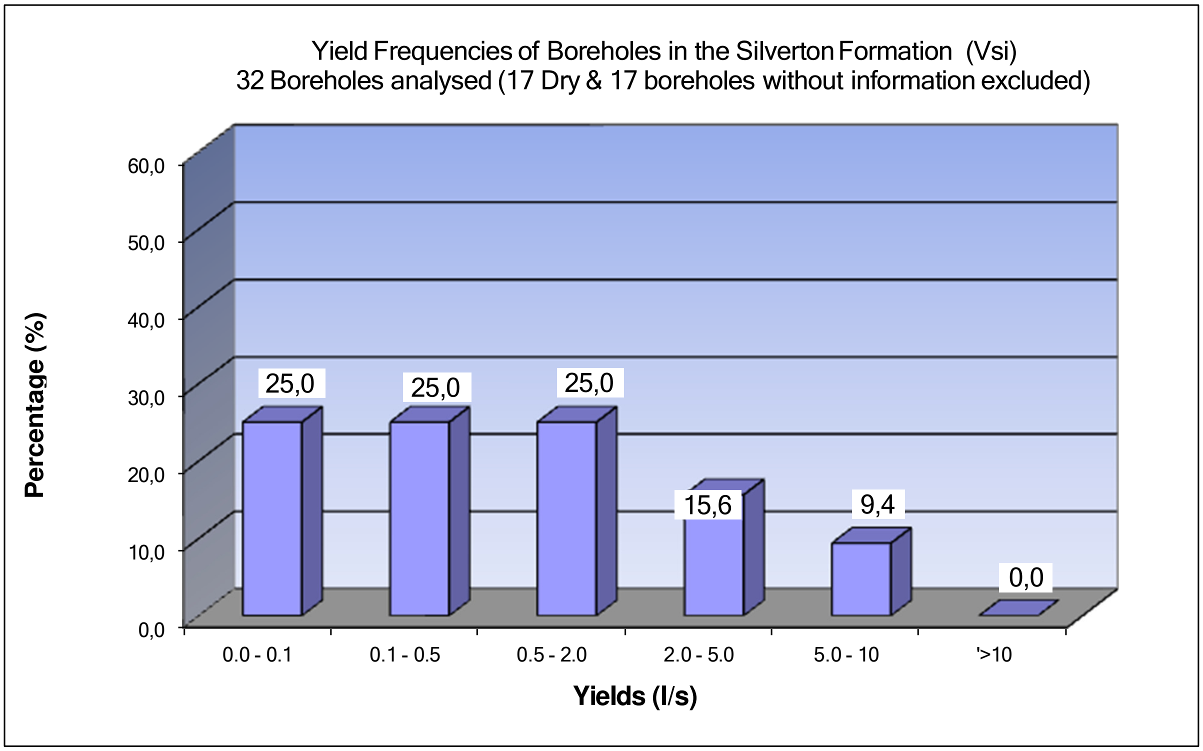


Figure 47: Yield frequency for fractured aquifers of the Silverton Formation (Vsi).

The yield frequency distribution, (Figure 47) indicates that 50% of successful boreholes have maximum yields of less than 0.5ℓ/s. A further 25% of boreholes yield between 0.5ℓ/s and 2ℓ/s, while 15.6% yield between 2ℓ/s and 5ℓ/s. Only 9.4% of the reported sources have maximum yields that exceed 5ℓ/s.

Information on static water levels and borehole depths is limited to a single data record, which reports a static water level of 15.04 meters below ground level (mbgl) and a borehole depth of 83.94 meters.

No data is available regarding water strike depths, groundwater chemistry, pump testing results, or recommended abstraction rates. For additional information concerning this groundwater resource unit, reference should be made to the 1:500 000 Hydrogeological Map Series, Map Sheet 2526 Johannesburg.

Groundwater abstraction within the unit primarily supplies farmsteads, livestock, and one or two rural villages. No evidence of large-scale irrigation was observed, based on interpretation of Google Earth imagery.

7.2.1.14 DASPOORT FORMATION (Vdp)

The arenaceous Daspoort Formation forms part of the upper Pretoria Group rocks of the Transvaal Supergroup. It overlies the Strubenkop shale unconformable and has a sharp contact with the overlying silt- and mudstones of the Silverton Formation, (Eriksson et al., 1993b). Fluvial and epeiric marine conditions prevailed during the deposition of the Daspoort clastic sediment into the intracratonic basin. The depositional environment was a distal fan and fluvial braidplain.

In the Thabazimbi area which represents the western part of the Transvaal Basin the thickness is up to 190m, it gradually thins towards the eastern part of the Basin where the thickness is 90m. It consists of orthoquartzite with thin interbeds of shale and siltstone, (Visser D.J.J. 1989).

The groundwater resource unit occurs as a thin arch in the south-western sector of the map sheet and covers approximately 1.4% of the map area, (Figure 48). The formation was extensively intruded by diabase mostly in the form of sills. These intrusives, various fault zones, fractures, joints and contact zones between sedimentary beds will be the main targets in the search for groundwater.

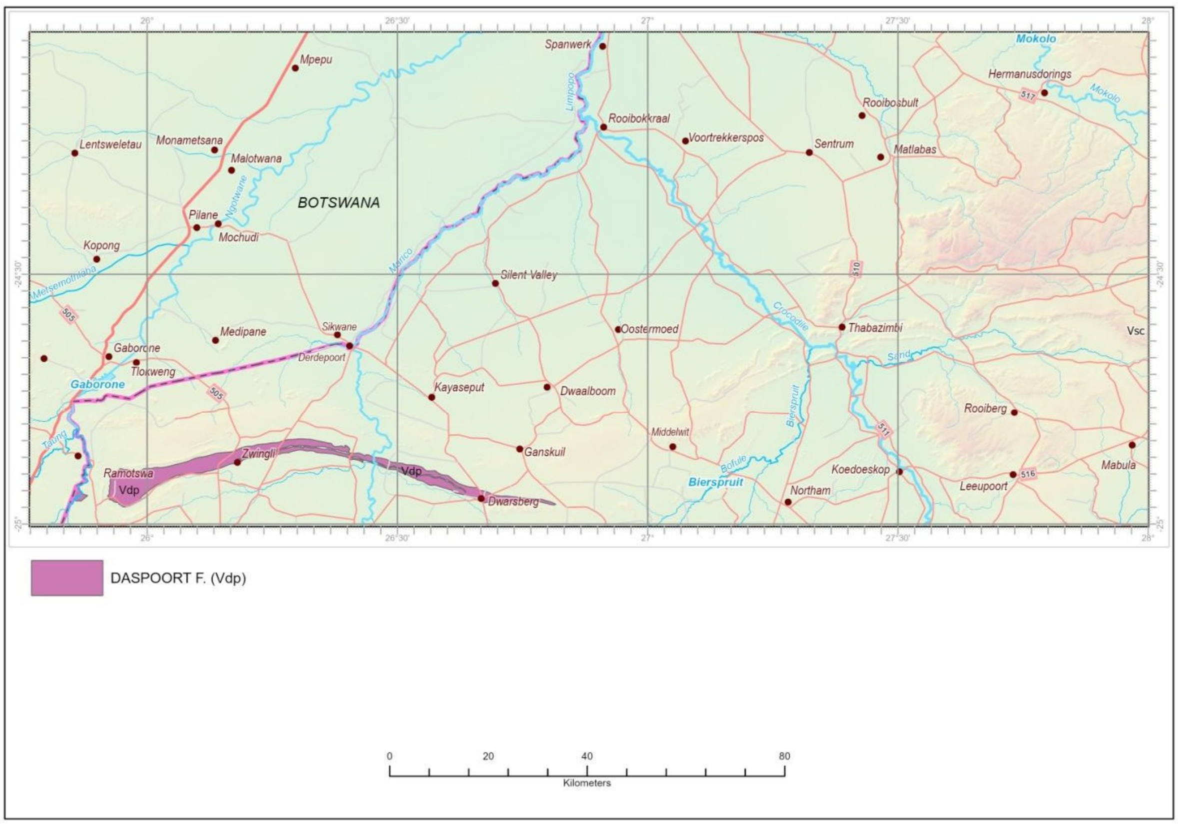


Figure 48: Geographical distribution of the Daspoort Formation (Vdp) and the associated groundwater sampling points.

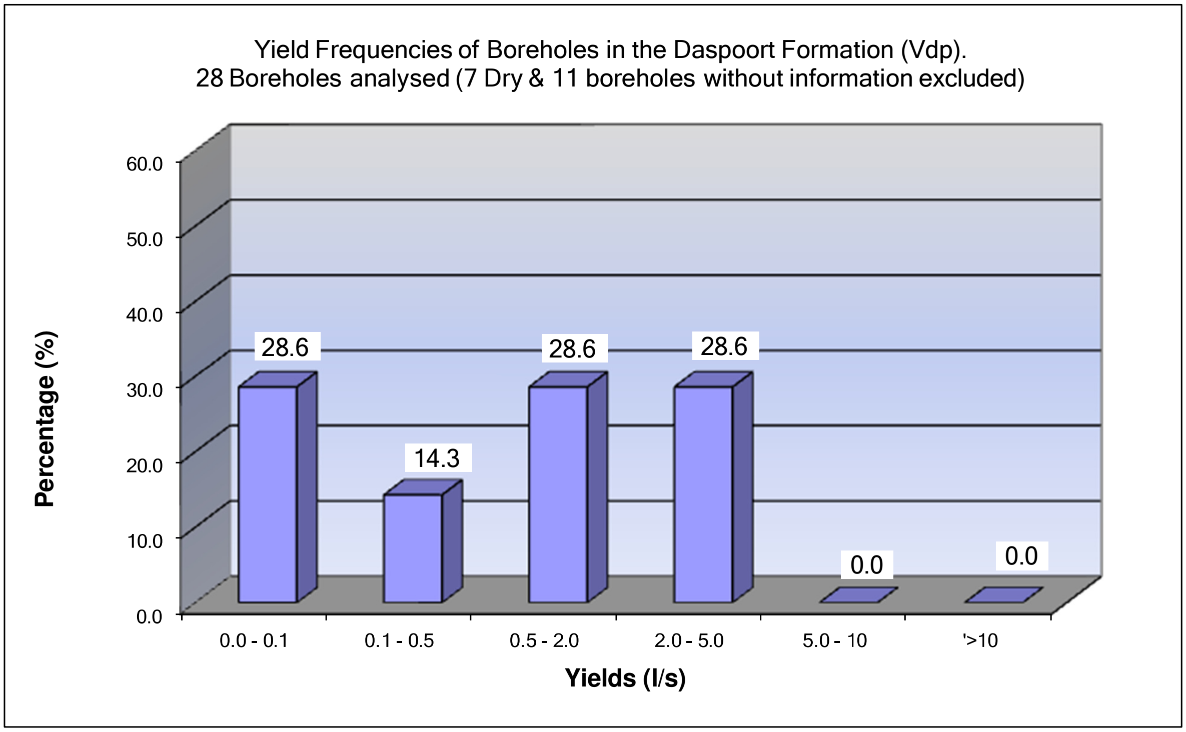


Figure 49: Yield frequency for fractured aquifers of the Daspoort Formation (Vdp).

The yield frequency distribution, (Figure 49) indicates that 42.9% of the successful boreholes yield less than 0.5ℓ/s. A further 57.2% of the boreholes yield between 0.5ℓ/s and 5ℓ/s. No yields are reported that exceeds 5ℓ/s.

No information is available on the depths of boreholes, water chemistry, static water levels, and installation depths or pump testing data this groundwater resource unit.

The unit forms a gently arching, easterly trending mountain range. Existing boreholes are located in the lower areas at the base of the mountain. The water abstracted is primarily used for farmsteads, livestock, and game watering. No evidence of large-scale irrigation has been observed within the unit, as indicated by Google map imagery evaluation.

7.2.1.15 TIMEBALL HILL FORMATION (Vti)

Timeball Hill Formation forms part of the Pretoria Group of the Transvaal Supergroup. The Formation reflects a transgressive sequence in a marine setting. It includes a range of sedimentary rocks reflecting its depositional environment. These rocks are usually well-bedded and show evidence of crossbedding, ripple marks, and other sedimentary structures, reflecting the interplay between depositional energy levels and sediment supply. The Timeball Hill Formation represents a record of paleo environmental changes that includes a transition to more oxygenated oceanic conditions. The thickness of the formation varies with the maximum reported as 1600m in the eastern part of the Transvaal Basin.

The formation consists of shale, quartzose sandstones (locally recrystallized to quartzite), lesser conglomerate lenses and a thin bed of diamictite at the top, (Visser, 1969; Button, 1973, 1986; Eriksson, 1973; Eriksson and Clendenin, 1990). The formation is the product of dominantly shallow marine sedimentation (Catuneanu and Eriksson, 2002) fed by fluvial-deltaic systems advancing into an epeiric embayment basin open to the ocean on the southeast, (Visser, 1971; Eriksson, 1973; Coetzee, 2002; Eriksson and Reczko, 1998).

The groundwater resource unit occurs as a thin arch in the south-western sector of the map sheet forming the valley area north of the mountains comprising rocks of the Daspoort Formation. In the far west it forms a thin easterly mountain range, but it is limited in extent.

The unit covers approximately 1.9% of the map area, (Figure 50). The formation was extensively intruded by diabase mostly in the form of sills. These intrusives, various fault zones, fractures, joints and contact zones between sedimentary beds will be the main targets in the search for groundwater.

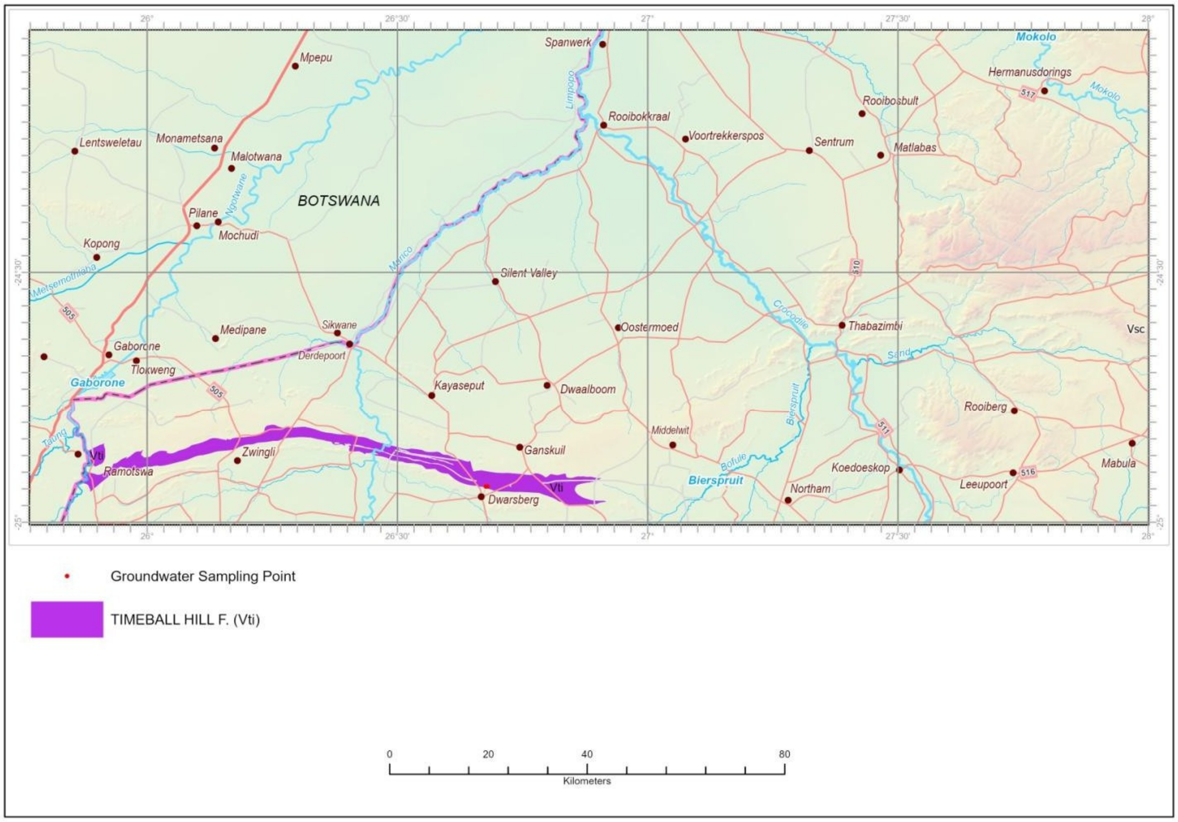


Figure 50: Geographical distribution of the Timeball Hill Formation (Vti) and the associated groundwater sampling points.

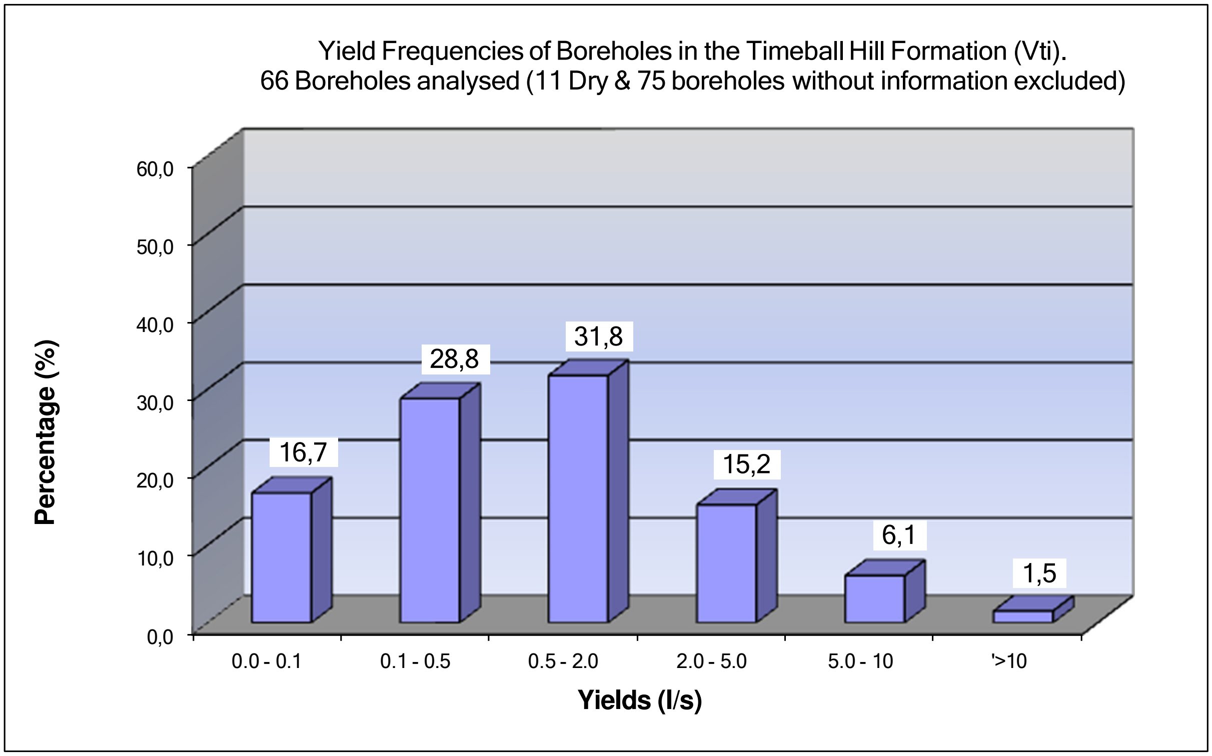


Figure 51: Yield frequency for fractured aquifers of the Timeball Hill Formation (Vti).

The yield frequency distribution, (Figure 51) indicates that 45.5% of the successful boreholes yield less than 0.5ℓ/s. A further 31.8% of the boreholes yield between 0.5ℓ/s and 2ℓ/s, while 21.3% yield between 2ℓ/s and 10ℓ/s. Only 1.5% of the reported sources have maximum yields that exceed 10ℓ/s.

Information on the static water level and borehole depth is only available from two data records; the static water level ranges from 29.8 meters below ground level (mbgl) to 31.78mbgl and the borehole depth ranges from 42.4m to 60m. No data was available on water strike depths, pump testing data or daily available abstraction. There was only one chemical analysis available, it could not be used as it was not complete.

Existing boreholes are in the lower areas at the northern base of a mountain range comprising rocks of the Daspoort Formation. The water abstracted is mainly used for farmsteads, livestock, game watering and four rural villages. Part of the unit forms part of the Madikwe game reserve. No evidence of large-scale irrigation occurs in the unit, (Google map imagery evaluation).

7.2.1.16 KLAPPERKOP QUARTZITE MEMBER (Vkp)

The Klapperkop Member of the Timeball Hill Formation forms part of the Pretoria Group of the Transvaal Supergroup. It includes a range of sedimentary rocks, reflecting its depositional environment and consists primarily of a wacke and ferruginous quartzite, interbedded graphitic and silty shale, (SACS, 1980, p204). The quartzites were deposited in a high-energy depositional environment associated with shallow marine to shelf environments. These rocks are usually well-bedded and show evidence of crossbedding, ripple marks, and other sedimentary structures, reflecting the interplay between depositional energy levels and sediment supply. The Klapperkop Member's rocks often show lateral variations depending on the specific locality within the outcrop area.

The groundwater resource unit occurs as a thin section west of ARM Andalusite mine located approximately 33km south-west of Thabazimbi. A second larger occurrence is within the centre-south to centre-south-eastern section of the map sheet. The unit covers approximately 0.33% of the map area, (Figure 52).

In the search for groundwater various faults occur on the boundary of the unit namely, eastern and western boundary as well as numerous faults on the southern boundary. These faults are depicted on the geological map. As with most sedimentary rocks, the contact zones between sedimentary layers may yield some water. No diabase sills are depicted on the geological map.

Water quality analysis indicates that in 50% of the samples, at least one constituent exceeds the maximum allowable limits for domestic use. In this groundwater resource unit, the primary contaminant of concern is the anion Chloride. The anion Nitrate exceeds the maximum allowable concentration limit in 25% of the samples.

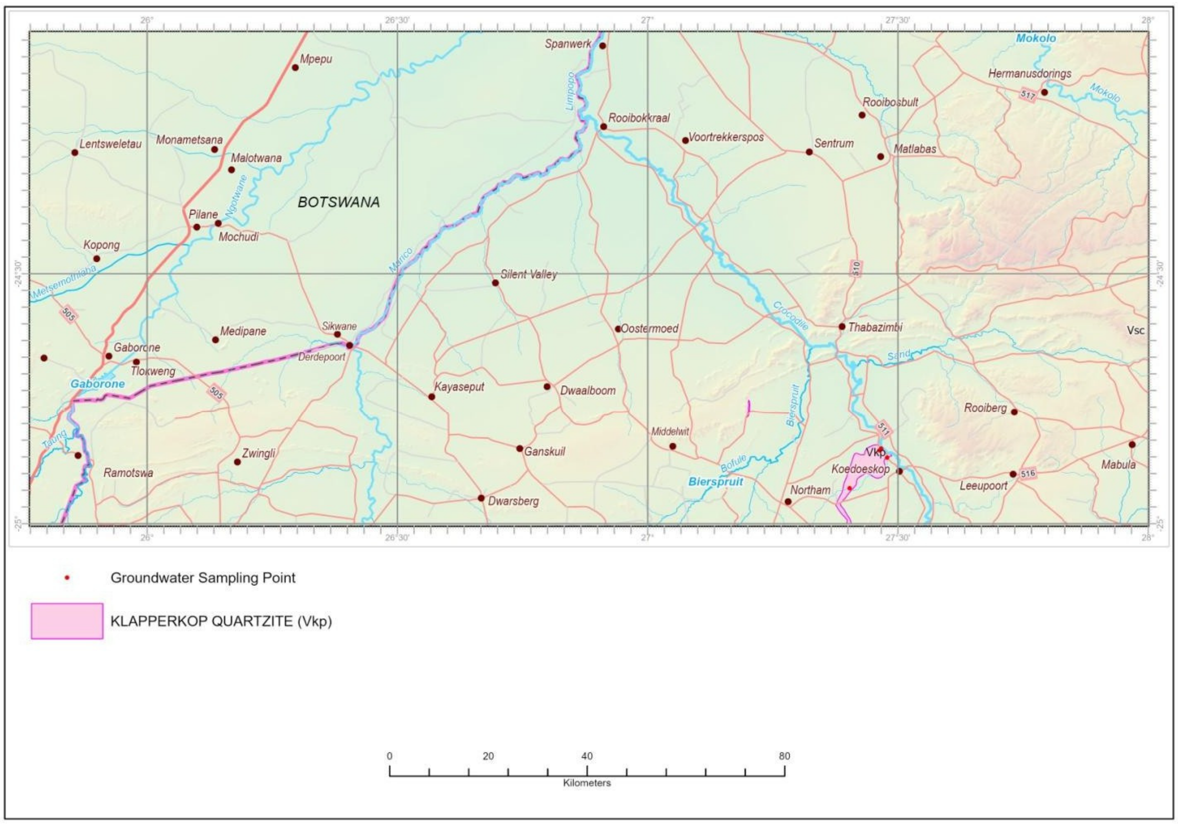


Figure 52: Geographical distribution of the Klapperkop Quartzite Member (Vkp) and the associated groundwater sampling points.

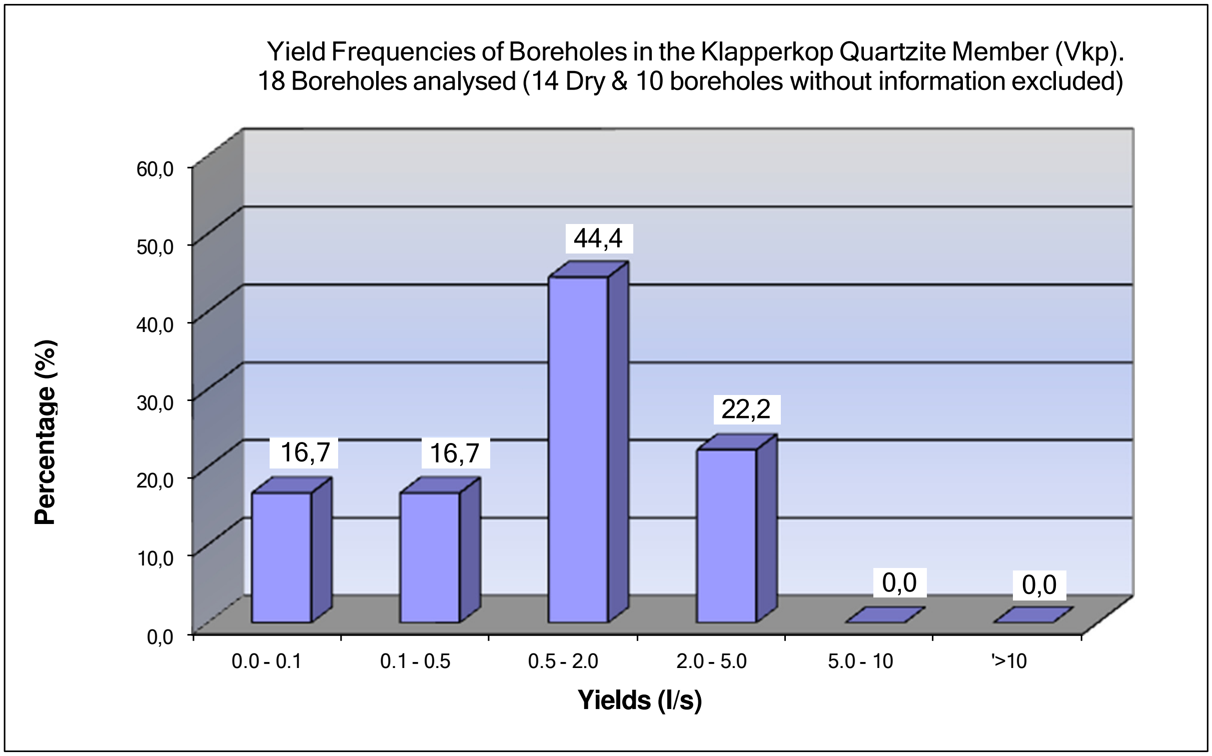


Figure 53: Yield frequency for fractured aquifers of the Klapperkop Quartzite Member (Vkp).

The yield frequency distribution, (Figure 53) indicates that 33.4% of the successful boreholes yield less than 0.5ℓ/s. A further 44.4% of the boreholes yield between 0.5ℓ/s and 2ℓ/s, while 22.2% of the boreholes yield between 2ℓ/s and 5ℓ/s. No records were available for boreholes yielding more than 5ℓ/s.

Information on the static water level is only available from one borehole; the static water level was reported as 21 meters below ground level (mbgl). No data was available on water strike depths, pump testing data or daily abstraction volumes.

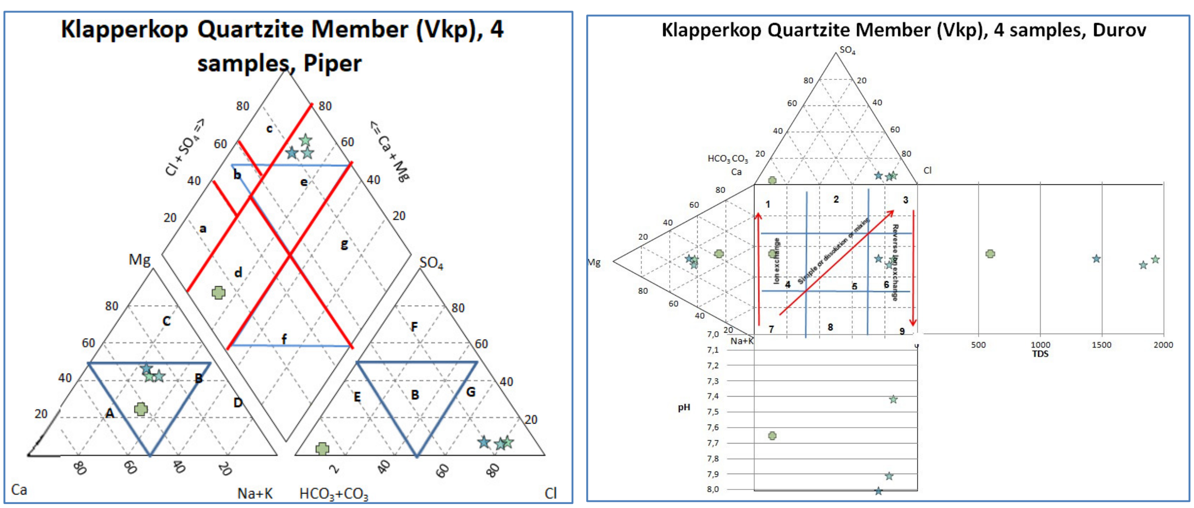


Figure 54: Trilinear diagrams, Piper, and Durov for the Klapperkop Quartzite Member (Vkp).

The trilinear Piper diagram, (Figure 54) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions in order to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths >

Alkali (100%), Weak acidic anions > Strong acidic anions (25%); Alkali >Alkali earths (0%); Strong acids > Weak acids (75%).

The groundwater in this unit classifies as:

- Mixed Calcium-Magnesium-Chloride type (75%),
- Mixed Calcium-Magnesium-Bicarbonate type (25%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- Anion discriminates and Na is dominant, indicates probable mixing or uncommon dissolution influences (75%),
- Anion discriminates and Ca dominant can be attributed to fresh recent recharge water exhibiting simple dissolution or mixing (25%), points plot along dissolution or mixing line.

Table 39: Chemical statistics for the Klapperkop Quartzite Member (Vkp).

Element / Parameter	Statistics Drawn from a population of 4 data points for the Klapperkop Quartzite Member (Vkp).									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	4	7,40	8,00	7,73	7,74	7,47	7,77	7,97	0,27	3,5%
Electrical Conductivity (mS/m EC)	4	64,9	309,1	150,1	220,2	112,6	253,5	301,2	109,5	49,7%
Total Dissolved Salts (mg/l TDS)	4	566,0	1839,0	1109,2	1383,8	810,8	1565,0	1811,7	579,8	41,9%
Calcium (mg/l Ca)	4	64,10	198,50	117,95	141,40	86,93	151,50	187,79	56,85	40,2%
Magnesium (mg/l Mg)	4	22,60	167,50	62,75	121,88	57,01	148,70	165,28	67,42	55,3%
Sodium (mg/l Na)	4	55,80	214,40	114,10	150,68	79,56	166,25	209,33	71,88	47,7%
Potassium (mg/l K)	4	1,47	6,14	2,70	3,81	1,69	3,82	5,93	2,32	60,9%
Chloride (mg/l Cl)	4	12,60	733,00	47,35	462,50	143,61	552,20	709,63	322,93	69,8%
Sulphate (mg/l SO_4)	4	5,50	92,50	18,04	58,95	23,14	68,90	86,80	37,52	63,6%
Total Alkalinity (mg/l) $CaCO_3$)	4	287,30	360,60	326,72	328,98	299,99	334,00	353,94	30,69	9,3%
Nitrate (mg/l N)	4	0,21	21,15	0,76	9,65	1,08	8,63	19,04	9,73	100,8%
Fluoride (mg/l F)	4	0,51	0,74	0,62	0,64	0,54	0,65	0,72	0,10	15,6%
Silicon as Si	4	18,57	27,18	22,35	22,94	19,03	23,01	26,80	4,25	18,5%
Iron (Fe)	0									
Manganese (Mn)	0									
Ortho Phosphate as Phosphorus as PO4	4	0,003	0,012	0,005	0,007	0,003	0,007	0,011	0,00	67,0%
ZAR	4	1,53	2,86	2,08	2,21	1,65	2,22	2,75	0,59	26,7%
LSI	3	Langelier Saturation Index (LSI)			Slightly Scaling		**66,7%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**0,0%**	Balanced Corrosion		**33,3%**

Table 39 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is ideal (25%) to marginal (75%) in terms of the Electrical conductivity (EC) with values ranging between 64.9 and 309.1mS/m.

The Total Dissolved Solids (TDS) is acceptable in 25% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 4 samples indicates elevated concentrations of Chloride (Cl > 600mg/l) in 50% and Nitrate (N >10mg/l) in 25% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly scaling (66.7%) and balanced (33.3%). The ZAR index indicates that 100% of the water is of a fair quality for irrigation (ZAR < 3).

Groundwater use in the area includes monitoring boreholes for the ARM Andalusite Mine; however, it is not known whether any production boreholes are in operation at the mine within this unit. Groundwater also supplies the hospital, as well as commercial and residential properties in Thabazimbi. Additional uses include livestock and game watering.

Large-scale irrigation occurs within the unit, predominantly along the Crocodile River. Irrigation water in this area is sourced from both surface water and the shallow alluvial aquifer. The reported alluvium thicknesses are up to 25 meters. Planned periodically releases from surface dams are part of the management strategies to sustain abstraction from alluvial aquifers for irrigation and mining.

7.2.1.17 PENGE FORMATION (Vpe) (Banded Ironstone)

Within the map sheet, the Penge Formation occurs as a few small outcrops. The most prominent exposures are located approximately 4 km west of Thabazimbi and 13 km north-west of Swartklip, where the formation forms part of the mountainous terrain. Another smaller occurrence forms an outer rim at the boundary with the underlying Malmani Dolomites, situated approximately 9 km west and north-west of the Mamba Cement plant, (Figure 55). The Penge Formation covers approximately 0.1% of the map area.

The Penge Formation typically comprises banded ironstone, carbonaceous shale, subordinate carbonate rocks, and breccia, overlying the dolomites of the Malmani Subgroup. In the western part of the Transvaal Basin, the formation consists almost exclusively of banded ironstone, with a thickness of approximately 300 meters. In this region, it constitutes the uppermost unit of the Chuniespoort Group. The beds generally dip moderately (20-30°) towards the centre of the basin, (Visser, 1989).

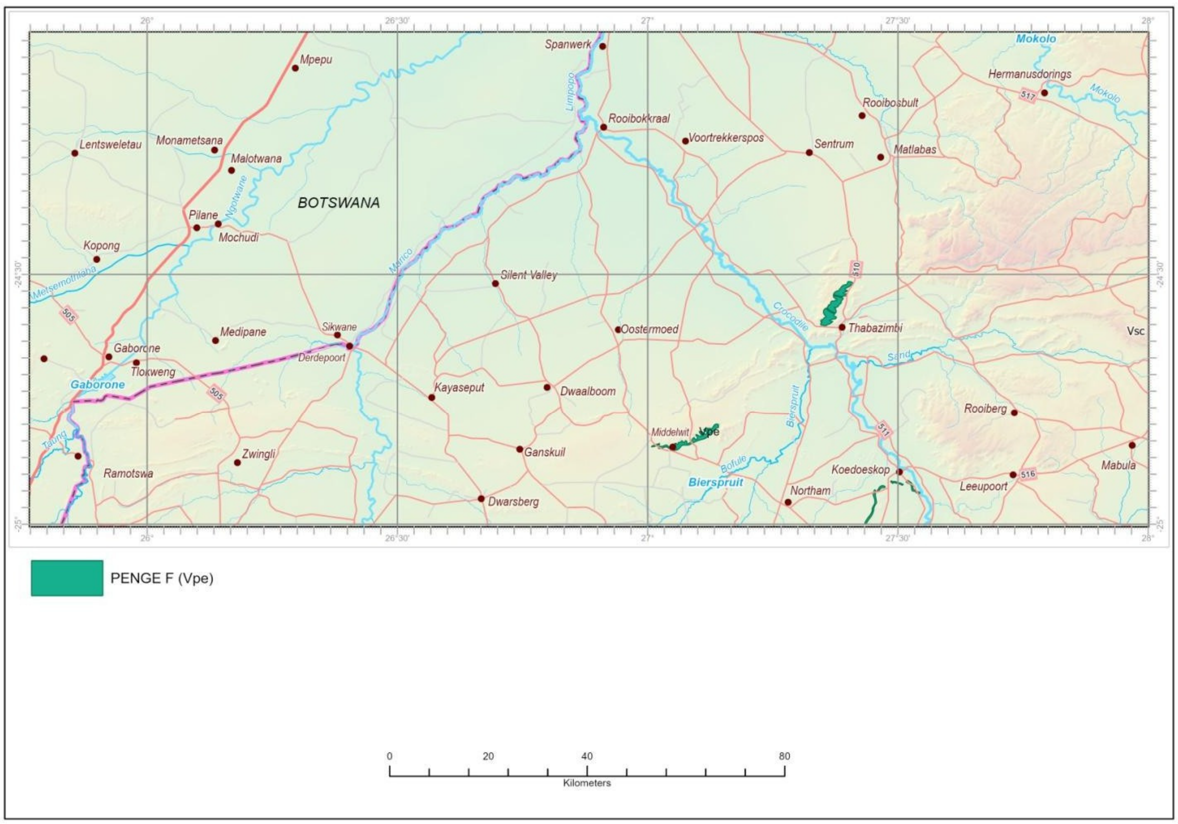


Figure 55: Geographical distribution of the fractured aquifers of the Penge Formation (Vpe) (banded ironstone) and the associated groundwater sampling points.

Exploration drilling conducted at the Thabazimbi iron ore mine (ISCOR) within the Chuniespoort Group reported that all boreholes intersected water within the brecciated banded ironstone of the Penge Formation. Some exploration and mining tunnels encountered significant groundwater inflows, which required sealing or active dewatering measures. Reported dewatering rates included 750m³/day from one tunnel and an inflow of 9ℓ/s (equivalent to 777.6m³/day) from another, (Hobbs, 1983).

Groundwater at the mining area from secondary aquifers was as follows: (Hobbs, 1983).

- Dolomite, banded ironstone and shaly dolomitic limestone of the Chuniespoort Group,
- Shale and quartzite of the Pretoria Group,
- Intrusive diabase dykes and sills of Post-Waterberg age.

At the mining site near Thabazimbi, the Chuniespoort Group strikes generally in an east-west direction. Tectonic activity, notably thrust faulting and folding, has caused these formations to dip steeply, with an average dip angle of 51° recorded in the mining area (Hobbs, 1983).

The secondary aquifers described in the mining area are expected to occur throughout the groundwater resource unit, with a similar hydrogeological setting.

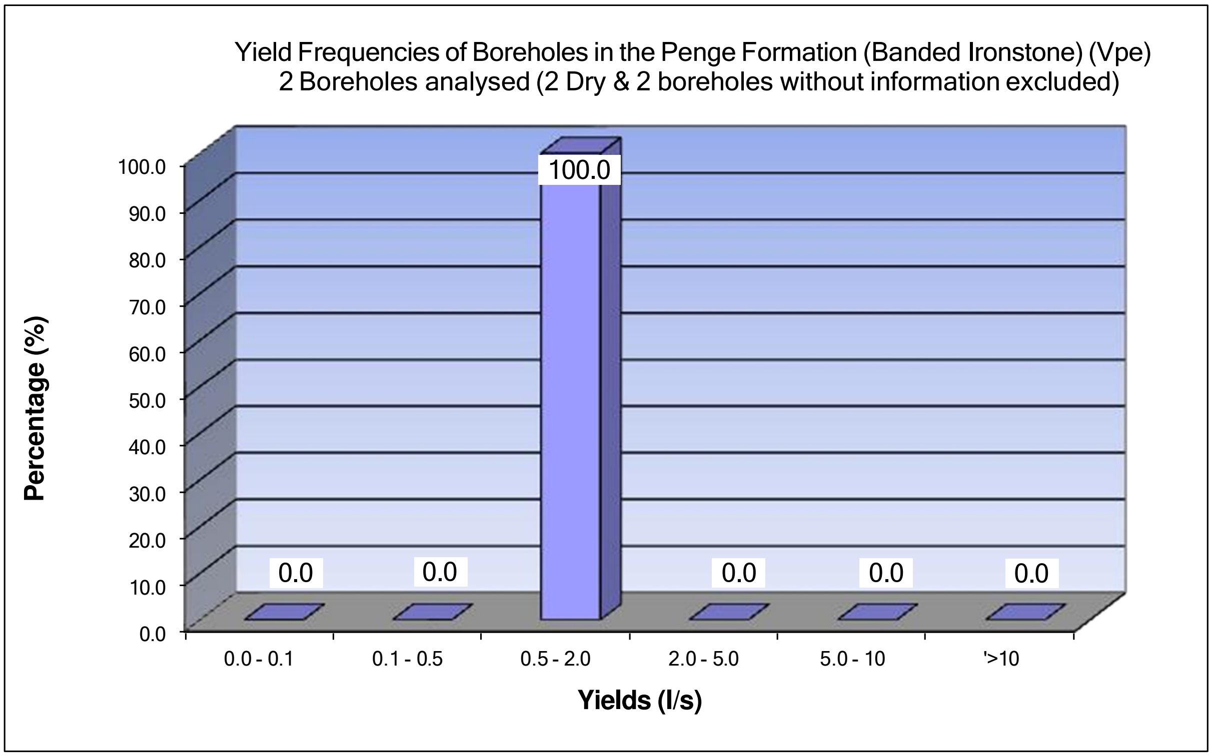


Figure 56: Yield frequency for the fractured aquifers of the Penge Formation (Vpe) (banded ironstone).

The yield frequency diagram, (Figure 92) indicates that the available yield data, derived from two borehole records, falls within the 0.5ℓ/s and 2ℓ/s range.

No data is available regarding borehole depths, groundwater chemistry, static water levels, or abstraction volumes for further characterization of the groundwater resource unit. For more detailed information, reference should be made to the 1:250 000 Modimolle map sheet and accompanying brochure.

Groundwater abstraction from this unit is considered minimal, with boreholes likely utilized for livestock watering and supply to farmsteads. Although large-scale irrigation fields occur within the unit, irrigation water is sourced primarily from the Crocodile River and the associated alluvial aquifer.

7.2.1.18 UNDIFFERENTIATED/UNNAMED VENTERSDORP SUPERGROUP (Rvz)

The undifferentiated/unnamed Ventersdorp Supergroup groundwater resource unit occurs at several scattered locations within the map sheet boundary. A prominent outcrop forms a thin, arch-shaped occurrence west of Thabazimbi, extending towards the south-western sector of the map sheet. The northern boundary of this outcrop is defined by the Archaean Granite and Granite Gneiss of the Western Transvaal Belt (Zjt on map)

Another outcrop in the south-western portion of the map has similar northern boundaries, while its southern boundary is the Gaborone Granite. Another two large outcrops in the same area are bounded to the north by the Gaborone Granite and, in places, by the Modipe Gabbro Complex. Their southern boundaries are formed by the contact between the Black Reef Formation and the Malmani Subgroup, where the Black Reef Formation is absent.

This unit covers approximately 3.8% of the map area, (*Figure 57*). On the geological map sheet, the lithology is depicted as the "Ventersdorp System," which is now referred to as the Buffelsfontein Group and classified as part of the Transvaal Supergroup, (SACS, 1980, p.123). Jansen (1974), at the time of the compilation of the Thabazimbi map sheet, noted that some of the stratigraphic positions within the area remained uncertain.

The Buffelsfontein Group, as defined by Tayler (1978), consists of a heterogeneous succession of acid and basic volcanic rocks and sediment. In the northwest, the basal portions of the succession rest unconformably on the Zwazian granitoids and greenstones. The succession is conformably overlain by clastic sediments of the Black Reef Formation, with gradational contact, (SACS, 1980, p.190).

The geological map sheet lists the rock types comprising this unit as acid lava (quartz porphyry, felsite, and rhyolite), agglomerate, tuff with interbedded quartzite, grit, conglomerate, breccia, and shale.

Due to the wide range of lithologies, drilling targets for groundwater exploration within this unit are highly site dependent. Preferred targets include fault zones, geological contacts, and zones of deep weathering. Syenitic Pilanesberg dykes, striking predominantly northwest, intruded the central portion of the unit.

Statistics on maximum yields indicates that only 12.3% of the boreholes yield more than 5ℓ/s. In terms of water quality, in 32.4% of the water samples, at least one element exceeds the maximum permissible limits for domestic use; for this unit, the anion of concern is nitrate.

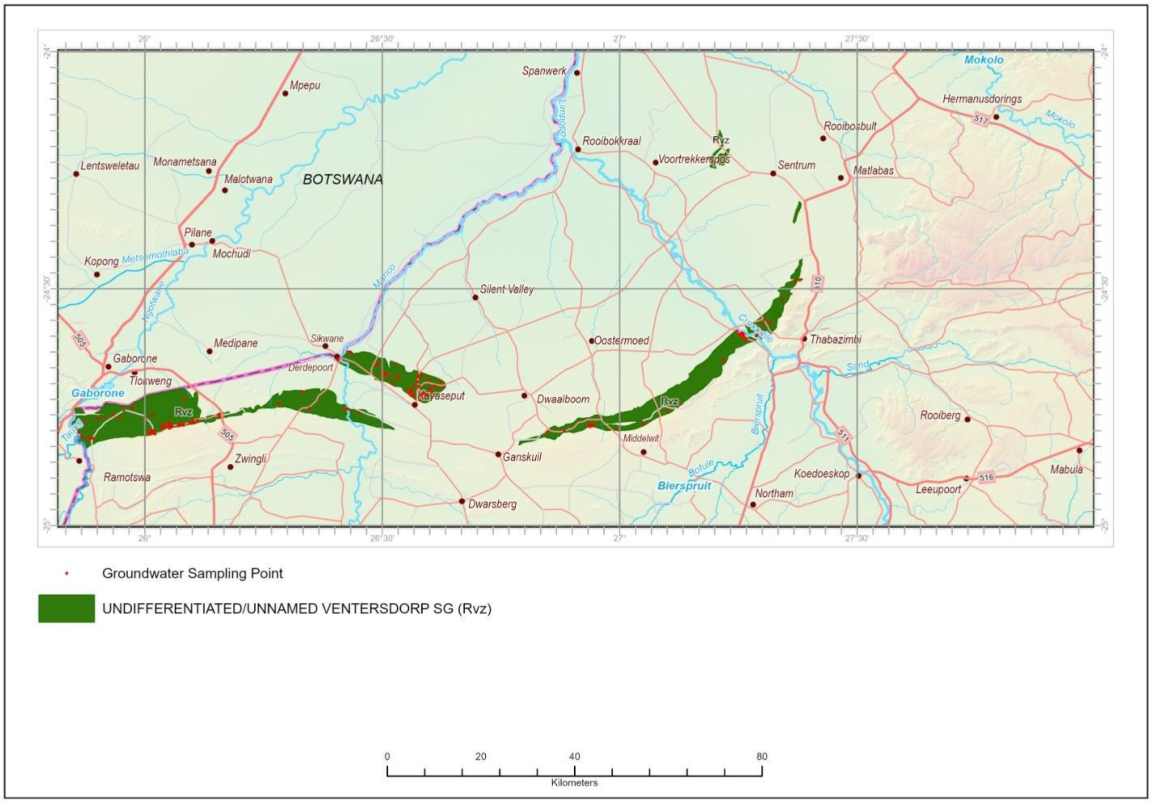


Figure 57: Geographical distribution of the Undifferentiated/unnamed Ventersdorp Supergroup (Rvz) and associated groundwater sampling points.

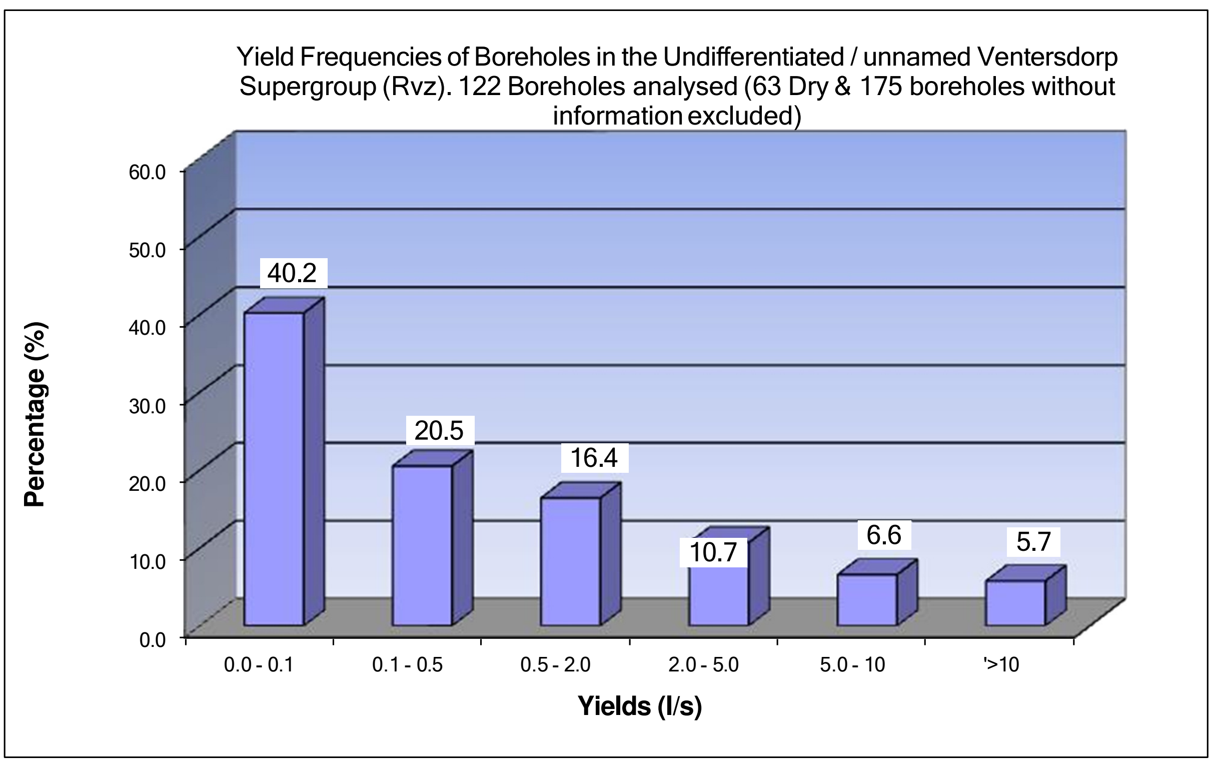


Figure 58: Yield frequency for the fractured aquifers of the Undifferentiated/unnamed Ventersdorp Supergroup (Rvz).

The analysis of 122 borehole records, (Figure 58) indicates that 60.7% of the maximum yields are suitable for small household use, (>0.1ℓ/s to 0.5ℓ/s). A further 16.4% of the boreholes have yields between 0.5ℓ/s to 2ℓ/s, while 10.7% yields between 2ℓ/s to 5ℓ/s and 12.3% of the boreholes yield more that 5ℓ/s.

Static water levels range from 2.2 meters below ground level (mbgl) to 35.1mbgl, with a median of 8.43mbgl and an average of 10.88mbgl, (based on 12 data points). The maximum borehole depth recorded is 130m, with an average depth of 94.3m and a median depth of 88m, (6 data points). Installation depths range from a minimum of 48m to a maximum of 66m, with an average installation depth of 58m, (6 data points).

The maximum recommended daily abstraction recorded for the unit is 864 cubic meters per day (m³/day), with an average abstraction of 388.8m³/day. The total number of boreholes subjected to pump testing within this groundwater resource unit on record is 5. The calculation on abstraction excludes one record reported as 1382.4m³/day. The reason for this high abstraction volume is not known.

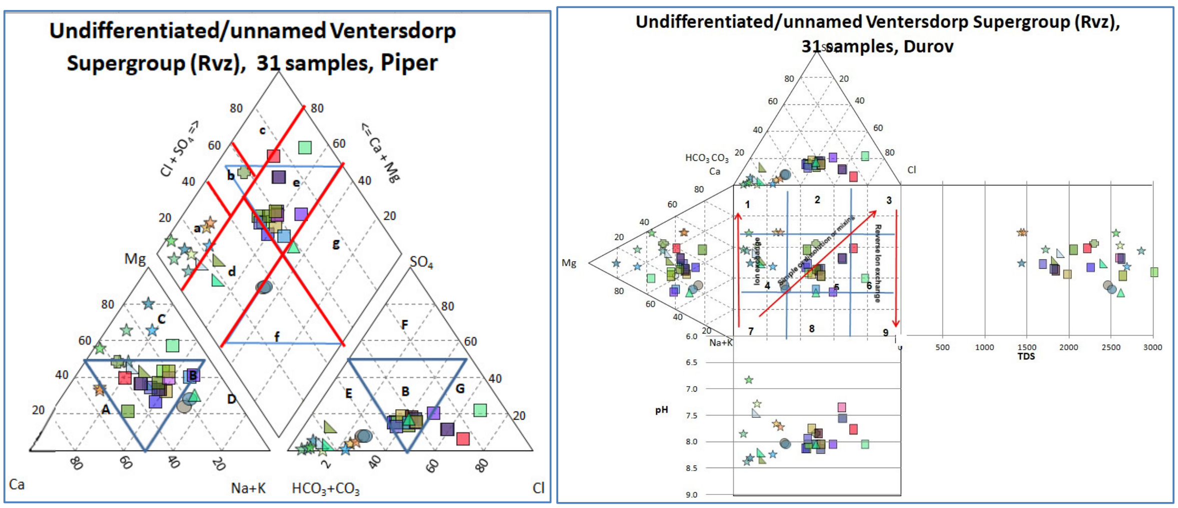


Figure 59: Trilinear diagrams, Piper, and Durov for the Undifferentiated Ventersdorp Supergroup (Rvz).

The trilinear Piper diagram, (Figure 59) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (90.3%), Weak acidic anions > Strong acidic anions (43.5%); Alkali >Alkali earths (9.7%); Strong acids > Weak acids (56.5%).

The groundwater in this unit classifies as:

- Mixed Calcium-Magnesium-Bicarbonate-Chloride type (29.1%);
- Mixed Calcium-Magnesium-Bicarbonate type (16.1%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride with prevailing Sodium (12.9%),
- Mixed Calcium-Magnesium-Chloride type (9.7%);
- Magnesium-Bicarbonate type (9.7%),
- Calcium-Bicarbonate type (9.7%),
- Sodium-Bicarbonate type (6.4%).
- Magnesium-Chloride (3.2%);
- Sodium-Bicarbonate-Chloride type (3.2%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- No dominant anion or cation, indicates water exhibiting simple dissolution or mixing (48.3%), plot along the dissolution or mixing line,
- Anion discriminant and Ca dominant, mixed water or water exhibiting simple dissolution. (34.5%),
- HCO_3 and Ca dominant, indication of recharge in sandstone (10.3%),
- Anion discriminates and Na is dominant, indicates probable mixing or uncommon dissolution influences (6.9%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 40: Chemical statistics for the Undifferentiated Ventersdorp Supergroup (Rvz).

Element / Parameter	Statistics Drawn from a population of 36 data points for the undifferentiated Ventersdorp Group (Rvz)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	34	6.7	8.3	7.8	7.8	7.3	8.0	8.2	0.3	4.4%
Electrical Conductivity (mS/m EC)	36	64.2	281.6	105.6	116.5	76.5	107.6	160.0	43.6	37.4%
Total Dissolved Salts (mg/l TDS)	34	526.0	2810.0	830.4	925.9	626.0	866.5	1271.4	403.2	43.6%
Calcium (mg/l Ca)	34	14.2	111.0	55.7	67.0	38.0	61.4	99.0	24.3	36.3%
Magnesium (mg/l Mg)	34	22.1	200.5	51.6	62.6	32.4	58.4	86.6	32.8	52.4%
Sodium (mg/l Na)	34	6.2	205.4	34.7	74.6	15.3	71.2	137.5	49.9	66.9%
Potassium (mg/l K)	34	0.5	10.0	2.7	4.4	1.8	3.6	10.0	2.9	66.7%
Chloride (mg/l Cl)	34	7.9	502.3	38.8	96.8	17.7	77.5	220.3	96.0	99.2%
Sulphate (mg/l SO_4)	34	2.0	218.0	12.4	42.7	5.5	44.1	60.8	40.8	95.4%
Total Alkalinity (mg/l) $CaCO_3$)	31	205.1	647.5	335.6	360.9	268.5	321.6	523.0	105.3	29.2%
Nitrate (mg/l N)	34	0.0	303.0	0.0	33.0	0.1	3.4	105.9	61.1	184.9%
Fluoride (mg/l F)	34	0.05	1.03	0.33	0.48	0.21	0.44	0.79	0.23	47.7%
Silicon as Si	25	10.9	34.5	17.6	19.0	13.3	19.0	27.4	5.6	0.3
Iron (Fe)	10	0.003	1.360	0.015	0.185	0.008	0.035	0.346	0.42	225.4%
Manganese (Mn)	10	0.001	0.190	0.004	0.048	0.001	0.050	0.082	0.06	115.0%
Ortho Phosphate as Phosphorus as PO4	30	0.003	0.750	0.005	0.130	0.003	0.000	0.750	0.28	217.3%
ZAR	34	0.11	3.88	0.70	1.65	0.34	1.64	3.49	1.10	66.7%
LSI	31	Langelier Saturation Index (LSI)			Slightly Scaling		**54.8%**	Highly Scaling		**0.0%**
		Highly corrosive		**0.0%**	Slightly corrosive		**0.0%**	Balanced Corrosion		**45.2%**

Table 40 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is ideal to good (86.1%) and marginal in 13.9% of the analysis in terms of the Electrical conductivity (EC) with values between 64.2 and 281.6mS/m.

The Total Dissolved Solids (TDS) is acceptable in 85.3% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 36 samples indicates elevated concentrations of Nitrate (N >10mg/l) in 32.4% and Magnesium (Mg > 200mg/l) in 2.9%; of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is predominantly slightly scaling (54.8%) and balanced (45.2%). The ZAR index indicates that 85.3% of the water is of a fair quality for irrigation (ZAR < 3).

The area underlain by this unit is predominantly mountainous, with groundwater primarily utilized for game, livestock watering, and supply to farm homesteads. No large-scale irrigation activities occur within the unit. Groundwater may also supply two rural villages located within the unit.

7.2.1.19 KWAGGASNEK FORMATION (Vkw)

The Kwaggasnek Formation, the second and older member of the Rooiberg Group, is, together with the Schrikkloof Formation, regarded as part of the Transvaal Supergroup. It predominantly comprises volcanic rocks. The upper part consists of the Union Tin Member, which is composed of shale, tuffaceous material, and agglomerate. (Agglomerate refers to large rock fragments associated with lava flows, ejected during explosive volcanic eruptions). A regional marker horizon, comprising a zone of quartzite xenoliths, occurs in the upper part of the formation and is overlain by the Union Tin Member.

The lower part of the formation is largely made up of massive, homogeneous rhyolite, which is locally flow-folded at the top. Pyroclastic flows dominate the sequence, with zones of minor, discontinuous sediments occurring sporadically, (SACS, 1980).

The Rooiberg lava attains its maximum development around the Nylstroom Syncline, where it is divided into two formations: the Schrikkloof Formation (Vsc) (younger member) and the Kwaggasnek Formation (Vkw). On the Thabazimbi map sheet, the occurrence of the Kwaggasnek Formation is confined to a small strip in the centre-east, which continues into the Modimolle map sheet (Figure 60). On the Modimolle map sheet, the groundwater resource unit is more widespread but still limited to narrow strips of outcrop. The unit covers approximately 0.01% of the total map area

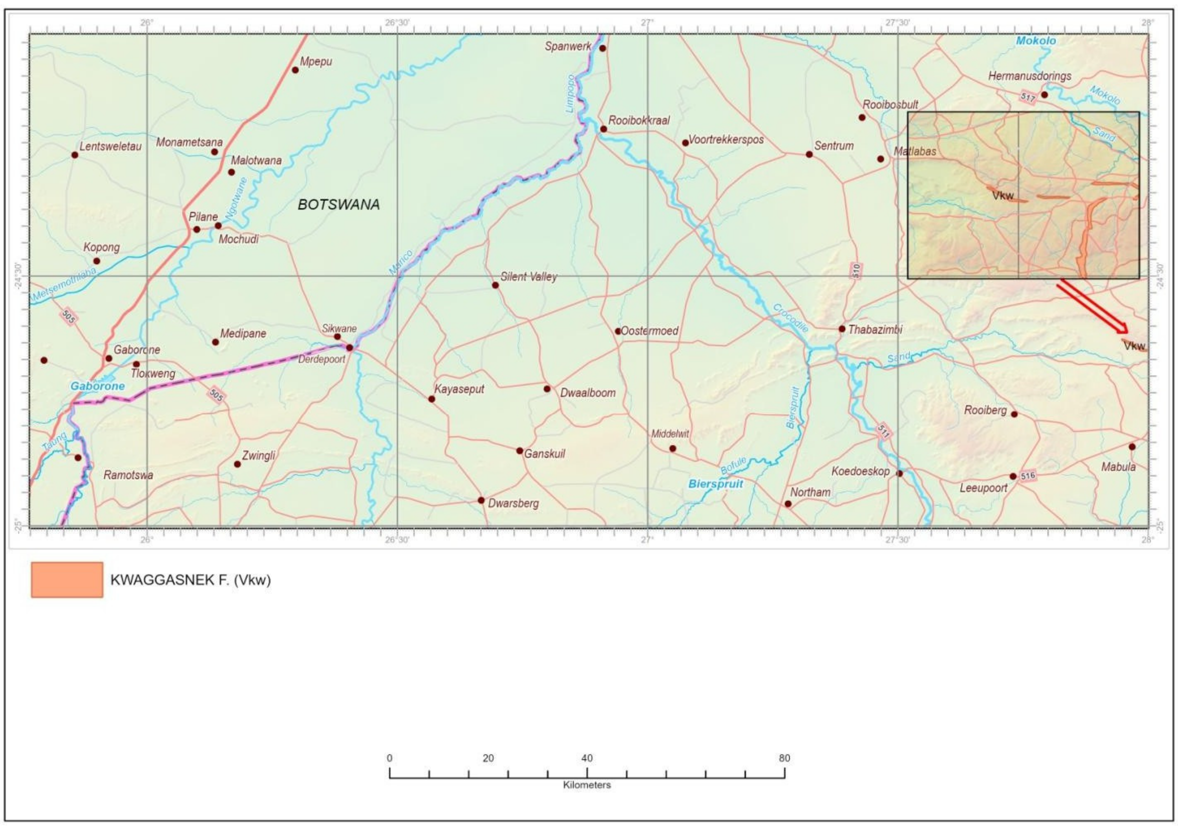


Figure 60: Geographical distribution of the Kwaggasnek Formation (Vkw) and the associated groundwater sampling points.

No information is available on borehole yields, water chemistry, borehole depths, water strike depths, or abstraction volumes for this groundwater resource unit. For more information on the groundwater resource unit, the Modimolle map sheet and brochure will provide more detail on the characteristics of the unit.

The unit occupies high ground and economic activities are limited. No large-scale abstraction occurs within the unit.

7.2.1.20 SCHRIKKLOOF FORMATION (Vsc).

The Schrikkloof Formation is the younger of the two members of the Rooiberg Group (upper formations). It comprises volcanic rocks, with the upper part consisting of ash-flow and tuffaceous material. The lower part is characterized by strongly flow-banded, fine-grained porphyritic rhyolite with intercalated pyroclastic deposits. Occasional quartzite lenses and quartzite xenoliths occur towards the base. The Schrikkloof Formation, together with the Kwaggasnek Formation, is currently regarded as part of the Transvaal Supergroup, (SACS, 1980).

The Rooiberg lava attains its maximum development around the Nylstroom Syncline, where it is divided into the Schrikkloof and Kwaggasnek formations. Within the Thabazimbi map sheet area, the Schrikkloof Formation outcrops as a narrow east-west trending strip that continues eastward into the Modimolle map sheet. A second, larger occurrence is present further south, in the south-eastern sector of the map. The Modimolle data was not combined for the assessment, as the cross-boundary occurrence within the Thabazimbi sheet is small compared to the much larger outcrop further east in the Modimolle area, (Figure 61). The unit covers approximately 1.1% of the total map area.

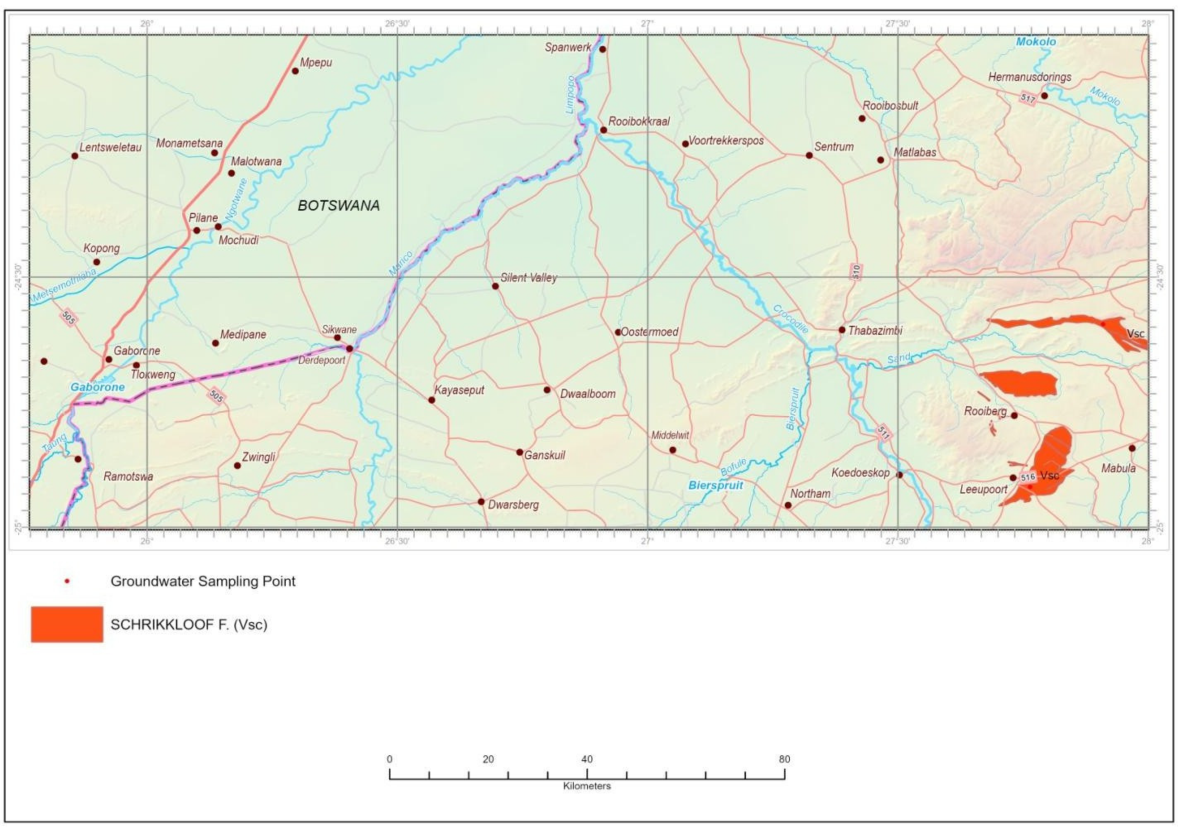


Figure 61: Geographical distribution of the Schrikkloof (Vsc) and the associated groundwater sampling points.

The groundwater potential of this unit is generally poor due to the low permeability and storativity of the rhyolite resulting in diminishing or failing yields after prolonged use of production boreholes. The low potential and its limited extent restrict the unit to an insignificant aquifer. Groundwater targets include faults and associated shear zones, fracture zones, and dyke contacts.

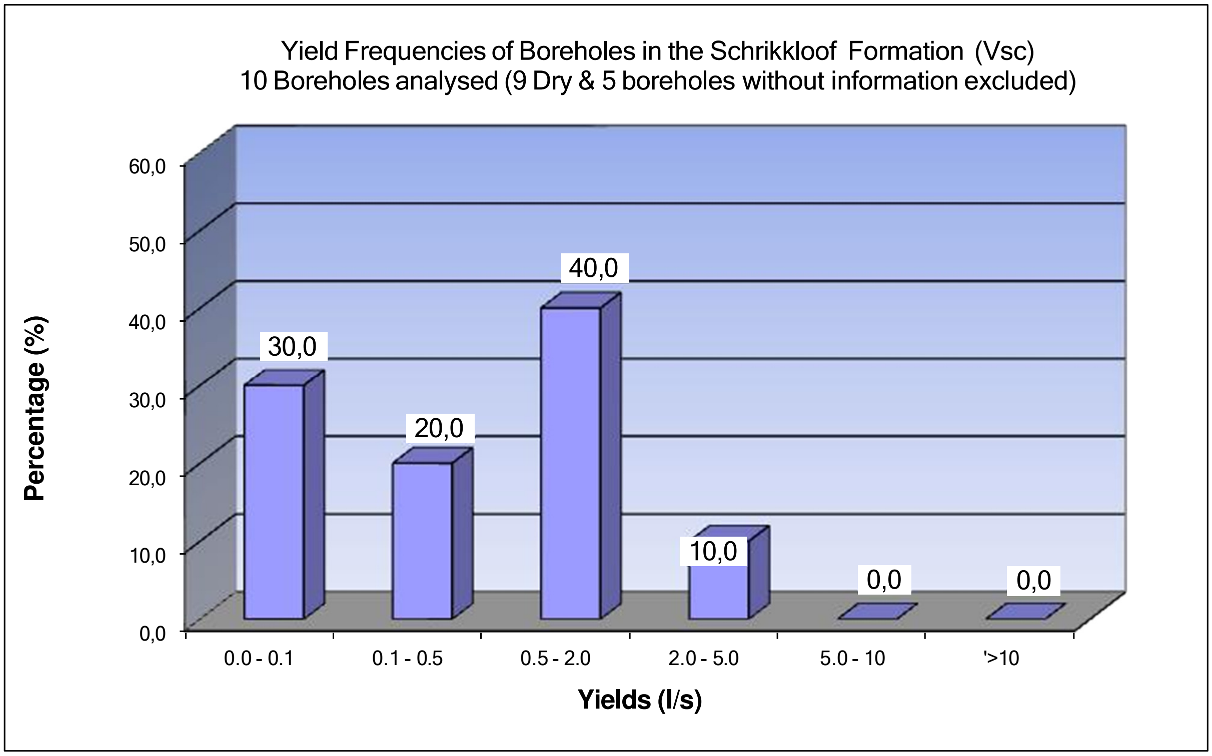


Figure 62: Yield frequency for fractured aquifers of the Schrikkloof Formation (Vsc).

The yield frequency distribution, (Figure 62) indicates that 50% of the successful boreholes yield less than 0.5ℓ/s. A further 40% of the boreholes yield between 0.5ℓ/s and 2ℓ/s, with only 10% of the boreholes yielding more than 2ℓ/s.

No information is available on borehole depths, water chemistry, water strike depths or abstraction volumes.

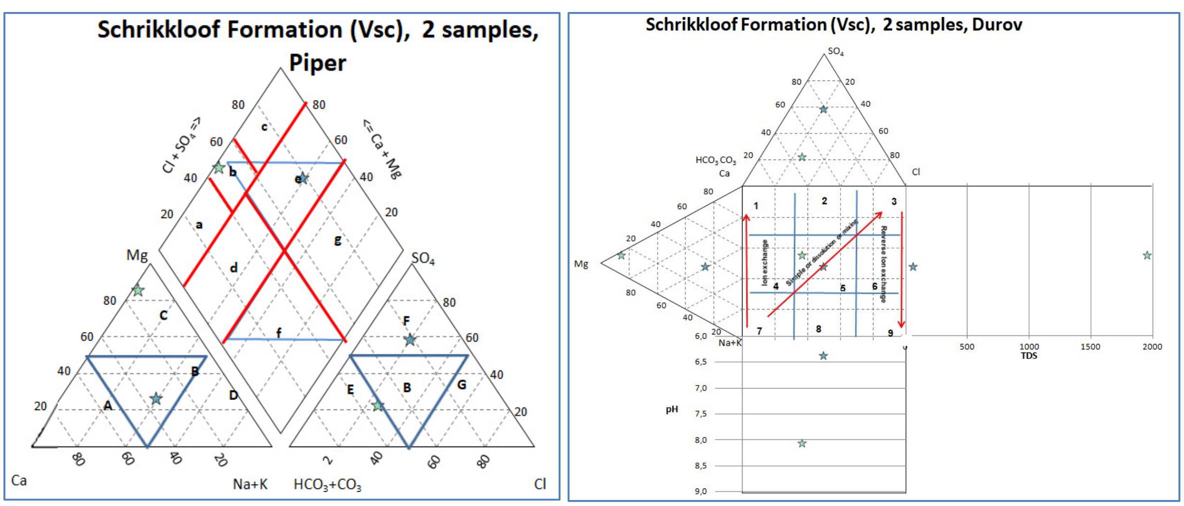


Figure 63: Trilinear diagrams, Piper, and Durov for the Schrikkloof Formation (Vsc).

The trilinear Piper diagram, (Figure 63) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions in order to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (100%), Weak acidic anions > Strong acidic anions (50%); Alkali >Alkali earths (0%); Strong acids > Weak acids (50%).

The groundwater in this unit classifies as:

- Mixed Calcium-Magnesium-Sulphate type with prevailing Sodium (50%),
- Magnesium-Bicarbonate type (50%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (100%), plot along the dissolution or mixing line,

Table 41: Chemical statistics for the Schrikkloof Formation (Vsc).

Element / Parameter	Statistics Drawn from a population of 2 data points for the Schrikkloof Formation (Vsc)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10^{th} percentile	50^{th} percentile (median)	90^{th} percentile	Standard Deviation	Coefficient of Variation
pH	2	6,31	8,02	7,06	7,16	6,48	7,16	7,85	1,21	16,9%
Electrical Conductivity (mS/m EC)	2	5,10	144,05	9,85	74,58	19,00	74,58	130,16	98,25	131,8%
Total Dissolved Salts (mg/l TDS)	2	52,00	1959,82	101,31	1005,91	242,78	1005,91	1769,04	1349,03	134,1%
Calcium (mg/l Ca)	2	3,00	57,82	5,70	30,41	8,48	30,41	52,34	38,76	127,5%
Magnesium (mg/l Mg)	2	1,40	244,14	2,78	122,77	25,67	122,77	219,87	171,64	139,8%
Sodium (mg/l Na)	2	3,30	9,56	4,91	6,43	3,93	6,43	8,94	4,43	68,9%
Potassium (mg/l K)	2	0,95	1,64	1,20	1,30	1,02	1,30	1,57	0,49	37,7%
Chloride (mg/l Cl)	2	5,00	81,52	9,42	43,26	12,65	43,26	73,87	54,11	125,1%
Sulphate (mg/l SO4)	2	19,70	101,11	32,98	60,41	27,84	60,41	92,97	57,57	95,3%
Total Alkalinity (mg/l) CaCO3)	2	14,90	483,34	28,91	249,12	61,74	249,12	436,49	331,24	133,0%
Nitrate (mg/l N)	2	0,05	49,33	0,10	24,69	4,98	24,69	44,40	34,85	141,1%
Fluoride (mg/l F)	2	0,01	0,20	0,01	0,10	0,03	0,10	0,18	0,14	132,4%
Silicon as Si	2	6,74	39,37	11,51	23,06	10,00	23,06	36,11	23,07	100,1%
Iron (Fe)	1	0,013	0,013	0,013	0,013	0,013	0,013	0,013		
Manganese (Mn)	1	0,002	0,002	0,002	0,002	0,002	0,002	0,002		
Ortho Phosphate as Phosphorus as PO4	2	0,006	0,007	0,007	0,007	0,006	0,007	0,007	0,00	12,3%
ZAR	2	0,12	0,39	0,19	0,26	0,15	0,26	0,37	0,19	74,3%
LSI	2	Langelier Saturation Index (LSI)			Slightly Scaling		**50,0%**	Highly Scaling		**0,0%**
		Highly corrosive		**50,0%**	Slightly corrosive		**0,0%**	Balanced Corrosion		**0,0%**

Table 41 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is good to ideal in terms of the Electrical conductivity (EC) with values ranging between 5.1 and 144.05mS/m.

The Total Dissolved Solids (TDS) is acceptable in 50% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 2 samples indicates elevated concentrations of Nitrate (N >10mg/l) in 50% and Magnesium (Mg > 200mg/l) in 50% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is highly corrosive (50%) to slightly scaling (50%). The ZAR index indicates that 100% of the water is of a fair quality for irrigation (ZAR < 3).

The unit predominantly occupies mountainous topography. The water abstracted supply people in farmsteads and lodges. Groundwater is also abstracted for livestock and game watering. No evidence of large-scale irrigation occurs within the unit.

In 50% of the water samples, at least one element exceeds the maximum allowed limits for domestic use. For this unit the anion of concern is Nitrate and the cation of concern is Magnesium. Note that the characterization of water chemistry is based on limited information.

7.2.2 CATEGORY C: KARST AQUIFERS.

The hydrogeological map series and accompanied brochures follow the same methodology for consistency. The Karst aquifer occurrence on the Thabazimbi map sheet however was divided into two groundwater resource units namely the Malmani Subgroup (Vma) and the Malmani Subgroup integrated with Pilanesberg dykes (Vds). The Malmani Subgroup was deposited during Vaalian times whilst the Pilanesberg Dyke System intruded the centre portion of Malmani only during post-Waterberg times. Despite the difference in age and the lack of hydrogeological data on the dyke system, it was decided to discuss the Malmani Subgroup together with the intruded dyke system as a separate groundwater resource unit, but still as a karst unit.

The geographical distribution of the Karst aquifers is shown as Figure 64. Karst aquifers cover approximately 10.3% of the total map area.

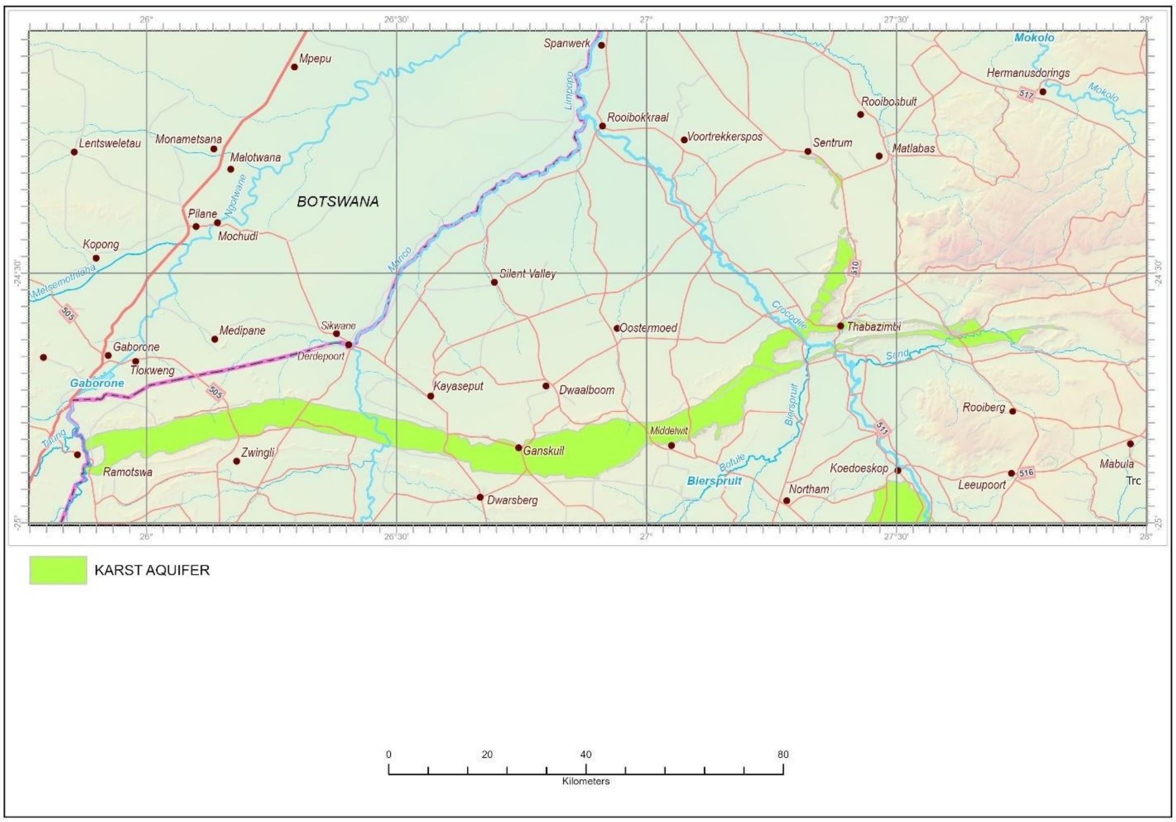


Figure 64: Geographical distribution of the Karst aquifers

7.2.2.1 MALMANI INTERGRATED WITH PILANESBERG DYKES (Vds).

Due to the unknown impact of the intrusive syenitic Pilanesberg dyke system on the groundwater characteristics of the Malmani Sub-Group, the Malmani dolomites are maintained and discussed as a Karst aquifer intruded by a dyke swarm i.e. Pilanesberg Dyke System. Due to the map scale, the locations of the dykes are not indicated but the portion of dolomite in which it occurs represents the unit.

During late or post Waterberg times, the Pilanesberg Dyke System or dyke swarm intruded the middle section of the Malmani Subgroup occurrence (emplaced during early Vaalian times) of the Thabazimbi map, (Figure 65). Detail mapping using aerial magnetic data, reveals that some of these dykes extend as far south as the Vaal River of which some, including the Robinson Dyke, strike through the Witwatersrand mining area. The Dyke System comprises syenite, nepheline syenite, monzonite, shonkinite, bostonite, diorite, and pyroxenite. It is a group of dykes that radiate in a south and south-easterly direction from the Pilanesberg Alkaline Ring Complex in the Pilanesberg National Park.

The Pilansberg Dyke System has also been correlated with a dyke swarm in south-eastern Botswana. The Pilanesberg Alkaline Ring Dyke Complex is one of the world's largest and best-preserved Alkaline Ring Dyke Complexes. It is a rare circular feature that emerged from the subterranean plumbing of an ancient volcano. The Complex was created about 1.2 billion years ago. The Pilanesberg area is fringed by three concentric rings of hills that rise from the surrounding plains. Mistakenly marketed by operators as an extinct volcano it is actually a very rare formation called a Ring Dyke Complex. In general terms a volcano must erupt at the surface but that did not happen. Instead, the magma cooled at depth before it erupted. It later collapsed in the centre, forming a volcano (now called the Mankwe dam). After millions of years of erosion, the remaining hard rock constitutes the mountains around the centre in concentric circles as currently visible. What we see now is not so much a volcanic crater, but a cross section through the magma pipes that were located deep below the mountain's summit.

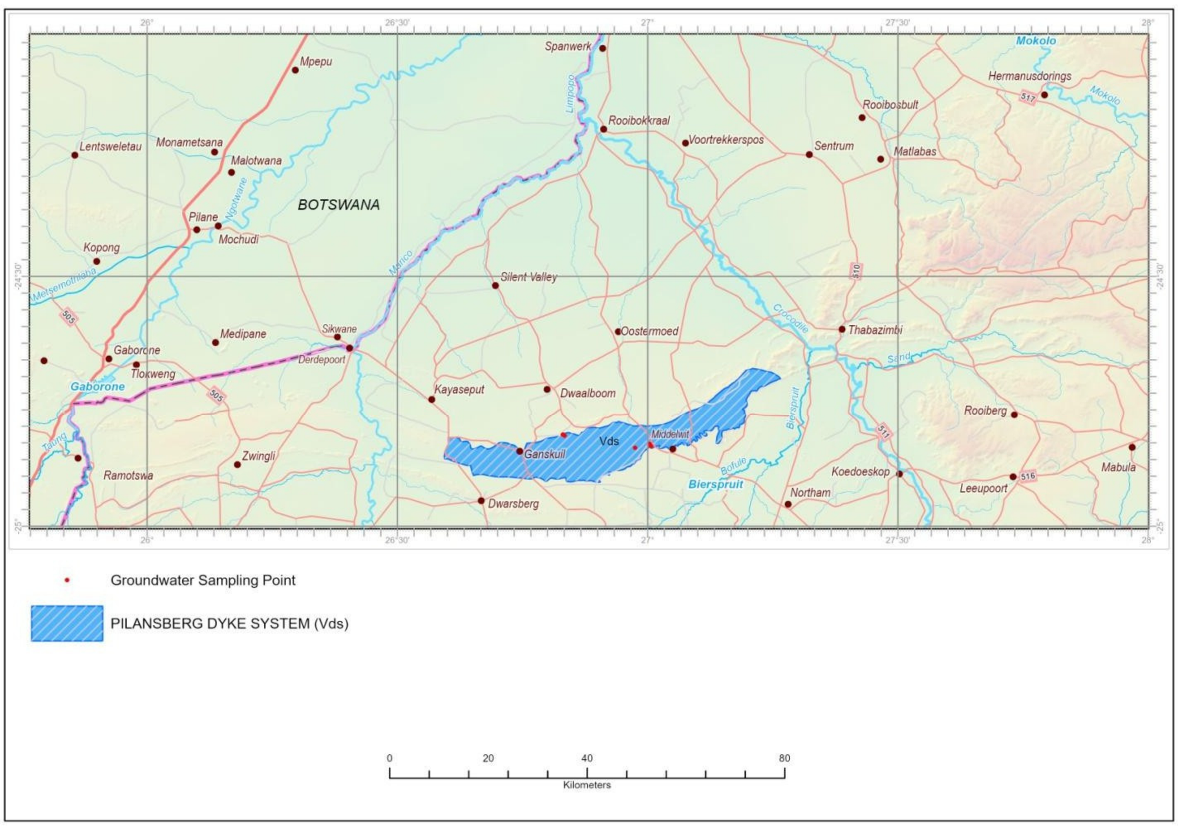


Figure 65: Geographical distribution of the Malmani Subgroup integrated with Pilanesberg dykes (Vds) and the associated groundwater sampling points.

Despite being a well-known geological event with a potential role in groundwater occurrence, the Pilanesberg Dykes could not be assessed as an aquifer on their own. The reason is that none of the collected information could confirm whether any of the boreholes in the intrusion area penetrated the dykes.

A median yield of 0.33ℓ/s was obtained for the dolomite with intrusive Pilanesberg dykes, whereas a median yield of 1.26ℓ/s was obtained for the dolomite with no intrusions. The statistics were obtained from 98 boreholes of which 44 had maximum yield data.

In terms of water quality, 25% of the water samples have at least one element that exceeds the maximum allowed limits for domestic use. For this unit the anion of concern is Sulphate.

Geophysical magnetic surveys targeting the Pilanesberg Dykes resulted in the conclusion that the response will be a negative anomaly in regard to the background values. The dykes are approximately 1300 million years old. Although the Pilanesberg Dykes are not investigated in detail in the research document, 'Karst of groundwater region 10' that represents a hydrogeological characterization of the Karst belt that occur more or less in a zone from Pretoria/Delmas in the east to Zeerust in the west, it is most likely that the dykes will form compartments within the dolomitic host rock.

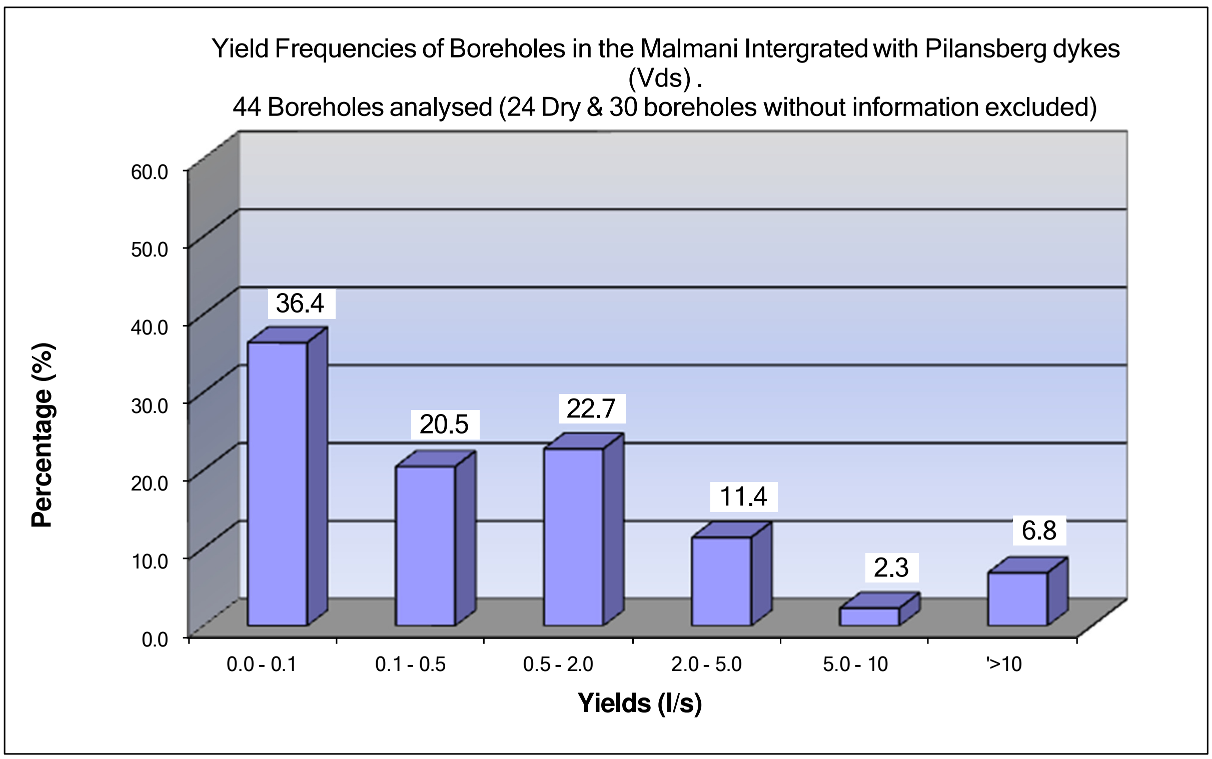


Figure 66: Yield frequency for fractured aquifers of the Malmani Subgroup integrated with Pilanesberg dykes (Vds).

The yield frequency distribution, (Figure 66) indicates that 56.9% of the successful boreholes yield less than 0.5ℓ/s. A further 22.7% of the boreholes yield between 0.5ℓ/s to 2ℓ/s and 11.4% of the boreholes between 2ℓ/s to 5ℓ/s. Only 2.3% of the boreholes yield between 5ℓ/s to 10l/s, with 6.8% of the boreholes yielding more than 10l/s.

Limited data is available on static water levels, borehole depths, installation depths and abstraction; only a single data point had information. The static water level is 8.03 meters below ground level (mbgl); the depth of the borehole is 58m; the installation depth is 51m and the daily recommended abstraction is 6.9 cubic meters per day (m³/day). The characterization in terms of the above will not be representative of the actual field conditions.

However, considering that 56.9% of successful boreholes yield less than 0.5ℓ/s indicates that the Formation may have a low potential. A proper scientifically orientated exploration project or a comprehensive hydro census may be initiated to research the hydrogeological properties of the unit.

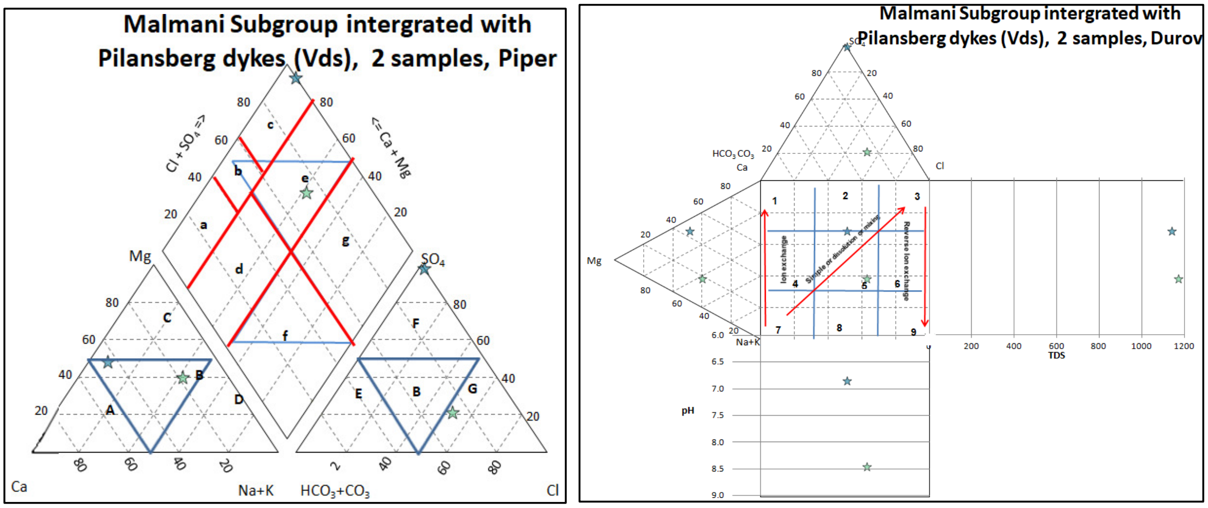


Figure 67: Trilinear diagrams, Piper and Durov for the Malmani Subgroup integrated with Pilanesberg dykes (Vds).

The trilinear Piper diagram, (Figure 67) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions in order to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (100%), Weak acidic anions > Strong acidic anions (0%); Alkali >Alkali earths (0%); Strong acids > Weak acids (100%).

The groundwater in this unit classifies as:

- Mixed Calcium-Magnesium-Sulphate type (50%);
- Mixed Calcium-Magnesium-Chloride type with prevailing Sodium (50%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- No dominant anion or cation indicates fresh recent recharge water exhibiting simple dissolution or mixing (100%), plot along the dissolution or mixing line.

Table 42: Chemical statistics for the Malmani Subgroup integrated with Pilanesberg dykes (Vds).

Element / Parameter	Statistics Drawn from a population of 5 data points for the Malmani Subgroup integrated with Pilansberg dykes (Vds)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	4	6.80	8.80	7.78	7.86	6.98	7.92	8.69	0.92	11.7%
Electrical Conductivity (mS/m EC)	4	52.2	159.6	97.0	116.7	71.1	127.5	153.6	46.7	40.0%
Total Dissolved Salts (mg/l TDS)	3	677.9	1176.0	938.3	1000.3	771.7	1147.0	1170.2	279.6	27.9%
Calcium (mg/l Ca)	3	63.60	165.10	89.40	104.53	67.86	84.90	149.06	53.52	51.2%
Magnesium (mg/l Mg)	3	84.60	113.40	100.94	102.70	89.70	110.10	112.74	15.76	15.3%
Sodium (mg/l Na)	4	4.20	164.70	10.84	52.47	6.21	20.50	124.32	75.62	144.1%
Potassium (mg/l K)	4	1.50	4.10	2.42	2.76	1.83	2.71	3.72	1.07	38.7%
Chloride (mg/l Cl)	4	8.10	250.40	13.71	70.85	8.85	12.45	179.57	119.73	169.0%
Sulphate (mg/l SO_4)	4	3.60	706.20	11.27	215.60	6.90	76.30	535.74	332.69	154.3%
Total Alkalinity (mg/l) $CaCO_3$)	2	261.40	361.20	303.30	311.30	271.38	311.30	351.22	70.57	22.7%
Nitrate (mg/l N)	4	0.16	7.02	0.51	2.93	0.39	2.27	6.00	3.10	105.9%
Fluoride (mg/l F)	4	0.06	0.47	0.17	0.36	0.18	0.46	0.47	0.20	55.8%
Silicon as Si	2	12.38	18.60	14.87	15.49	13.00	15.49	17.98	4.40	28.4%
Iron (Fe)	2	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.00	0.00%
Manganese (Mn)	2	0.006	0.591	0.012	0.299	0.065	0.299	0.533	0.41	138.6%
Ortho Phosphate as Phosphorus as PO4	2	0.003	0.005	0.004	0.004	0.003	0.004	0.005	0.001	35.4%
ZAR	3	0.18	3.18	0.37	1.27	0.23	0.45	2.63	1.66	130.8%
LSI	1	Langelier Saturation Index (LSI)			Slightly Scaling		**100.0%**	Highly Scaling		**0.0%**
		Highly corrosive		**0.0%**	Slightly corrosive		**0.0%**	Balanced Corrosion		**0.0%**

Table 43 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is ideal to good (75%) to marginal in (25%) of the analysis in terms of the Electrical conductivity (EC) with values ranging between 52.2 and 159.6mS/m.

The Total Dissolved Solids (TDS) is acceptable in 100% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 5 samples indicates elevated concentrations of Sulphate (SO4 >600mg/l) in 25% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is predominantly slightly scaling (100%). The ZAR index indicates that 66.7% of the water is of a fair quality for irrigation (ZAR < 3).

PPC Dwaalboom is falling within this unit as well as two rural villages, (Mokgalaneng & Disake). Water is used for monitoring, water supply to a manufacturing industry, rural water supply, a lodge, farmsteads and livestock and game watering. No evidence of large-scale irrigation occurs in the unit.

7.2.2.2 MALMANI SUBGROUP (Vma).

The Malmani Subgroup forms part of the Chuniespoort Group within the Transvaal Supergroup. It consists of an alternation of chert-bearing and chert free dolomite. The division between the different formations that constitute the Malmani Subgroup is based on the chert content and type of algal structures.

At its base, carbonaceous shale and quartzite are found in some localities. The contact with the underlying Black Reef Formation is gradational and conformable, an indication of continuous deposition of sediments, (Visser D.J.J. 1989).

In the Thabazimbi area, the thickness of the Malmani Subgroup varies between 200 and 1800m, (Vegter, J.R., 1984).

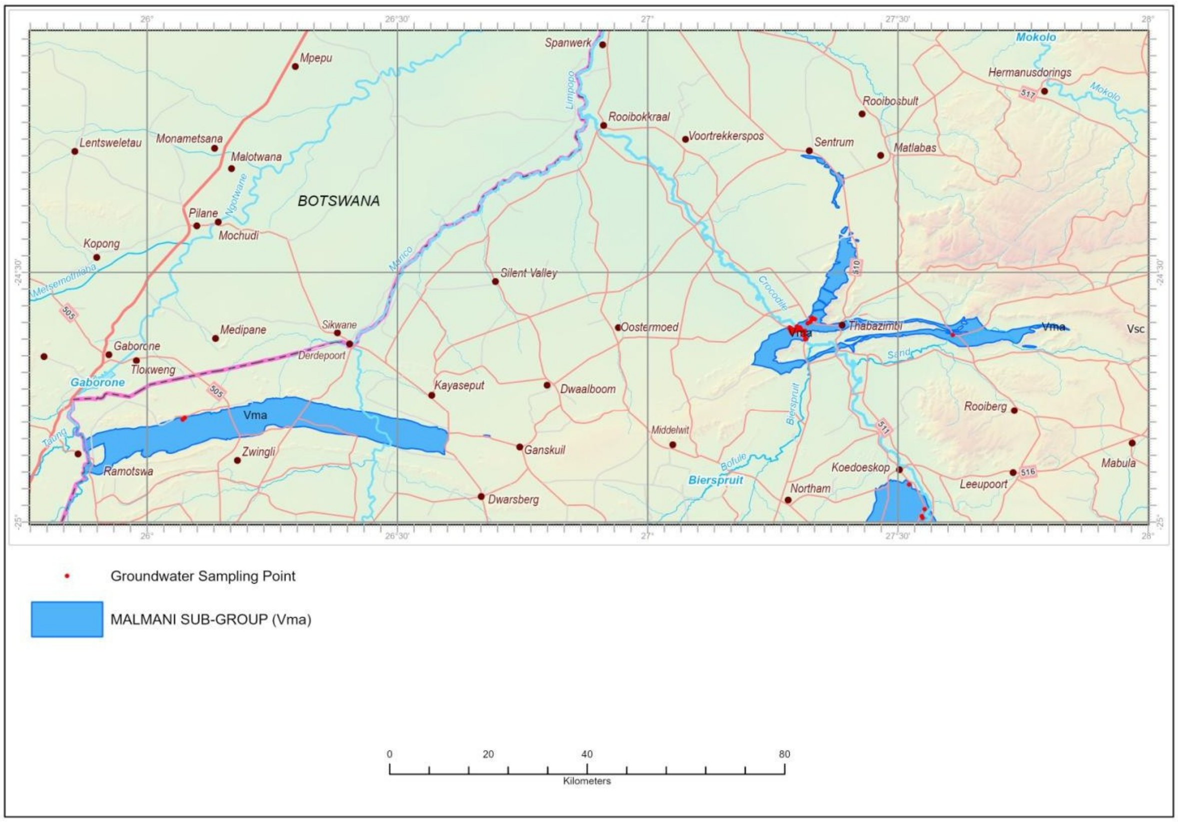


Figure 68: Geographical distribution of the Malmani Subgroup (Vma) and the associated groundwater sampling points.

Karst occurs mainly within the map sheet as a continuous outcrop in the form of an arch, (Figure 64, page 130). The Karst section in the centre of the arch is not indicated on the inset map, (Figure 68) as it is depicted as Malmani Intergrated with Pilanesberg Dykes. From the west (Limpopo River) the Malmani Subgroup stratigraphical unit is trending easterly up to the centre of the map where it turns to the north. Near Thabazimbi the northern striking section split in two with the one section following an easterly direction, (Figure 68). The dip of the unit is generally moderate (20-30º) and always towards the centre of the basin, but around the arch it is steep (60º); this corresponds to an average dip of 51º as reported at the old ISCOR iron mine area near Thabazimbi, (Hobbs, 1983).

The unit covers approximately 7.4% of the map area. A smaller outcrop is in the central-southern part of the map sheet in the area where the Mamba Cement Plant is located. Previous work on the dolomites in this area suggests that is essentially uncaverned, although isolated solution cavities might occur. Exploration boreholes drilled by the government indicated very little weathering of the dolomite below the alluvial overburden, (Bosazza, 1953 and Keyser, 1955).

The deposition of the Chuniespoort Group was within a shallowly submerged epeiric continental platform on which cyanobacteria flourished and formed the thick stromatolitic carbonate beds associated with the Malmani Subgroup. After a period of uplift, a clastic epicontinental sea formed on the craton which marked the end of the chemical (carbonate and banded iron stone) sedimentation. The subsequent deposition of the Pretoria Group on the basin within the Kaapvaal Craton marks a radical change in environment during the Palaeoproterozoic, (Eriksson et al., 2006). Deposition of clastic sediment was accompanied by the extrusion of significant thicknesses of volcanic deposits.

Dissolution of dolomite will lead to the development of a Karst landscape that is characterized by features such as subsistence (dolines and sinkholes) and the formation of caves that are very common in the Malmani Subgroup in other areas such as the Tarlton area. Martini and Kavalieris, (1976), identified 4 types of karst morphology on the Malmani Dolomite. Within the map sheet the type is the Bushveld type where caves are uncommon.

The dolomite is covered in the map area over wide areas by a mantle of red sandy soil and residual debris of highly variable thickness. The mantle is derived from recent dolomitic dissolution and the weathering of older pre-existing and incorporated karst regolith. Incorporated in the mantle are fluvial and aeolian Quaternary sediments. The debris reaches more than 150m in places and consists typically of angular fragments of chert, grit, sand, clay and manganiferous earth in highly variable proportions, (Vegter, J.R., 1984). Drilling can thus be extremely difficult in such areas that will influence groundwater development financially.

Priority targets in the Malmani Subgroup unit will be dykes, sills, faults, joints and bedding planes that may enhance dissolution along the contact zones. The chert rich dolomite is regarded to have a greater potential for groundwater development than the chert free dolomite. Features in the Malmani dolomite more to the south of the map area includes 'geological valleys' filled with residual debris and Karoo strata, (Vegter, J.R., 1984).

The occurrence of groundwater in dolomitic aquifers can be divided into compartments if enough detail is available, especially on static groundwater levels, the location of regional dykes as interpreted from remote sensing techniques and aerial geophysical methods such as aerial magnetic surveys. This is as large dykes and sills can form impermeable boundaries within the dolomite thus one compartment can have a different average static water table that can differ from the next. The dolomite west of Pretoria was extensively covered in various reports with the most comprehensive being the report, (Groundwater Region 10 Karst Belt, 2014) No information could be obtained regarding compartments within the dolomite of the map area; the availability of information on groundwater sources, especially static water levels, were limited.

In the search for groundwater the gravity geophysical method is extensively used in dolomitic areas. It is also extensively used for geotechnical investigations for infrastructure development. Where regional areas are covered, Residual Bouguer anomaly maps are produced to interpret the thickness of the overburden below the surface or for depicting mass excesses (dolomitic bedrock) and mass deficiencies (residual debris and leached dolomite). The magnetic and electromagnetic methods are used to locate dykes within the dolomite, (Vegter, J.R., 1984).

The author was involved with a problematic borehole in the Tarlton area, (south of map boundary). The borehole had a very high yield (>60ℓ/s) and was the only production borehole supplying a large daily volume. After a few years the borehole started to pump sand. It was re-drilled and 40m of Karoo sand was encountered. It was concluded that due to the pumping, sand mitigated towards the borehole. In the Klerkskraal Dam area (south of map boundary) boreholes are often developed that encounter excessive wad, thus leading to the colouring of the water (muddy). Farmers in the area stated that continuous pumping over time will result in clear water. The areas where this problem occurs is within the Malmani dolomite that is characterized by Kars landscape overlain by thick highly weathered dolomite (wad) and shallow to deep caves with wad mobilized or deposited in caves and voids. Caves are reported in borehole logs at depths up to 114m although it is possible that deeper caves may occur. The conditions within the dolomite of the map area may differ from the above as caves are uncommon.

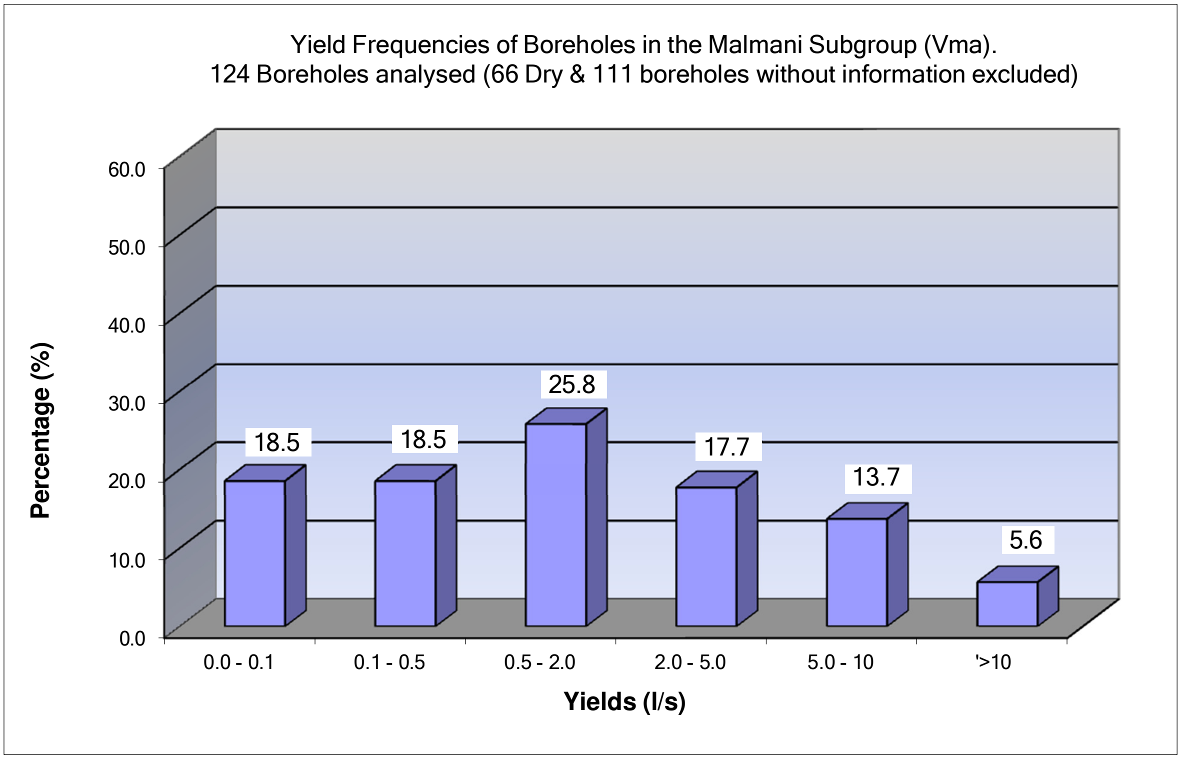


Figure 69: Yield frequency for fractured aquifers of the Malmani Subgroup (Vma).

The yield frequency distribution, (Figure 69) indicates that 37.1% of the successful boreholes yield less than 0.5ℓ/s. A further 25.8% of the boreholes yield between 0.5ℓ/s and 2ℓ/s and 17.7% of the boreholes yield between 2ℓ/s and 5ℓ/s. For 13.7% of the boreholes the yield is between 5ℓ/s and 10ℓ/s, with only 5.6% of the boreholes yielding more than 10ℓ/s.

The static water level ranges from 6 meters below ground level (mbgl) to 44.2mbgl, with a median of 8.13mbgl and an average of 15.03mbgl; (based on 12 data points). The maximum depth recorded is 174m, with an average of 75.7m and a median depth of 100m; (15 data points). Limited data is available on installation depths and abstraction, only a single borehole had data, the installation depth is 45m and the abstraction is 190m^3/day.

Activities not related to farming within the unit are limited as the largest area is used for game and livestock. It is therefore most likely that extensive research or groundwater development was not yet conducted in the area. A proper scientifically orientated exploration program or a comprehensive hydro census may be initiated to research the hydrogeological properties of the unit.

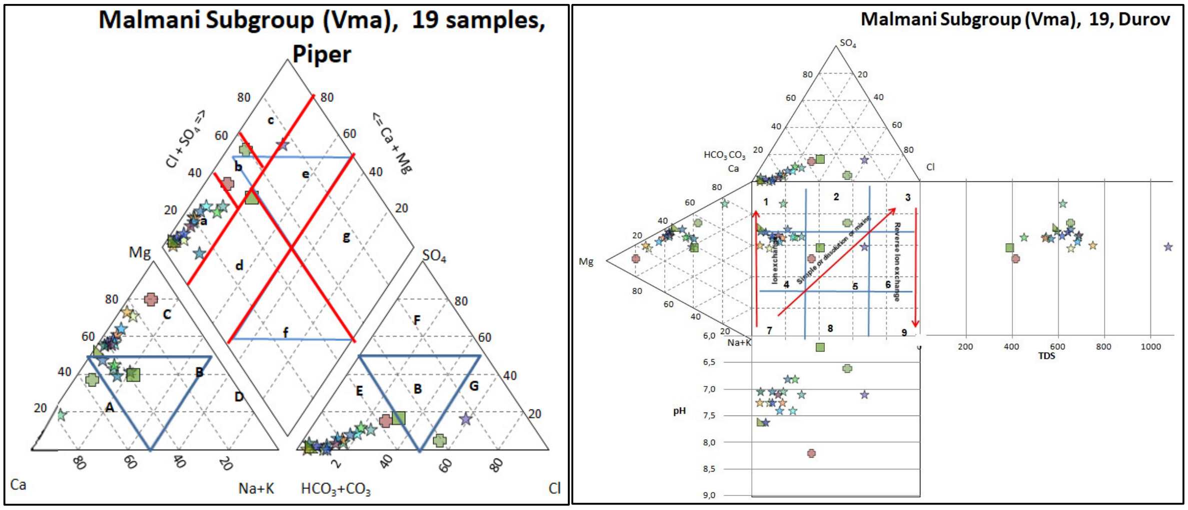


Figure 70: Trilinear diagrams, Piper and Durov for the Malmani Subgroup (Vma).

The trilinear Piper diagram, (Figure 70) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions in order to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (100%), Weak acidic anions > Strong acidic anions (89.5%); Alkali >Alkali earths (0%); Strong acids > Weak acids (10.5%).

The groundwater in this unit classifies as:

- Magnesium-Bicarbonate type (57.7%),
- Mixed Calcium-Magnesium-Bicarbonate type (15.8%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type (5.3%);
- Mixed Calcium-Magnesium-Bicarbonate prevailing Sodium and Chloride type (5.3%);
- Mixed Calcium-Magnesium-Chloride type (5.3%);
- Calcium-Chloride type (5.3%);
- Calcium-Bicarbonate type (5.3%)

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (63.2%),
- HCO_3 and Ca dominant, indicates recharge water in limestone (15.8%),
- No dominant anion or cation indicates fresh recent recharge water exhibiting simple dissolution or mixing (10.4%), plot along the dissolution or mixing line,
- Dominated by Ca and HCO_3 and significant Mg, dolomite type of water (5.3%),
- Cl dominant anion and Na dominant cation reverse ion exchange of Na-Cl waters (5.3%),

Table 43: Chemical statistics for the Malmani Subgroup (Vma).

Element / Parameter	Statistics Drawn from a population of 39 data points for the Malmani Subgroup (Vma).									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	32	6,70	8,45	7,66	7,68	7,11	7,70	8,08	0,38	4,9%
Electrical Conductivity (mS/m EC)	38	48,60	202,00	94,09	103,26	73,57	89,40	168,30	35,11	34,0%
Total Dissolved Salts (mg/l TDS)	26	302,00	1275,00	678,75	735,59	512,00	745,00	866,00	205,28	27,9%
Calcium (mg/l Ca)	26	16,50	302,30	73,56	102,61	51,70	81,50	169,55	61,58	60,0%
Magnesium (mg/l Mg)	26	23,90	303,65	59,21	82,07	34,50	67,60	120,50	60,79	74,1%
Sodium (mg/l Na)	26	5,40	83,50	11,76	21,09	6,00	13,20	41,50	20,41	96,8%
Potassium (mg/l K)	26	0,72	13,15	1,84	2,97	1,02	2,08	5,70	2,63	88,6%
Chloride (mg/l Cl)	26	4,90	287,90	19,91	60,80	8,60	28,00	190,30	81,73	134,4%
Sulphate (mg/l SO_4)	26	1,88	133,00	7,21	27,79	2,00	17,65	74,00	34,69	124,9%
Total Alkalinity (mg/l) $CaCO_3$)	26	205,00	579,80	374,30	395,95	284,15	405,65	489,55	86,21	21,8%
Nitrate (mg/l N)	31	0,02	23,07	0,32	5,00	0,38	2,87	10,67	5,88	117,5%
Fluoride (mg/l F)	26	0,05	8,40	0,21	0,61	0,13	0,28	0,55	1,60	263,0%
Silicon as Si	20	6,80	40,00	13,06	15,36	9,07	14,26	18,73	7,90	51,4%
Iron (Fe)	8	0,0001	0,710	0,001	0,092	0,002	0,003	0,220	0,25	270,5%
Manganese (Mn)	9	0,0001	2,002	0,001	0,262	0,001	0,003	0,560	0,66	250,8%
Ortho Phosphate as Phosphorus as PO4	18	0,003	0,026	0,004	0,006	0,003	0,003	0,013	0,01	100,8%
ZAR	26	0,06	1,36	0,22	0,39	0,12	0,28	0,82	0,35	88,5%
LSI	20	Langelier Saturation Index (LSI)			Slightly Scaling		**75,0%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**0,0%**	Balanced Corrosion		**25,0%**

Table 43 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is ideal to good (86.8%) to marginal in (13.2%) of the analysis in terms of the Electrical conductivity (EC) with values ranging between 48.6 and 202mS/m.

The Total Dissolved Solids (TDS) is acceptable in 92.3% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 39 samples indicates elevated concentrations of Magnesium (Mg > 200mg/l) in 7.7%; Nitrate (N >10mg/l) in 6.5%; Calcium (Ca > 300) in 3.8% and Fluoride (F >1.5mg/l) in 3.8% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is predominantly slightly scaling (70%) and balanced (30%). The ZAR index indicates that 100% of the water is of a fair quality for irrigation (ZAR < 3).

A section of the unit in the west is part of the Madikwe game reserve with associated lodges and game watering. The rest of the area, water is predominantly used for farmstead and livestock watering. The only abstraction for large-scale irrigation occurs in the eastern part of the unit along the Sandriver. Within this section the Mamba Cement manufacturing plant occurs, high-quality limestone is mined that are used in the process.

In 7.7% of the water samples, at least one element exceeds the maximum allowed limits for domestic use. For this unit the cation of concern is Magnesium.

7.2.3 CATEGORY D: INTERGRANULAR AND FRACTURED AQUIFERS

- Irrigasie Formation (P-Tr)
- Ecca Formation (Ppe)
- Nebo Granite (Mn)
- Rashoop Granophyre Suite (Mr)
- Diabase Intrusions (N-Za)
- Undifferentiated Rustenburg Layered Suite (Vrs)
- Crocodile River Fragment (Vco)
- Gaborone Granite (Zga), includes unnamed Hyperite
- Granite and Granite Gneiss, Western Transvaal Belt (Zjt)
- Modipe Gabbro Complex (Zme)
- Swaziland System (Basic & ultrabasic rocks of the area correlated with Archaean & Jamestown Complexes (Zsj)

Intergranular and fractured aquifers cover approximately 44.7% of the total map area. Figure 71 shows the Geographical distribution of the intergranular and fractured aquifers.

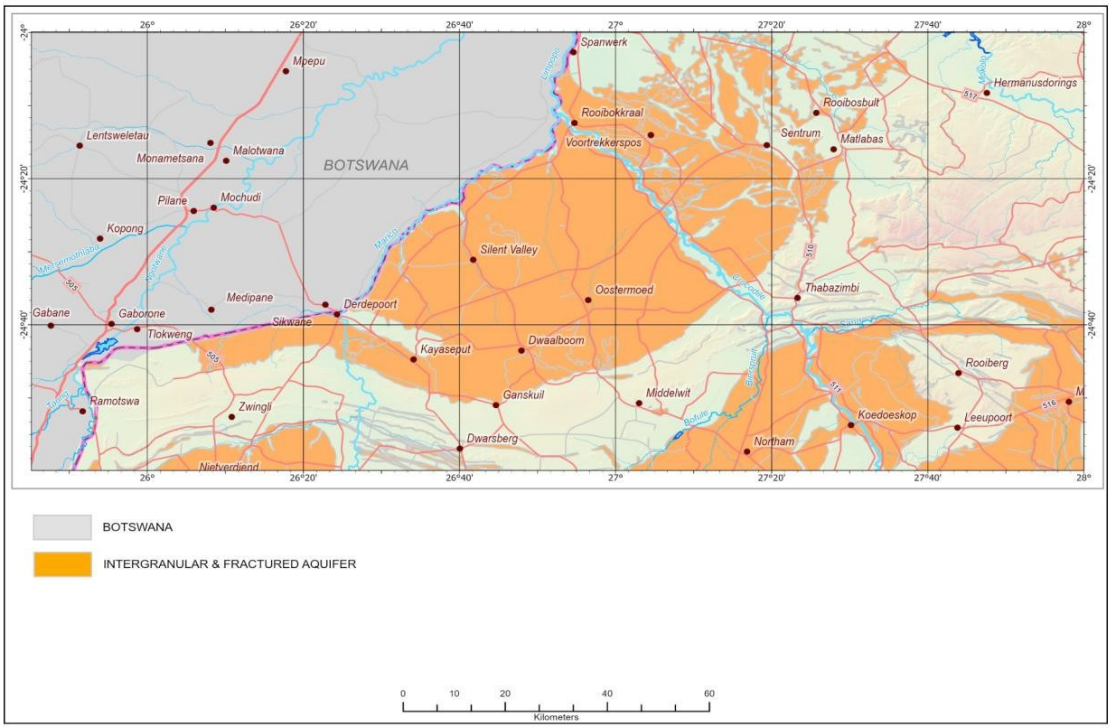


Figure 71: Geographical distribution of the intergranular and fractured aquifers on the Thabazimbi map sheet.

7.2.3.1 IRRIGASIE FORMATION (P-Tr).

The Irrigasie Formation, which underlies the Clarens Formation in the map area, occurs only as a small outcrop in the south-eastern section of the map, where it extends into the Modimolle map area (Figure 72). This Formation consists of a succession of mudstone, siltstone, sandstone, conglomerate, shale, grit, and marl, and is intruded by minor dolerite dykes and sills. Within the Thabazimbi map sheet, the occurrence is limited to the south-eastern section, covering approximately 0.37% of the total map area.

The sedimentary rocks of the Irrigasie Formation exhibit low to very low primary permeability and low storage potential. Despite this, a high number of successful boreholes, though many are low-yielding, suggest that it is not difficult to find sufficient water for single household use or livestock watering.

Groundwater occurrence in these sedimentary rocks is controlled either by lithology (such as the contact zones between different sediment types) or by secondary structures (such as fractures or joints developed locally along bedding planes). Groundwater can also be found in more extensively developed fractures, joints, faults, and associated shear zones. These secondary structures were formed by regional tectonics associated with the two synclinal flexures and post- Karoo tectonic episodes, (Fayazi, 1994). Minor dolerite intrusions, occurring as dykes and sills, also created additional secondary fractures and joints at their contact with the host rock.

The depth to the groundwater level in the area varies between 10 and 20 meters, (Fayazi, 1994).

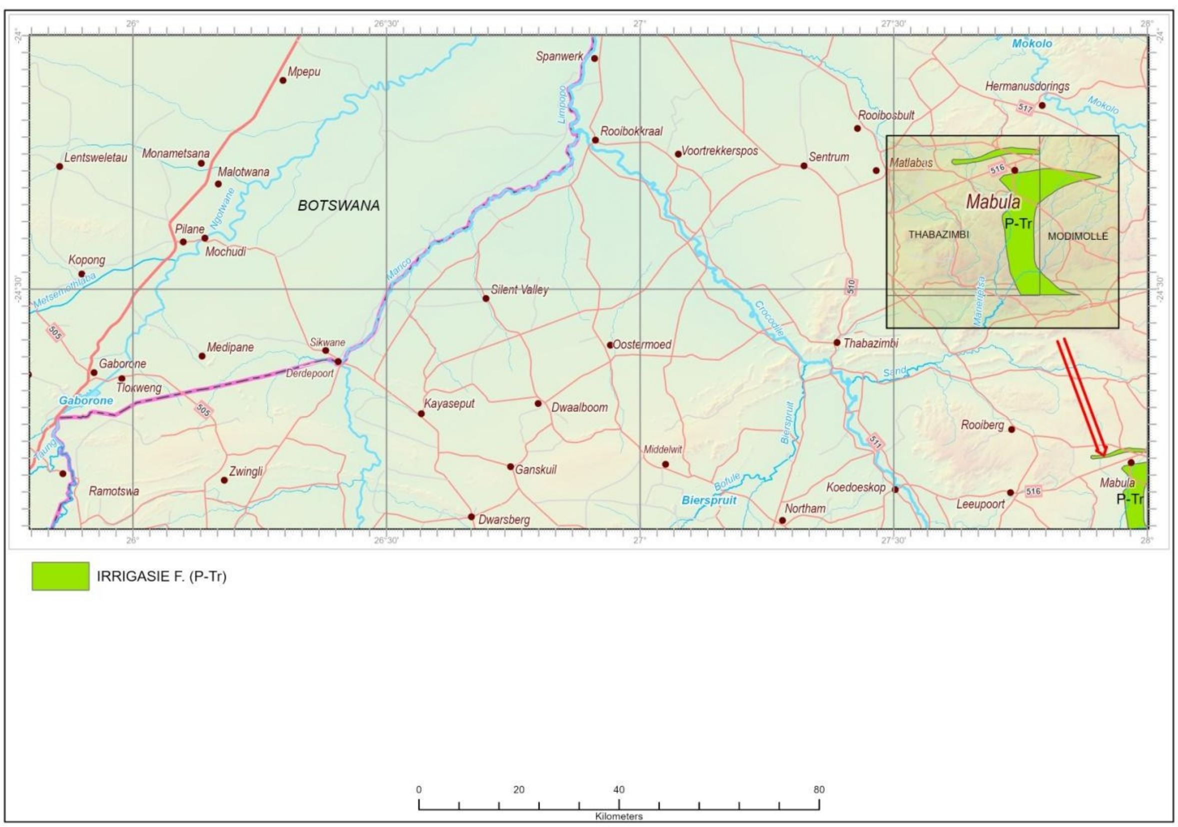


Figure 72: Geographical distribution of the Irrigasie Formation (P-Tr) and the associated groundwater sampling points.

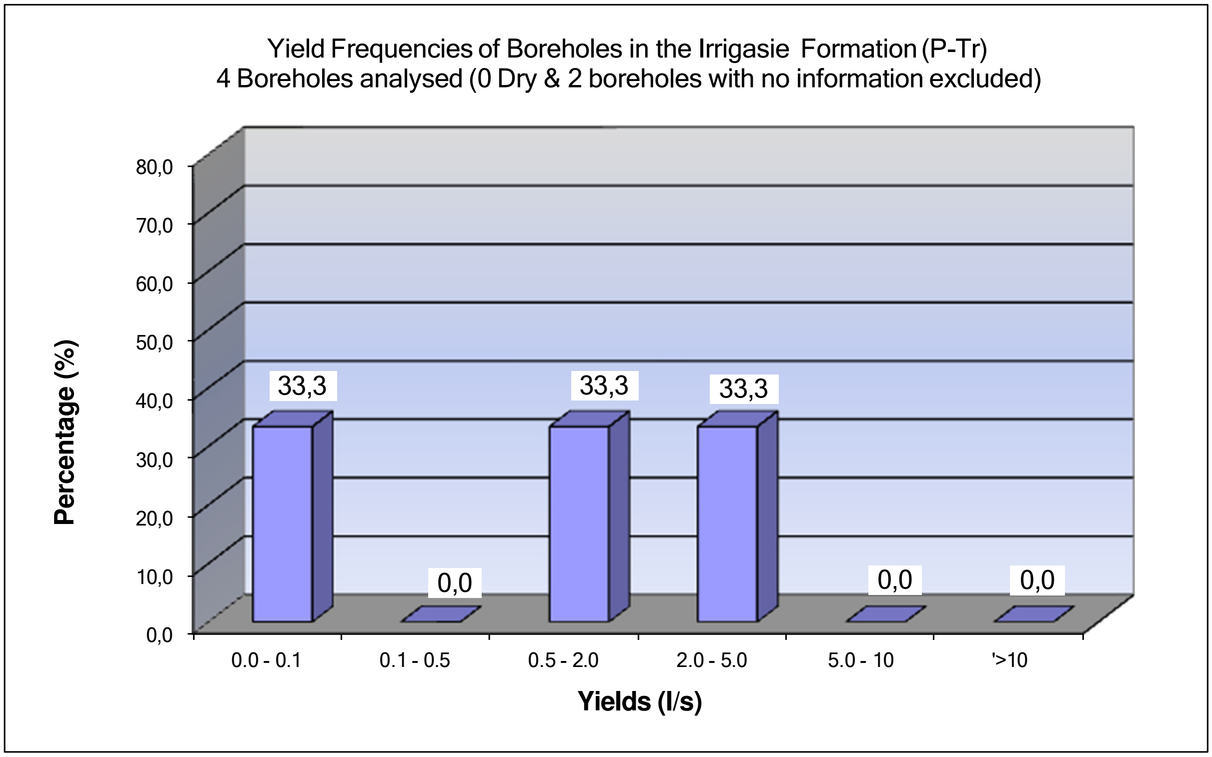


Figure 73: Yield frequency for the intergranular and fractured aquifers of the Irrigasie Formation (P-Tr).

Due to limited data the yield diagram, (Figure 73) may not be representative of the aquifer unit. Data is available for 3 boreholes; the statistics show that 66.6% of the boreholes yield less than 2ℓ/s and a single borehole that represent 33.3% of the boreholes yield between 2ℓ/s and 5ℓ/s.

No information is available on borehole depths, water strike depths or abstraction volumes for this groundwater resource unit; therefore, a proper characterization could not be done. Only 2 chemical analyses were available, these two samples could not be used for the Durov and Piper diagrams as the data did not pass the accuracy of the chemical analysis. The accuracy was checked by the plausibility of the Electrical Conductivity (EC) and Electro Neutrality (E.N). For more information on the groundwater resource unit the Modimolle map sheet and brochure will provide more detail on the characteristics of the unit.

Table 44: Chemical statistics for the Irrigasie Formation (P-Tr).

Element / Parameter	Statistics Drawn from a population of 2 data points for the Irrigasie Formation (P-Tr)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	2	7,35	7,60	7,47	7,47	7,37	7,47	7,57	0,18	2,4%
Electrical Conductivity (mS/m EC)	2	36,1	44,1	39,7	40,1	36,9	40,1	43,3	5,7	14,2%
Total Dissolved Salts (mg/l TDS)	1	325,7	325,7	325,7	325,7	325,7	325,7	325,7		
Calcium (mg/l Ca)	2	34,70	39,69	37,03	37,19	35,20	37,19	39,19	3,53	9,5%
Magnesium (mg/l Mg)	2	8,40	25,75	12,67	17,07	10,13	17,07	24,01	12,27	71,8%
Sodium (mg/l Na)	2	10,33	31,60	15,57	20,96	12,45	20,96	29,47	15,04	71,8%
Potassium (mg/l K)	1	0,55	0,55	0,55	0,55	0,55	0,55	0,55		
Chloride (mg/l Cl)	2	4,50	5,61	4,99	5,05	4,61	5,05	5,50	0,78	15,5%
Sulphate (mg/l SO_4)	2	5,00	12,19	7,09	8,60	5,72	8,60	11,47	5,09	59,2%
Total Alkalinity (mg/l) $CaCO_3$)	1	168,88	168,88	168,88	168,88	168,88	168,88	168,88		
Nitrate (mg/l N)	2	0,75	3,33	1,22	2,04	1,01	2,04	3,07	1,82	89,4%
Fluoride (mg/l F)	2	0,21	1,10	0,36	0,66	0,30	0,66	1,01	0,63	95,7%
Silicon as Si	1	17,77	17,77	17,77	17,77	17,77	17,77	17,77		
Iron (Fe)	0									
Manganese (Mn)	0									
Ortho Phosphate as Phosphorus as PO4	1	0,021	0,021	0,021	0,021	0,021	0,021	0,021		
ZAR	2	0,31	1,25	0,50	0,78	0,41	0,78	1,16	0,66	84,6%
LSI	1	Langelier Saturation Index (LSI)			Slightly Scaling		**0,0%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**0,0%**	Balanced Corrosion		**100,0%**

Table 44 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. The overall water quality in terms of the electric conductivity (EC) is ideal with values between 36.1 and 44.1mS/m. In the adjacent map where the unit is more widespread the water quality was reported to be marginal to poor.

The Total Dissolved Solids (TDS) is acceptable in both the available analyses (TDS ≤ 1200mg/l). No problematic chemical parameters were identified but in the adjacent Modimolle hydrogeological map sheet 105 chemical analyses were evaluated. For the groundwater resource unit in the adjacent map 26.7% of the water samples were not acceptable for human consumption. The anions of concern are Fluoride, Chloride and Nitrate. The cations of concern are Magnesium, Sodium and Calcium.

For the occurrence in the Thabazimbi map sheet the Langelier Saturation Index (LSI) indicates that the water from both analyses is balanced. For the adjacent map sheet the water was corrosive but predominantly slightly scaling (67.6%) and 25.4% balanced and the ZAR index indicated that 20.8% of the water is of a fair quality for irrigation (ZAR < 3). For the two samples within the Thabazimbi map sheet both is of a fair quality.

The total irrigation area utilizing centre pivots within this unit is approximately 60 hectares, based on Google imagery. The centre pivots are most likely operated on a three-year rotational basis. The source of water for these centre pivots is currently unknown.

Other cultivated areas in the unit employ dryland farming methods, relying solely on rainfall for crop production.

For more detailed information on this groundwater resource unit, the adjacent Modimolle Map Sheet can be consulted, as it provides further insights into the occurrence of the unit within the Springbok Flats Basin.

7.2.3.2 ECCA GROUP (Ppe)

The Ecca Group forms part of the Karoo Supergroup. Within the map area, a small remnant of the Ecca Group is located near the Botswana border in the north-western sector of the map sheet. The Ecca rocks overlay Archaean rocks of the Western Transvaal Mobile Belt and are extensively covered by Tertiary to Quaternary Kalahari sand. Another occurrence is found in the south- eastern corner of the map sheet, where it extends as part of the Settlers-Tuinplaas Basin, located some distance west of the Springbok Flats Basin. The Ecca Group groundwater resource unit covers approximately 0.37% of the map area, (Figure 74).

The Springbok Flats occurrence consists of an unclassified succession of fine-grained sandstone and shaly sandstone, interbedded with shale and siltstone, with a maximum thickness of approximately 100 meters. This succession may be equivalent to the Vryheid Formation of the Main Karoo Basin, (De Jager, 1984).

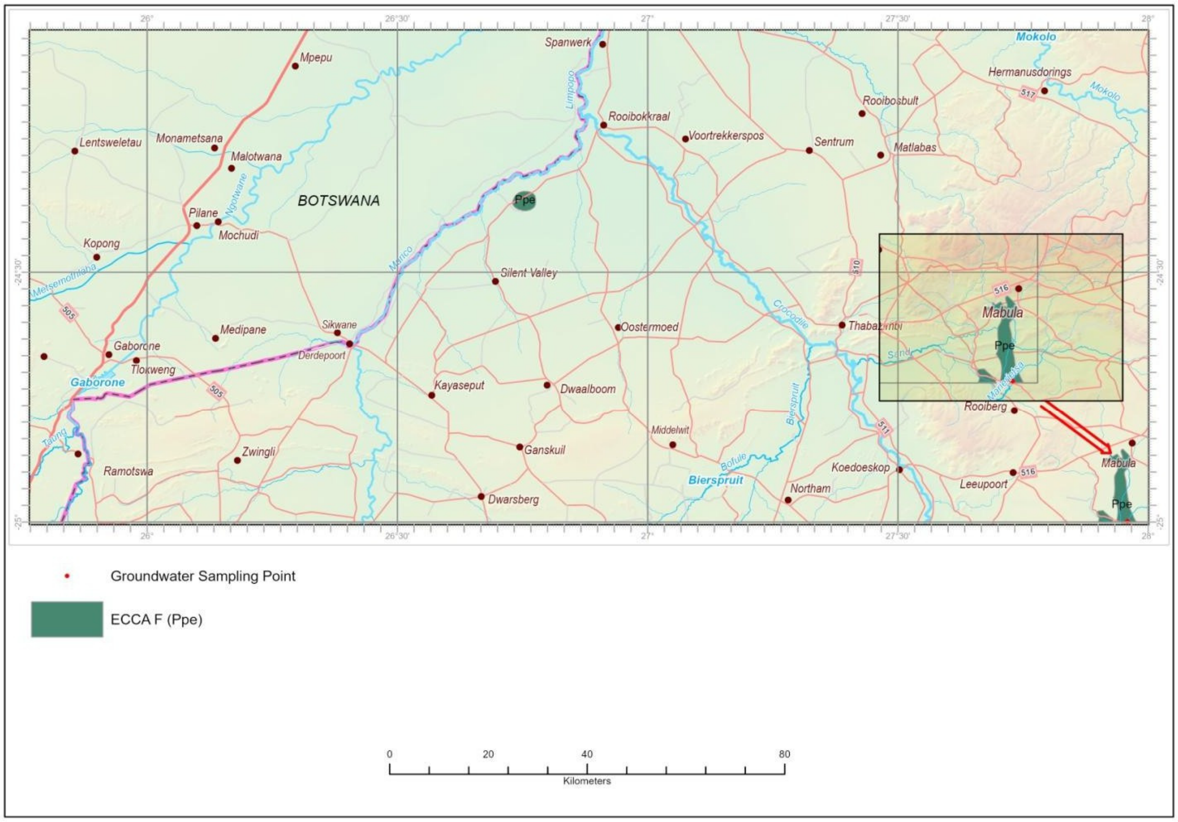


Figure 74: Geographical distribution of the Ecca Group (Ppe) and the associated groundwater sampling points.

Rocks in this unit have a low to very low primary permeability with low storage potential. Limited yield data for boreholes within the Thabazimbi map area indicate that 75%, (Figure 75) of the successful boreholes yield less than 2ℓ/s. This correlates well with the 78.6% of successful boreholes yielding less than 2ℓ/s found within the Modimolle map sheet boundaries of the same groundwater resource unit.

Water is generally obtained in fractures and joints locally developed along bedding plains; contact zones between sediments; fault and associated shear zones and extensively developed fractures and joints due to regional tectonics of the two synclinal flexures and post-Karoo tectonic episodes, (Fayazi, 1994). Water also occurs in fractures developed at the contact zones with intrusive dolerite sills and dykes.

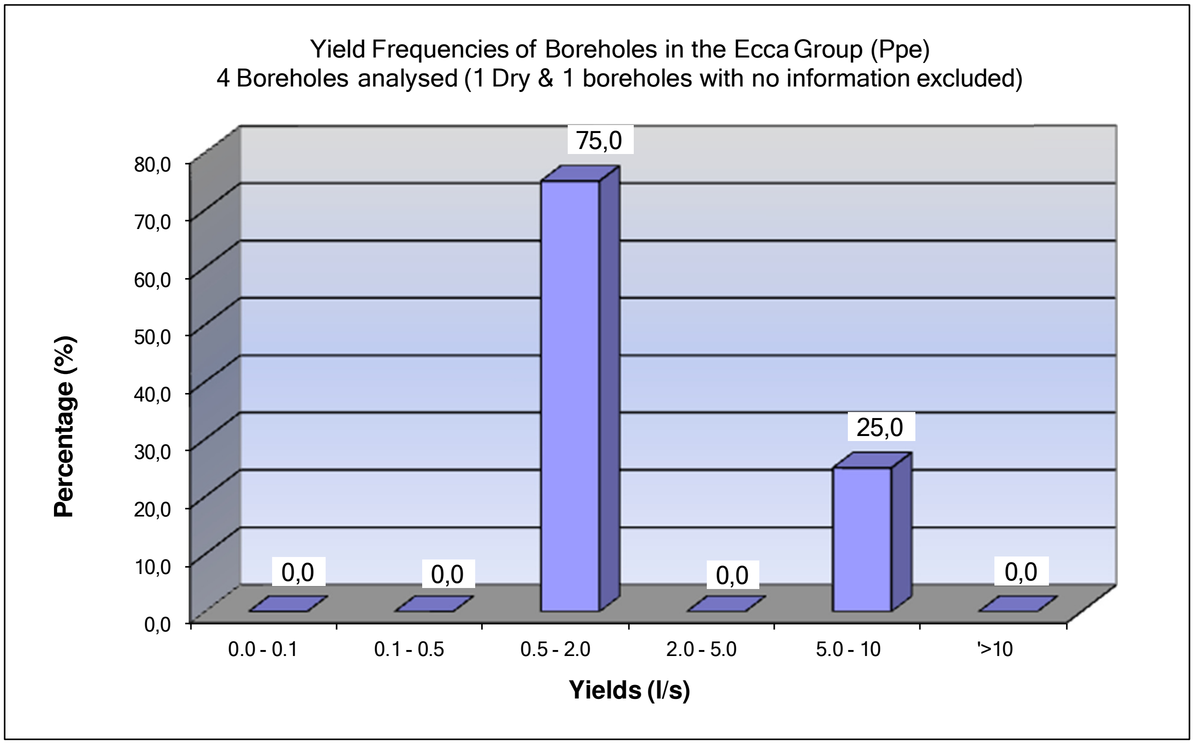


Figure 75: Yield frequency for the fractured aquifers of the Ecca Group (Ppe).

The groundwater resource unit exhibits a low to very low primary permeability and a low storage potential. Although available data is limited, the statistics align with findings from adjacent hydrogeological map sheets. As shown in Figure 75, approximately 75% of the successful boreholes yield less than 2ℓ/s.

No or limited information is available on borehole yields, water chemistry, borehole depths, water strike depths, or abstraction volumes for this groundwater resource unit. Consequently, a comprehensive characterization of the unit could not be undertaken.

For more detailed information on the characteristics of this groundwater resource unit, reference can be made to the Modimolle and Lephalale map sheets and brochures.

7.2.3.3 NEBO GRANITE (Mn)

The Lebowa Granite Suite includes all the granite rocks of the Bushveld Complex. Within the map sheet it is represented by Nebo Granite that occurs in various locations. The largest outcrop of the unit is the occurrence near Sentrum which is approximately 35km north of Thabazimbi; other scattered smaller and larger outcrops are within the south-eastern sector of the map sheet with some occurrences of the unit extending easterly into the adjacent Modimolle map sheet. It covers approximately 6.8% of the map sheet area, (Figure 76).

The unit within the Thabazimbi map sheet is described as predominantly consisting of Granites, it may vary between granophyric, porphyritic, pegmatitic or aplitic, (See Table 45 below).

Table 45: Granite types based on crystal size and formation.

Feature	Granophyric	Porphyritic	Pegmatitic	Aplitic
Crystal Size	Fine, intergrown quartz & feldspar	Large phenocrysts in fine matrix	Very large crystals	Very fine-grained
Formation	Rapid cooling or late-stage crystallization	Two-stage cooling	Late-stage crystallization in volatile-rich melt	Late-stage crystallization in granitic melts

The unit forms a sheet-like body of unknown thickness and is in general coarse-grained although varying, homogenous, and pinkish with small occurrences of a porphyritic variety occurs, (Council of Geoscience). From the yield diagram, (Figure 77) 72.3% of the boreholes with information yield less than 2ℓ/s. The maximum yield of the unit correlates well with the statistics of the unit that fall within the adjacent 1:250 000 scale hydrogeological map sheets namely Lephalale (71.7% or 127 data points) and Modimolle (83.9% or 771 data points).

For domestic use, elevated Fluoride and Nitrate concentration that exceeds the maximum allowable limits is of concern within the Nebo Granite groundwater resource unit.

Table 46: Fluoride and Nitrate concentrations within the adjacent 1:250 000 map sheets.

Map Sheet	Fluoride (F >1.5mg/l) (% unacceptable)	Nitrate (N >10mg/l) (% unacceptable)
Thabazimbi	26.5%	11.8%
Lephalale	68.2%	28%
Modimolle	45.5%	13.3%
Polokwane	39.2%	17.9%

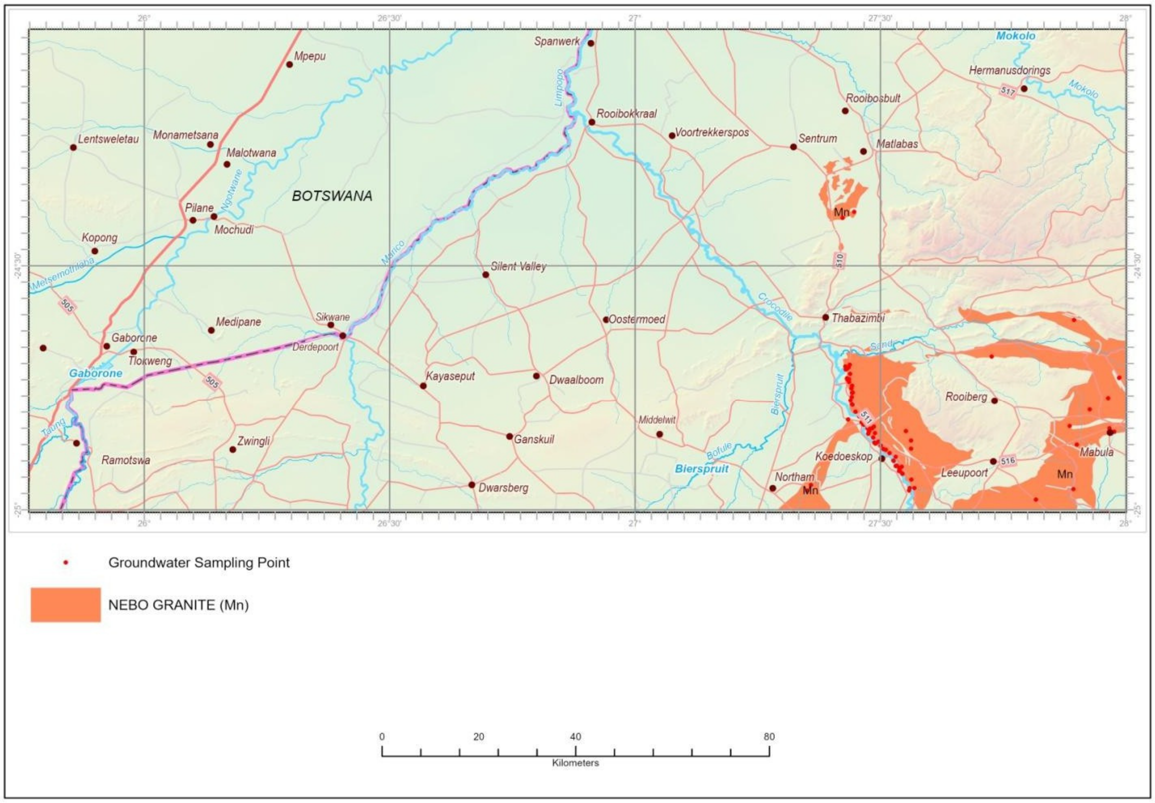


Figure 76: Geographical distribution of the Nebo Granite (Mn) and the associated groundwater sampling points.

The groundwater potential and storage capacity of the unit is generally poor although the occasional good yield (6% > 5ℓ/s) does occur. A scientific approach is recommended for the unit when developing groundwater sources as the average yield obtained will be higher compared with random drilling, (statistics from other map sheets for the unit).

Water is found in deep weathered zones, faults, fractured zones and within the dyke contact/metamorphosed zone. Deep drilling (>180m) in the unit, especially in the Nebo area has yielded limited success to obtain high yielding boreholes. For the development of low yielding boreholes with a restricted investigation area such as schools or clinics, deep drilling is recommended as low yielding strikes <0.3ℓ/s can be found at deeper depths, (90-140m), provided that a proper scientific survey was done in determining the drilling position. The occurrence of the unit near Sentrum is extensively intruded by a diabase sill.

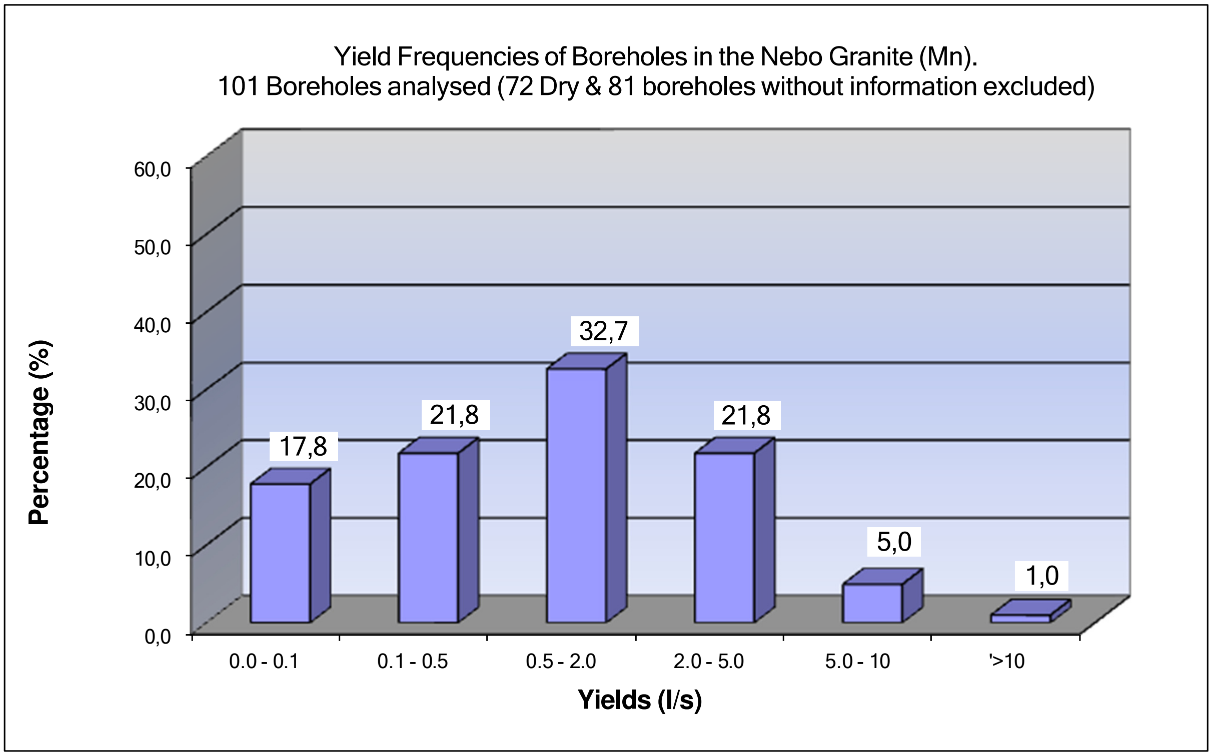


Figure 77: Yield frequency for the intergranular and fractured aquifers of the Nebo Granite (Mn).

Statistics indicate that 39.6%, (Figure 77) of the successful boreholes yield less than 0.5ℓ/s. A further 32.7% of the boreholes yield between 0.5ℓ/s to 2ℓ/s, while 21.8% of the boreholes yield 2ℓ/s to 5ℓ/s. Only 6% of the boreholes yield more than 5ℓ/s.

The static water level ranges from 6.76 meters below ground level (mbgl) to 59.4mbgl, with a median of 23mbgl and an average static water level of 24.16mbgl, (based on 15 data points). The maximum depth recorded is 200m, with an average depth of 80.5m and a median depth of 39m (13 data points). The maximum installation depth is 115m, with an average of 97.5m, (based on only 2 data points). The maximum recommended daily abstraction on record is 379.3 cubic meters per day (m^3/day), with an average of 141m^3/day. This data is not sufficient for a correct characterization of the groundwater resource unit.

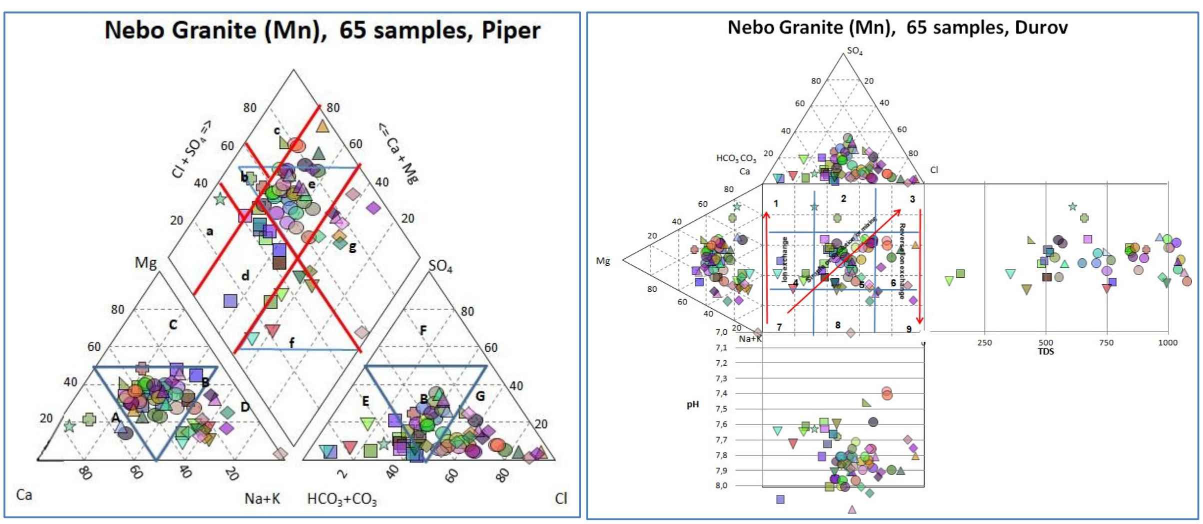


Figure 78: Trilinear diagrams, Piper, and Durov for the Nebo Granite (Mn).

The trilinear Piper diagram, (Figure 78) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (76.9%), Weak acidic anions > Strong acidic anions (29.2%); Alkali >Alkali earths (23.1%); Strong acids > Weak acids (70.8%).

The groundwater in this unit classifies as:

- Mixed Calcium-Magnesium-Chloride (43.1%);
- Sodium-Chloride type (15.4%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with increased Sodium (15.4%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with increased Sodium and Sulphate (7.7%);
- Calcium-Bicarbonate type (6.1%).
- Sodium-Bicarbonate type (6.1%);
- Mixed Calcium-Magnesium-Bicarbonate type (3.1%);
- Sodium-Mixed-Bicarbonate-Chloride type (3.1%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (72.3%), plot along the dissolution or mixing line,
- Anion discriminates and Na dominant, some SO_4 probable mixing or uncommon dissolution influences (9.6%),
- Anion discriminates and Na dominant, indicates probable mixing or uncommon dissolution influences (7.7%),
- Cl and Na dominant, frequently indicative of end-point gradient waters through dissolution (4.6%),
- Cl is the dominant anion and Na the dominant cation, indicative that the groundwater relates to reverse ion exchange of Na-Cl waters (3.1%),
- The water type is dominated by Ca and $HCO_{3,}$ If Na is significant an important ion exchange is presumed (3.1%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 47: Chemical statistics for the Nebo Granite (Mn).

Element / Parameter	Statistics Drawn from a population of 88 data points for Nebo Granite (Mn).									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10 th percentile	50 th percentile (median)	90 th percentile	Standard Deviation	Coefficient of Variation
pH	84	6,56	8,90	7,59	7,61	7,15	7,60	8,00	0,39	5,2%
Electrical Conductivity (mS/m EC)	85	12,10	682,70	83,01	133,36	55,92	107,40	229,94	104,97	78,7%
Total Dissolved Salts (mg/l TDS)	81	90,00	4049,00	588,94	917,12	444,00	767,00	1466,00	648,15	70,7%
Calcium (mg/l Ca)	83	1,80	288,34	34,54	83,78	30,80	74,30	152,38	54,52	65,1%
Magnesium (mg/l Mg)	83	2,00	325,80	21,86	50,20	13,62	41,80	82,84	43,96	87,6%
Sodium (mg/l Na)	83	8,30	1076,90	59,20	128,46	36,26	77,30	276,74	158,90	123,7%
Potassium (mg/l K)	81	0,39	19,02	2,56	4,54	1,47	3,40	8,85	3,50	77,1%
Chloride (mg/l Cl)	83	3,80	2089,00	43,98	209,31	30,90	103,00	518,88	314,17	150,1%
Sulphate (mg/l SO4)	83	2,00	613,80	15,40	58,41	5,66	40,50	119,70	76,04	130,2%
Total Alkalinity (mg/l) CaCO3)	82	21,80	810,60	194,27	278,07	134,69	274,20	426,39	133,58	48,0%
Nitrate (mg/l N)	85	0,02	39,04	0,22	7,32	0,11	3,05	23,65	9,60	131,3%
Fluoride (mg/l F)	83	0,15	4,19	0,80	1,35	0,45	0,95	3,22	1,07	79,4%
Silicon as Si	75	0,87	40,68	11,18	21,52	6,63	21,92	36,39	10,52	48,9%
Iron (Fe)	6	0,003	0,132	0,009	0,042	0,006	0,030	0,091	0,05	114,7%
Manganese (Mn)	6	0,001	0,185	0,004	0,043	0,002	0,010	0,118	0,07	166,7%
Ortho Phosphate as Phosphorus as PO4	75	0,003	0,153	0,005	0,011	0,003	0,006	0,015	0,02	215,3%
ZAR	83	0,19	36,85	1,53	2,98	1,07	1,80	5,54	4,45	149,7%
LSI	79	Langelier Saturation Index (LSI)			Slightly Scaling		**38,0%**	Highly Scaling		**0,0%**
		Highly corrosive		**2,5%**	Slightly corrosive		**11,4%**	Balanced Corrosion		**48,1%**

Table 47 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality in terms of Electrical conductivity (EC) is ideal to good in (57.6%); moderate (23.5%) and unacceptable (>370mS/m) in (2.4%) of the analysis. Value ranges between 12.1 and 682.7mS/m.

The Total Dissolved Solids (TDS) is acceptable in 80.2% of the samples (TDS ≤ 1200mg/l). An evaluation of the major cations and anions for 88 samples shows elevated concentrations of Fluoride (F >1.5mg/l) in 26.5%; Nitrate (N >10mg/l) in 11.8%; Chloride (Cl > 600mg/l) in 4.8% Sodium (Na > 400mg/l) in 4.8%; Magnesium (Mg > 200mg/l) in 1.2% and Sulphate (SO4 >600mg/l) in 1.2% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water may be slightly to highly corrosive (13.9%), slightly scaling (38%) and balanced (48.1%). The ZAR index indicates that 78.3% of the water analysis is of a fair quality for irrigation (ZAR < 3).

The land use within the unit is predominantly game reserves with groundwater use related to these activities. Groundwater is abstracted for farmsteads and limited livestock watering within the south-eastern section of the map, in an area listed as Kromdraai Plots. Large scale irrigation occurs near the Crocodile River; however, the water used for irrigation is not from the Nebo Granite but from a combination of surface water and groundwater pumped from the alluvial aquifer.

7.2.3.4 RASHOOP GRANOPHYRE SUITE (Mr)

The Bushveld Complex has been divided into a mafic portion termed the Rustenburg Layered Suite and a felsic portion represented by the Rashoop Granophyre Suite and Lebowa Granite Suite. The Rashoop Granophyre Suite is genetically related to the volcanic rocks of the Rooiberg Group, it is regarded as the plutonic equivalent, (Walraven, 1982 & 1985). The Rashoop Granophyre Suite occurs in all parts of the Bushveld Complex. The discussion on the granophyre characteristics is inclusive of the granophyre dykes that probably intruded about the same time as the Rashoop Granophyre. Within the map sheet it covers approximately 0.08% of the map sheet; it occurs as an elongated small outcrop west of Sentrum and in scattered small elongated outcrops in the south-eastern sector of the map sheet, (Figure 79).

The Rashoop Granophyre Suite is composed of predominantly homogeneous granophyre as well as associated granophyric granite, granophyre porphyry and pseudogranophyre. Base on textural variations it was subdivided into three formal units, namely the Stavoren Granophyre, Rooikop Granophyre Porphyry and the Zwartbank Pseudogranophyre, (SACS, 1980).

The Stavoren Granophyre is the most widespread and considered to be the oldest component of the Bushveld Complex. It comprises of coarse-grained quartz and potash feldspar, (K-Feldspar), (SACS, 1980), which are regularly intergrown, together with hornblende which is inclined to form aggregates between the intergrowths, (Visser D.J.J. 1989).

The Rooikop Granophyre Porphyry is found as sill-like intrusions in the Rooiberg Felsite and Loskop Formation. The best development of this rock is south of the map area. It consists of phenocrysts of K-feldspar and quartz set in a fine-grained granophyric groundmass, (SACS, 1980).

The Zwartbank Pseudogranophyre consists of irregular quartz feldspar intergrowths, the occurrence is more widespread, and it is located in the same geological setting as the normal granophyre, (Walraven, 1976).

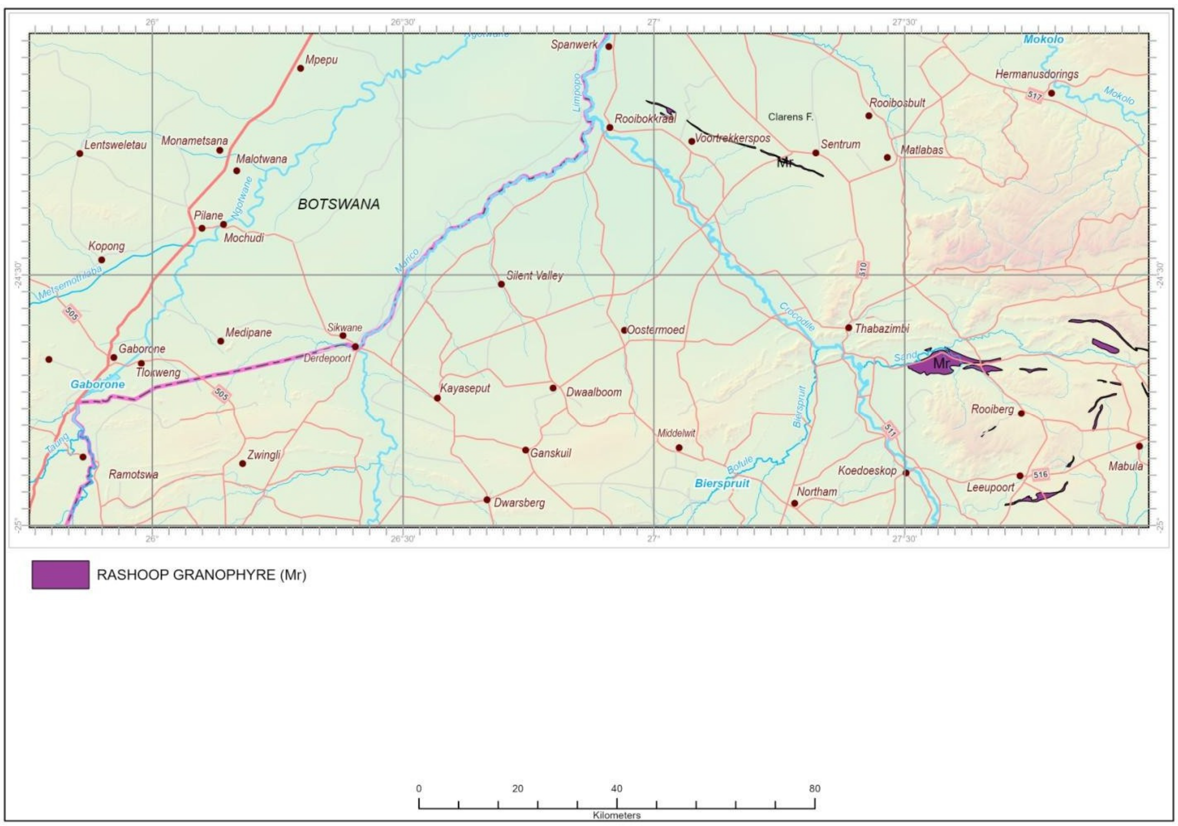


Figure 79: Geographical distribution of the Rashoop Granophyre Suite (Mr) and the associated groundwater sampling points.

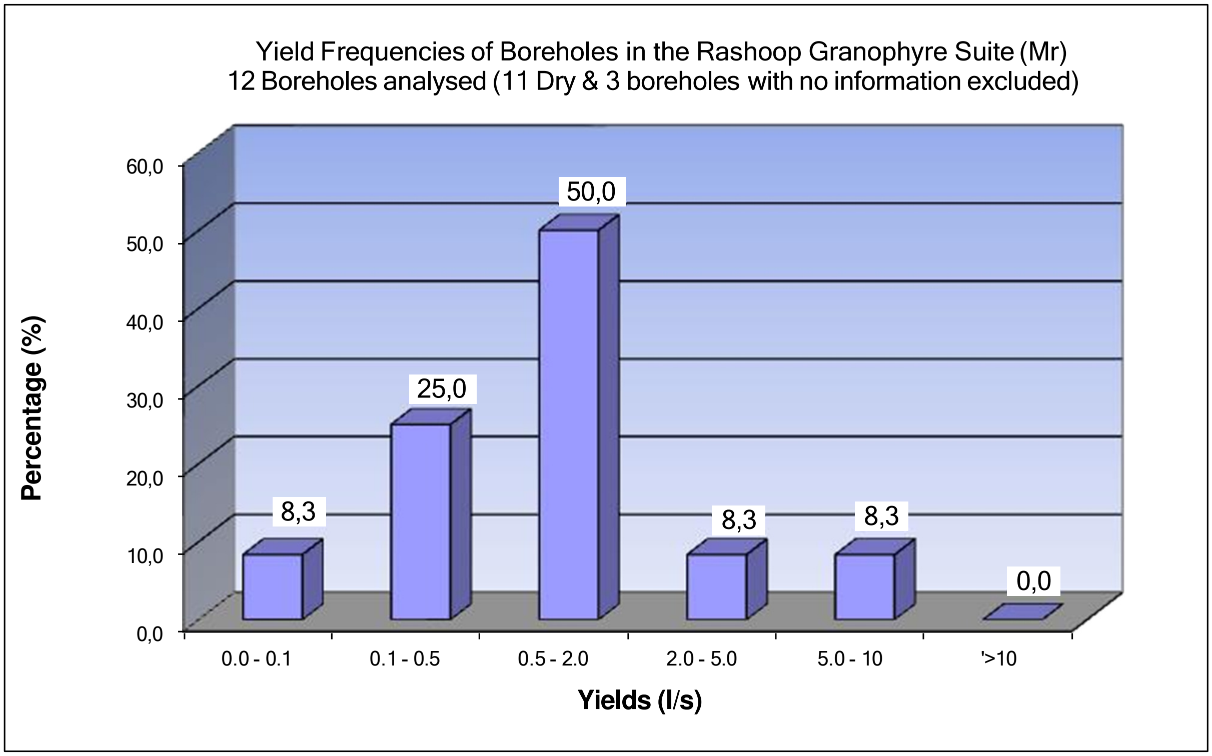


Figure 80: Yield frequency for fractured aquifers of the Rashoop Granophyre Suite (Mr).

The analysis of 12 borehole records indicates that 33.8% of the boreholes yield less than 0.5ℓ/s, with 50% of the boreholes yield between 0.5ℓ/s and 2ℓ/s. Only 16.6% of the boreholes yield between 2ℓ/s and 10ℓ/s.

The static water level ranges from 28.96 meters below ground level (mbgl) to 48mbgl, with a median of 43mbgl and an average static water level of 38.99mbgl, (based on 5 data points). No information is available on depths, water strike depths and abstraction volumes for an accurate characterization of the unit.

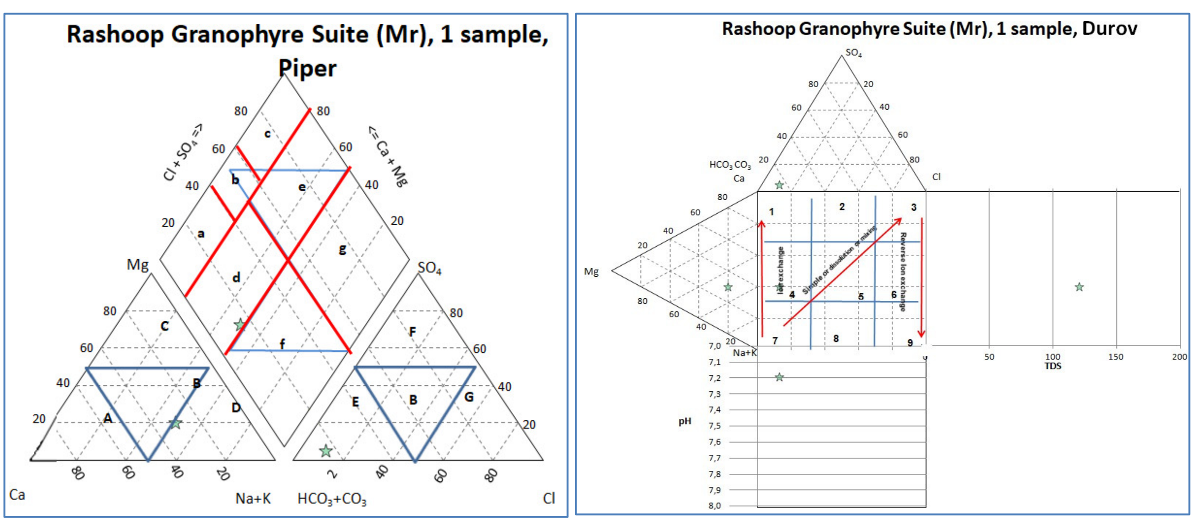


Figure 81: Trilinear diagrams, Piper, and Durov for the Rashoop Granophyre Suite (Mr).

The trilinear Piper diagram, (Figure 81) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (100%), Weak acidic anions > Strong acidic anions (100%); Alkali >Alkali earths (0%); Strong acids > Weak acids (0%).

The groundwater in this unit classifies as:

- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (100%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- Anion discriminate and Ca dominant indicating mixed water or water exhibiting simple dissolution (100%),

Table 48: Chemical statistics for the Rashoop Granophyre Suite (Mr).

Element / Parameter	Statistics Drawn from a population of 1 data points for the Rashoop Granophyre Suite (Mr)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	1	7,17	7,17	7,17	7,17	7,17	7,17	7,17		
Electrical Conductivity (mS/m EC)	1	14,50	14,50	14,50	14,50	14,50	14,50	14,50		
Total Dissolved Salts (mg/l TDS)	1	121,00	121,00	121,00	121,00	121,00	121,00	121,00		
Calcium (mg/l Ca)	1	8,40	8,40	8,40	8,40	8,40	8,40	8,40		
Magnesium (mg/l Mg)	1	3,50	3,50	3,50	3,50	3,50	3,50	3,50		
Sodium (mg/l Na)	1	15,80	15,80	15,80	15,80	15,80	15,80	15,80		
Potassium (mg/l K)	1	0,59	0,59	0,59	0,59	0,59	0,59	0,59		
Chloride (mg/l Cl)	1	3,00	3,00	3,00	3,00	3,00	3,00	3,00		
Sulphate (mg/l SO_4)	1	2,00	2,00	2,00	2,00	2,00	2,00	2,00		
Total Alkalinity (mg/l) $CaCO_3$)	1	68,60	68,60	68,60	68,60	68,60	68,60	68,60		
Nitrate (mg/l N)	1	0,02	0,02	0,02	0,02	0,02	0,02	0,02		
Fluoride (mg/l F)	1	2,16	2,16	2,16	2,16	2,16	2,16	2,16		
Silicon as Si	1	26,93	26,93	26,93	26,93	26,93	26,93	26,93		
Iron (Fe)	0									
Manganese (Mn)	0									
Ortho Phosphate as Phosphorus as PO4	1	0,028	0,028	0,028	0,028	0,028	0,028	0,028		
ZAR	1	1,16	1,16	1,16	1,16	1,16	1,16	1,16		
LSI	1	Langelier Saturation Index (LSI)			Slightly Scaling		0,0%	Highly Scaling		0,0%
		Highly corrosive		0,0%	Slightly corrosive		100,0%	Balanced Corrosion		0,0%

Table 48 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Limited analysis was available for accurate characterization. The Modimolle occurrence of the unit is not close to the Thabazimbi occurrence and a combined data set was therefore not used in the characterization. A comparison was made between the two data sets.

The overall water quality is ideal in terms of the Electrical conductivity (EC); this corresponds with findings in the adjacent Modimolle map sheet. This evaluation is based on a single sample within the Thabazimbi map sheet and 2 samples within the Modimolle map sheet. The electric conductivity (EC) value is 14.5mS/m and the Total Dissolved Solids (TDS) are acceptable in all the samples (TDS ≤ 1200mg/l).

For the single available analysis of the water chemistry from a borehole falling within the Thabazimbi map sheet area, the Fluoride concentration is 2.16mg/l that exceeds the maximum allowed limit (Fluoride (F >1.5mg/l). The Fluoride concentrations for the analysis that falls within the Modimolle map sheet area were within limits.

The Langelier Saturation Index (LSI) from a single sample indicates that the water is slightly corrosive; for the occurrence in the Modimolle map sheet it was balanced (2 samples available). The ZAR index indicates that 100% of the water is of a fair quality for irrigation (ZAR < 3).

The water in this unit is used for game, livestock watering and rural farms. No large-scale irrigation occurs within the unit, based on Google Earth imagery evaluation.

7.2.3.5 DIABASE INTRUSIONS (N-Za)

This unit consists of diabase intrusions from Swazian age up to Namibian that includes sills and dykes that occur in all the pre-Karoo formations in the area.

Characterization of this unit was based only on boreholes located on sills, as it was not possible to reliably distinguish boreholes drilled on dykes from those drilled into the surrounding host rocks. Therefore, boreholes on dykes were excluded from the characterization. The data used primarily comes from boreholes intersecting the major sills depicted on the geological map sheet, which were used to compile the Thabazimbi hydrogeological map.

Diabase sills cover approximately 4.9% of the map sheet area. Outcrops are mainly located in the north-eastern corner of the map sheet, predominantly within the Aasvoëlkop Formation. Sills are also mapped within older formations of the Waterberg Supergroup, including the Schilpadkop Formation, the Alma Formation, and the Kransberg Subgroup. Extensive sill intrusions are present in parts of the Nebo Granite (Figure 82).

It should be noted that dykes were not included in the hydrogeological characterization of the unit. Their distribution across the map sheet is shown on the inset map (Figure 7, page 26). According to the geological map notes, dykes generally strike west-northwest to north-northwest and cut across most formations present in the area.

Due to their abundance, sills and dykes are the most common groundwater targets within the sedimentary rocks of the Waterberg Supergroup and the clastic sediments of the Transvaal Supergroup. In the Nebo Granite, dykes are also the primary groundwater target. For further information, refer to the relevant sections discussing these groundwater resource units.

The results when targeting diabase intrusions are however varied, but most of the time it will result in some water strikes. Sills are seen as difficult targets in the search for groundwater, the options when dealing with sills are as follows:

- Target either one or both contact zones (upper or lower). This option depends on the depth of the sill; if on the surface it will only be one contact (lower). The thickness of the sill must be taken into consideration.
- When the sills are occurring near the surface, the first target will be to find deep weathered and fractured zones and the second is the lower contact zone. Deep weathered and fracture zones are predominantly influenced by structural controls such as faults, joints, or younger dyke intrusions into the sill. The problem is to detect these zones and the determination of the thickness of the sill.
- To target the 'vertical' contact in other words the edge of the sill. In such a case the, target zone will be similar as when dealing with a dyke.
- Sills are more likely to be found in the rocks of the Waterberg Group than in the other pre-Karoo geological settings where diabase in the form of dyke intrusions is more common. The term dolerite is used for a similar composition rock that intruded predominantly as dykes within the Karoo Sedimentary rocks.
- The use of geophysical instruments and geological observations are highly recommended when searching for groundwater in the vicinity of diabase intrusions. Extensive soil coverage within the map area limits visual discoveries, especially in the non-Waterberg Sediments.

When dealing with intrusive dykes, the use of remote sensing techniques, aerial magnetic surveys, and geophysical methods is highly recommended when exploring for groundwater. In most cases, anomalies identified in magnetic and electromagnetic geophysical data will correspond to dykes.

Among these methods, the magnetic method is particularly effective and is highly recommended when searching for diabase dykes.

However, targeting dykes for groundwater exploration does not always guarantee successful water strikes. Several critical factors must be considered namely the type of host rock; static water level, lateral extent, is the anomaly related to diabase or some other rock type such as amphibolite or syenite which are more common in the older gneissic areas; the thickness or width of the dyke; spherical or 'blokkies klip' weathering / fracturing; dip and strike.

When utilizing interpreted aerial magnetic data, usually presented as maps showing magnetic intensity over large areas, dykes are often targeted along their strike in locations where possible weathering (indicated by lower background magnetic readings) occurs, or where joints, faults, or fracture zones intersect or displace the dyke. These magnetic maps can also be used to delineate compartments within dolomitic aquifers, improving the understanding of groundwater flow patterns and storage.

In the Swazian rocks, dykes often give rise to ridges but in the sedimentary rocks they usually form negative topographic features characterized by dense vegetation. Within the Waterberg Supergroup 'U-shape valleys' often indicates the presence of diabase dykes especially in the plateau area, (north-eastern corner of the map sheet). Geophysical data interpretation usually identifies the dyke on either side of these valleys and not within as expected. The scale of the map excludes the inclusion of all dyke intrusions. Diabase occurrences within the map sheet vary from aphanitic (very fine, crystals cannot be distinguished with the naked eye) to coarse-grained, are greenish black, of gabbroic composition and have an ophitic texture (random plagioclase laths are enclosed by pyroxene or olivine), (Geological map sheet explanatory brochure).

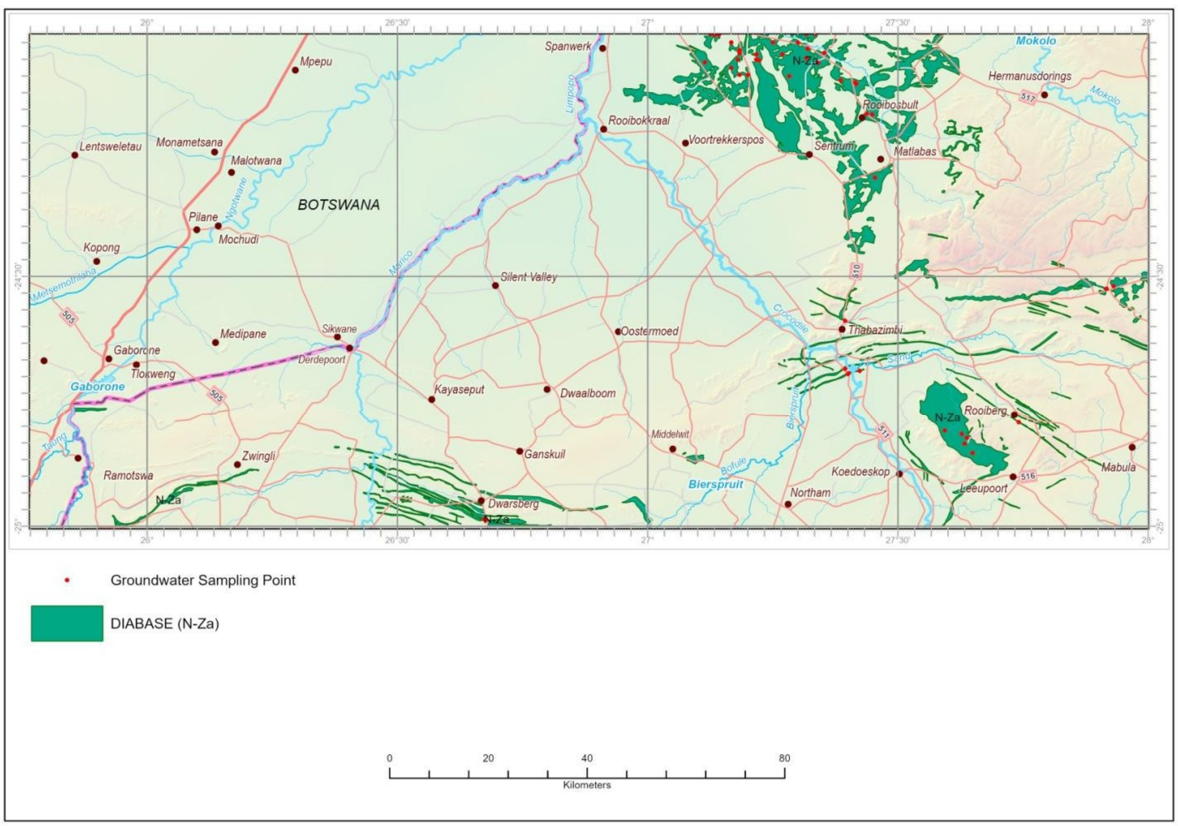


Figure 82: Geographical distribution of the Diabase intrusions (N-Za) and the associated groundwater sampling points.

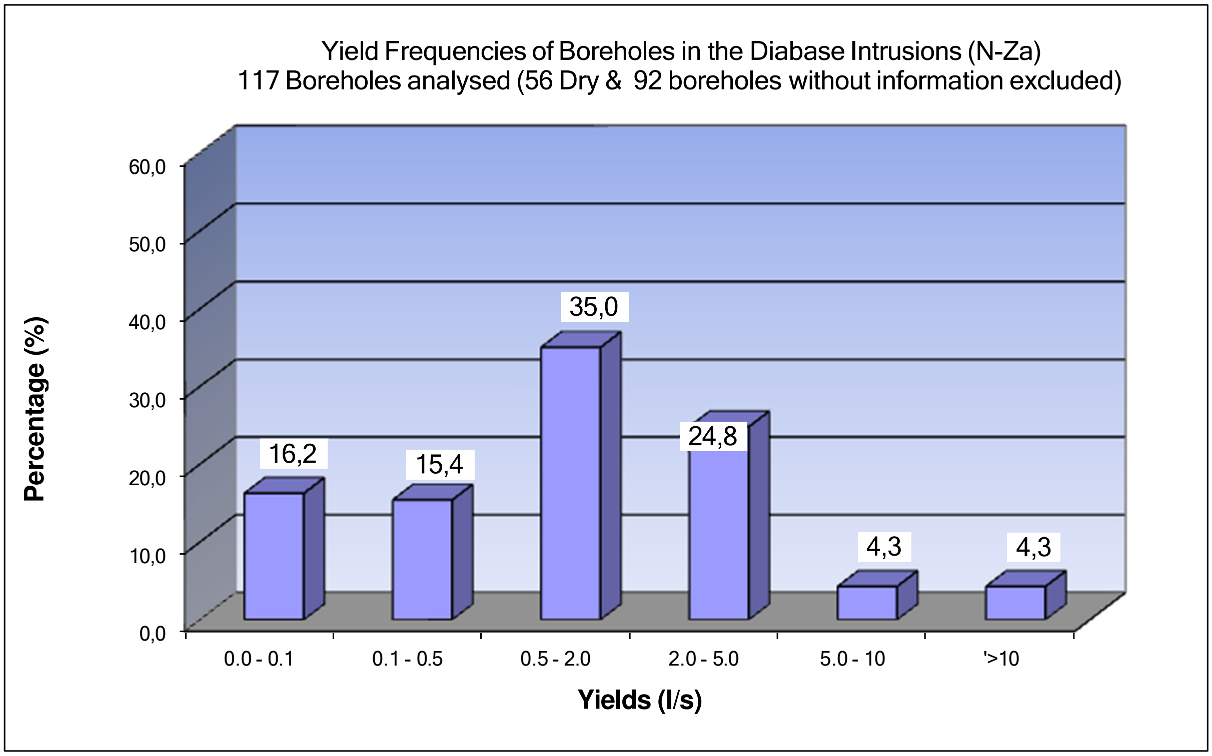


Figure 83: Yield frequency for the intergranular and fractured aquifers of the Diabase intrusions (N-Za).

Figure 83, represents the maximum yields of boreholes drilled in the diabase sill intrusions. Boreholes drilled targeting the numerous dyke intrusions is not included in the analysis due to the scale of the map sheet. Statistics of 117 borehole resources indicate that 31.6% of the successful boreholes yield less than 0.5ℓ/s. A further 35% of the boreholes yield between 0.5ℓ/s to 2ℓ/s, while 24.8% of the boreholes yield between 2ℓ/s to 5ℓ/s. Only 8.6% of the boreholes yield more than 5ℓ/s, (Figure 92).

The static water level ranges from 3.8 meters below ground level (mbgl) to 70mbgl, with a median of 29.33mbgl and an average static water level of 30.06mbgl, (based on 104 data points). The data set available included three water levels that were excluded from the calculation as it was considered to represent pumped drawdown water levels. The water levels excluded were 90, 100 and 115mbgl. The maximum depth recorded is 272m, with an average of 134.4m and a median depth of 126m, (5 data points). The maximum installation depth is 100m and the average is 66.5m (4 data points). The maximum recommended daily abstraction on record is 241.9 cubic meters per day (m^3/day) and the average is 162m^3/day. The total number of boreholes subjected to pump testing within this unit on record is 4.

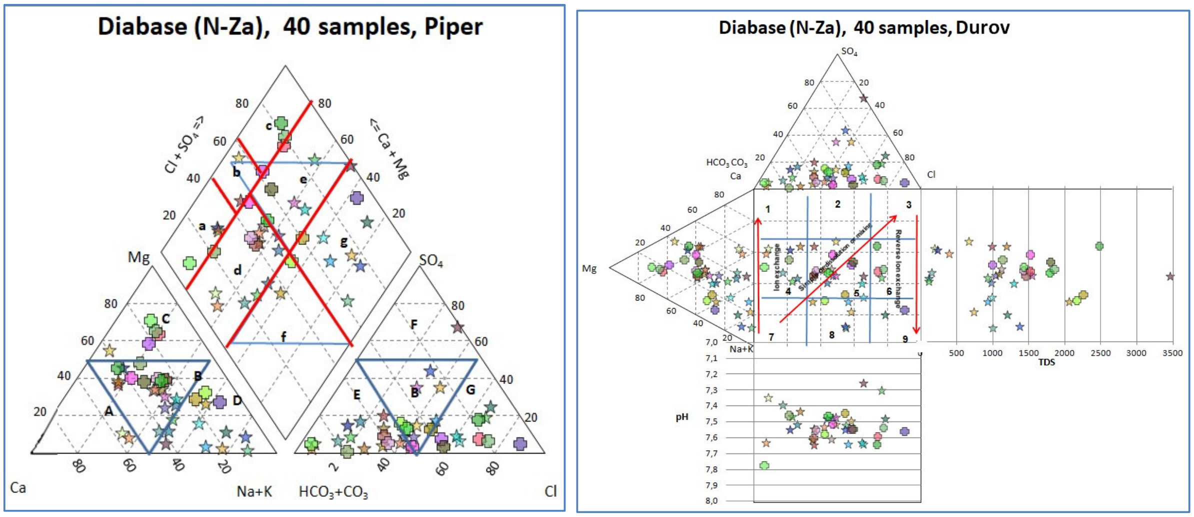


Figure 84: Trilinear diagrams, Piper, and Durov for Diabase (N-Za).

The trilinear Piper diagram, Figure 84 facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (75%), Weak acidic anions > Strong acidic anions (57.5%); Alkali >Alkali earths (25%); Strong acids > Weak acids (42.5%).

The second evaluation was on the water type:

- Mixed Calcium-Magnesium-Bicarbonate type with increasing Sodium (36.4%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type (12.5%);
- Magnesium-Chloride (10%);
- Sodium-Chloride type (10%);
- Mixed Calcium-Magnesium-Bicarbonate type (7.5%);
- Sodium-Mixed-Bicarbonate-Chloride type (7.5%);
- Calcium-Bicarbonate type (6.1%).
- Sodium-Bicarbonate type (5%);
- Magnesium-Bicarbonate-Chloride type (2.5%);
- Magnesium-Bicarbonate type (2.5%);

The trilinear Durov diagram defines the hydrochemical processes along with the water type;

- No dominant anion or cation indicates fresh recent recharge water exhibiting simple dissolution or mixing (45%), plot along the dissolution or mixing line,
- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (22.5%),
- Anion discriminates and Na dominant, some SO_4 probable mixing or uncommon dissolution influences (17.5%),
- Cl dominant anion and Na dominant cation, reverse ion exchange of Na-Cl waters (10%),
- Cl and Na dominant, frequently indicative of end-point gradient waters through dissolution (5%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 49: Chemical statistics for the Diabase intrusions (N-Za).

Element / Parameter	Statistics Drawn from a population of 51 data points for Diabase (N-Za)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	49	6,71	8,30	7,48	7,49	6,98	7,55	7,88	0,34	4,6%
Electrical Conductivity (mS/m EC)	50	7,90	613,10	52,57	111,40	25,36	93,85	170,69	91,88	82,5%
Total Dissolved Salts (mg/l TDS)	50	65,00	3565,00	401,17	774,37	223,60	692,50	1241,38	553,48	71,5%
Calcium (mg/l Ca)	50	4,40	271,70	31,31	61,54	14,40	57,56	95,61	45,64	74,2%
Magnesium (mg/l Mg)	50	0,99	195,30	8,12	48,88	2,24	48,70	75,94	39,78	81,4%
Sodium (mg/l Na)	50	4,60	857,00	26,10	99,16	6,90	77,00	217,20	132,21	133,3%
Potassium (mg/l K)	50	0,37	32,82	2,63	5,46	1,48	3,67	10,19	5,60	102,6%
Chloride (mg/l Cl)	50	1,50	1618,00	17,06	129,68	5,07	75,96	238,65	235,17	181,3%
Sulphate (mg/l SO_4)	50	2,00	1008,50	9,47	62,42	2,00	23,83	133,61	144,12	230,9%
Total Alkalinity (mg/l) $CaCO_3$)	46	31,00	573,05	147,70	268,65	71,70	265,40	459,30	150,04	55,9%
Nitrate (mg/l N)	49	0,02	37,91	0,18	6,89	0,10	3,13	17,35	9,46	137,2%
Fluoride (mg/l F)	49	0,10	8,46	0,51	1,44	0,22	0,73	3,22	1,98	137,1%
Silicon as Si	47	9,09	88,00	22,69	29,59	14,03	27,06	45,81	14,98	50,6%
Iron (Fe)	6	0,00	2,11	0,01	0,38	0,00	0,05	1,08	0,85	225,8%
Manganese (Mn)	7	0,00	0,21	0,01	0,08	0,00	0,05	0,21	0,09	116,9%
Ortho Phosphate as Phosphorus as PO4	44	0,00	0,06	0,01	0,02	0,01	0,01	0,04	0,01	85,3%
ZAR	50	0,09	11,32	0,83	2,42	0,53	1,66	5,67	2,47	102,1%
LSI	46	Langelier Saturation Index (LSI)			Slightly Scaling		**26,1%**	Highly Scaling		**0,0%**
		Highly corrosive		**2,2%**	Slightly corrosive		**26,1%**	Balanced Corrosion		**45,7%**

Table 49 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality in terms of Electrical conductivity (EC) is ideal to good in (84%); moderate (14%) and unacceptable (>370mS/m) in (2%) of the analysis. Values range between 7.9 and 613.1mS/m.

The Total Dissolved Solids (TDS) is acceptable in 88% of the samples (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 51 samples indicates elevated concentrations of Fluoride (F >1.5mg/l) in 24.5%; Nitrate (N >10mg/l) in 10.2%; Chloride (Cl > 600mg/l) in 2% Sodium (Na > 400mg/l) in 2%; and Sulphate (SO4 >600mg/l) in 2% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly to highly corrosive (28.3%), slightly scaling (26.1%) and predominantly balanced (45.7%). The ZAR index indicates that the water is of a fair quality in 78% of the samples for irrigation (ZAR < 3).

This unit includes sills and diabase dykes. Irrespective of the regional geology, diabase dykes are more prevalent compared with other geological lineaments such as faults. Thus, in many cases the only available groundwater target in an area earmarked for development (schools, hospitals etc.) will be a diabase dyke; therefore, this unit will represent all types of water user's namely domestic, commercial, agriculture, mining etc. A rural settlement Sentrum falls within this unit, the water supply is a combination between surface water and groundwater.

In 24.5% of the water samples at least one element exceeds the maximum allowed limit for domestic use. In this unit the anions of concern are Fluoride followed by Nitrate that exceeds the maximum allowable concentration in 10.2% of the analysis.

7.2.3.6 UNDIFFERENTIATED RUSTENBURG LAYERED SUITE (Vrs)

The Bushveld Complex has been divided into a mafic portion termed the Rustenburg Layered Suite and a felsic portion represented by the Rashoop Granophyre Suite and Lebowa Granite Suite. Within the South African context the Rustenburg Layered Suite outcrop in three separate, large, ach-like areas, generally referred to as Western, Eastern and Northern lobes or limbs of the Bushveld Complex, (SACS, 1980, p225-241).

The Undifferentiated Rustenburg Layered Suite groundwater resource unit includes all the lithological units identified within the far-western limp. Within the Thabazimbi map sheet the unit is represented at two locations, the first is in the Northam area in the centre-southern part and the second in the south-west where it occur as a large outcrop as well as some smaller scattered thin south-easterly outcrops that terminates against a major north-north-west striking fault, (Figure 85). The unit covers approximately 5% of the map area.

The western limb is divided into 9 lithological units; in short it is as follows: (SACS, 1980, p229 & 235),

- Bierkraal Magnetite Gabbro, consists of magnetite gabbro with layers of magnetite and anorthosite,
- Pyramid Gabbro-Norite, consists of gabbro and norite with interlayered anorthosite,
- Mathlagame Norite-Anorthosite, consists of alternating layers of leuconorite, anorthosite, pyroxenite and chromitite,
- Ruighoek Pyroxenite, consisting of feldspathic pyroxenite with chromitite layers,
- Tweelaagte Bronzitite, consisting of Pyroxenite,
- Groenfontein Harzburgite, consisting of alternating layers of harzburgite and pyroxenite,
- Makgope Bronzitite, consisting of monomineralic pyroxenite, most likely occurring south of the Thabazimbi map sheet,
- Eerlyk Bronzitite, consisting of feldspathic pyroxenite with discontinuous harzburgite and norite layers near the base,
- Kolobeng Norite, consisting of norite and quartz norite.

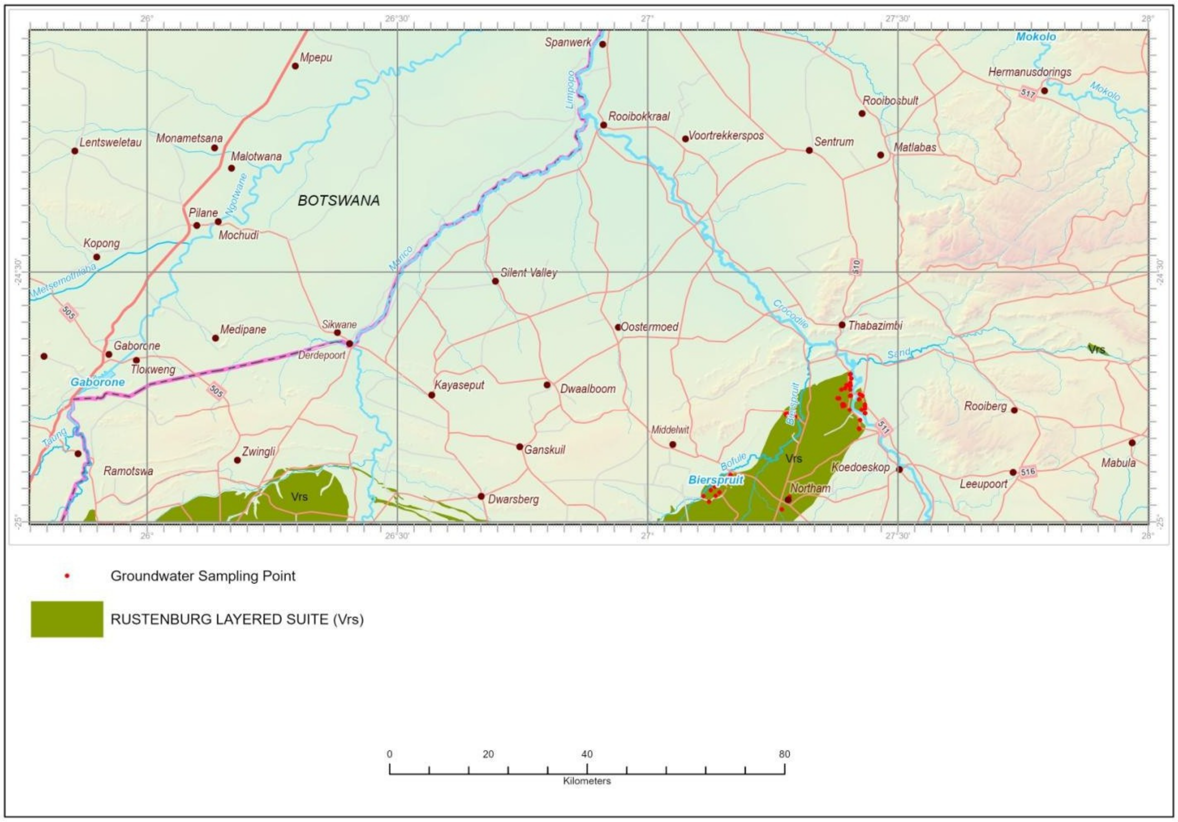


Figure 85: Geographical distribution of the Undifferentiated Rustenburg Layered Suite (Vrs) and the associated groundwater sampling points.

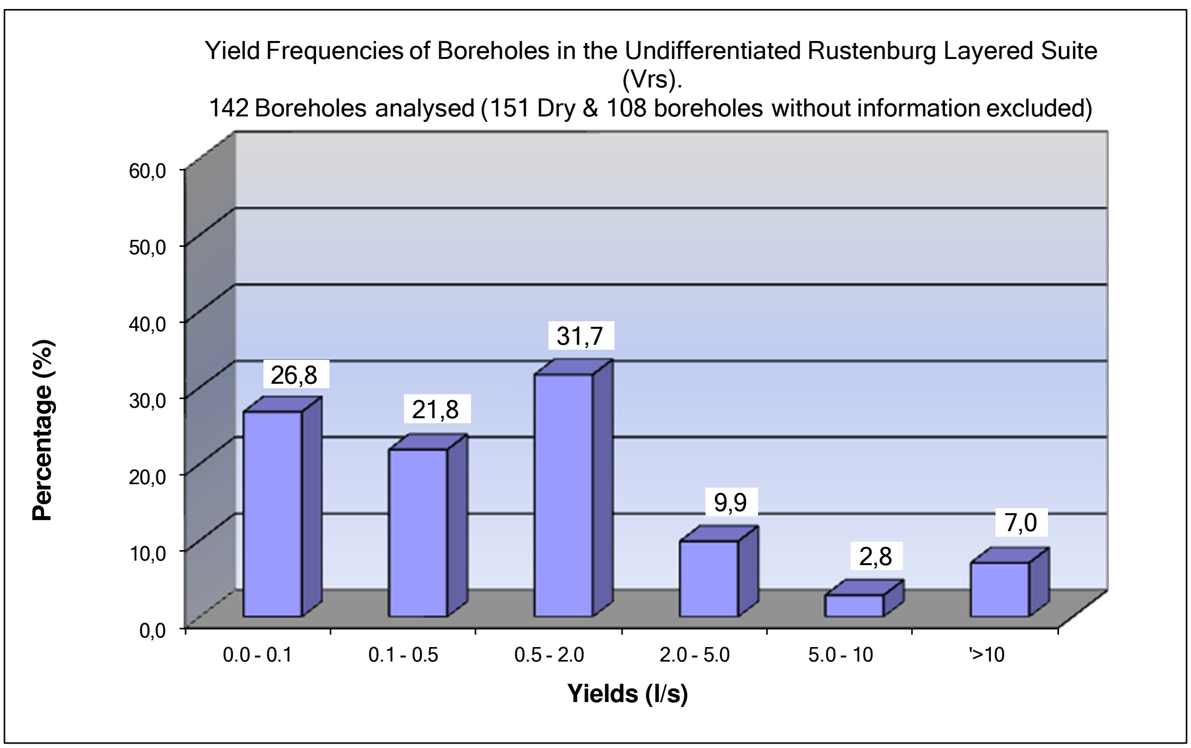


Figure 86: Yield frequency for the intergranular and fractured aquifers of the Undifferentiated Rustenburg Layered Suite (Vrs).

Statistics indicate that 48.6% of the successful boreholes yield less than 0.5ℓ/s. A further 31.7% of the boreholes yield between 0.5ℓ/s to 2ℓ/s, while 9.9% of the boreholes yield between 2ℓ/s and 5ℓ/s. Only 9.8% of the boreholes yield more than 5ℓ/s, (Figure 86).

The static water level ranges from 2.25 meters below ground level (mbgl) to 49.91mbgl, with a median of 19.79mbgl and an average static water level of 21.16mbgl (based on 39 data points). The data set reported one water level as 92.93mbgl; it was ignored in the calculation as it most likely represents a pumped drawdown level. The maximum depth recorded is 115m, with an average of 54m and a median depth of 49m (28 data points). The maximum installation depth is 42m and the average is 38.3m, (4 data points).

The maximum recommended daily abstraction on record is 302.4 cubic meters per day (m³/day) and the average is 221.9m³/day. The total number of boreholes subjected to pump testing within this unit on record is 6.

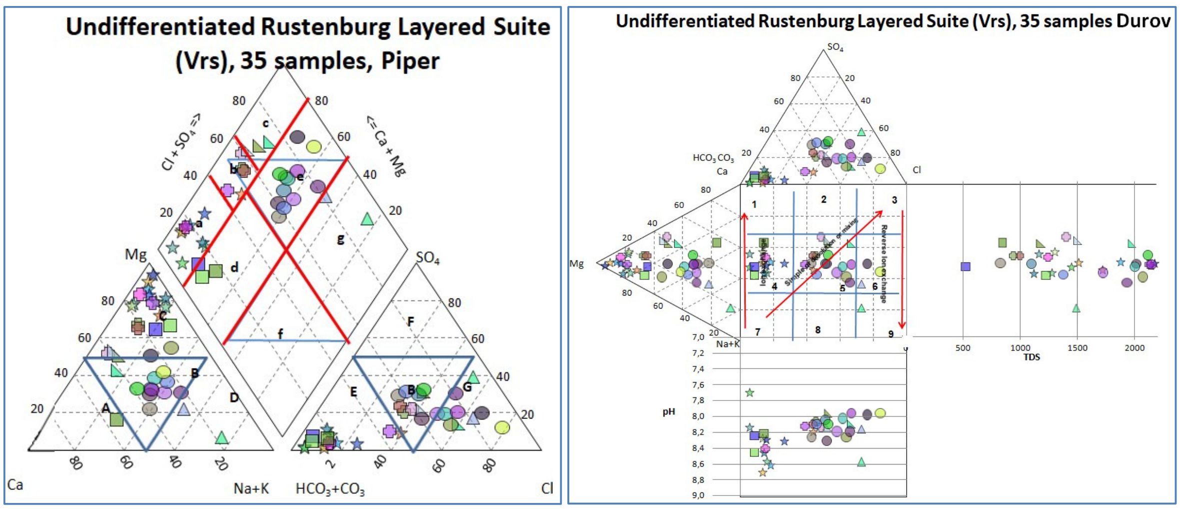


Figure 87: Trilinear diagrams, Piper and Durov for the Undifferentiated Rustenburg Layered Suite (Vrs).

The trilinear Piper diagram, (Figure 87) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (94.3%), Weak acidic anions > Strong acidic anions (44.3%); Alkali >Alkali earths (5.7%); Strong acids > Weak acids (55.7%).

The groundwater in this unit classifies as:

- Magnesium-Bicarbonate type (34.4%),
- Mixed Calcium-Magnesium-Sodium-Chloride type (17.1%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with increased Sodium and Sulphate (17.1%);
- Magnesium-Bicarbonate-Chloride type (14.3%),
- Magnesium-Chloride (5.7%);
- Sodium-Chloride type (5.7%);
- Mixed Calcium-Magnesium-Bicarbonate type (5.7%);

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- No dominant anion or cation, indicates water exhibiting simple dissolution or mixing (51.4%), plot along the dissolution or mixing line,

- Anion discriminant and Ca dominant, mixed water or water exhibiting simple dissolution. (37.1%),
- Anion discriminates and Na is dominant, indicates probable mixing or uncommon dissolution influences (8.6%),
- Cl and Na dominant, frequently indicative of end-point gradient waters through dissolution (2.9%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 50: Chemical statistics for the Undifferentiated Rustenburg Layered Suite (Vrs).

Element / Parameter	Statistics Drawn from a population of 58 data points for the Undifferentiated Rustenburg Layered Suite									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	58	6,99	8,52	7,72	7,74	7,41	7,73	8,15	0,32	4,1%
Electrical Conductivity (mS/m EC)	58	39,3	540,0	114,7	147,3	80,6	117,6	250,6	91,6	62,2%
Total Dissolved Salts (mg/l TDS)	57	260,0	3632,0	782,4	995,5	555,0	765,2	1668,2	617,5	62,0%
Calcium (mg/l Ca)	57	2,22	579,00	15,23	68,12	4,35	47,00	130,62	84,34	123,8%
Magnesium (mg/l Mg)	57	9,65	343,00	67,81	114,67	45,60	102,00	182,80	66,85	58,3%
Sodium (mg/l Na)	58	9,88	358,00	29,38	73,69	12,51	36,63	191,10	80,18	108,8%
Potassium (mg/l K)	57	0,80	31,40	1,80	4,03	1,06	1,73	5,90	6,24	154,7%
Chloride (mg/l Cl)	58	4,14	1418,00	33,90	180,90	10,93	75,50	493,60	258,16	142,7%
Sulphate (mg/l SO_4)	58	0,14	950,00	6,13	96,63	7,81	58,40	206,30	143,76	148,8%
Total Alkalinity (mg/l) $CaCO_3$)	50	67,70	852,00	312,86	392,68	202,95	382,15	564,00	162,98	41,5%
Nitrate (mg/l N)	58	0,02	28,69	0,24	5,24	0,10	2,49	13,65	6,51	124,3%
Fluoride (mg/l F)	52	0,03	1,15	0,14	0,29	0,10	0,26	0,70	0,25	86,9%
Silicon as Si	34	13,15	43,48	29,05	31,51	22,62	32,65	41,66	7,99	25,3%
Iron (Fe)	34	0,001	0,160	0,007	0,024	0,004	0,010	0,050	0,03	146,6%
Manganese (Mn)	34	0,001	0,810	0,004	0,075	0,001	0,010	0,236	0,16	213,3%
Ortho Phosphate as Phosphorus as PO4	38	0,003	0,926	0,008	0,142	0,003	0,010	0,800	0,30	210,9%
ZAR	57	0,15	6,83	0,55	1,33	0,23	0,62	2,91	1,38	103,3%
LSI	49	Langelier Saturation Index (LSI)			Slightly Scaling		46,9%	Highly Scaling		0,0%
		Highly corrosive		0,0%	Slightly corrosive		2,0%	Balanced Corrosion		51,0%

Table 50 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is ideal to good (65.5%), marginal (31%) and unacceptable in 3.4% of the analysis in terms of the Electrical conductivity (EC) with values ranging between 39.3 and 540mS/m; the 90th percentile is 250.6mS/m.

The Total Dissolved Solids (TDS) is acceptable in 78.9% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 58 samples indicates elevated concentrations of Magnesium (Mg > 200mg/l) in 7%; Chloride (Cl > 600mg/l) in 6.9%; Nitrate (N >10mg/l) in 5.2%; Calcium (Ca > 300) in 1.8% and Sulphate (SO4 >600mg/l) in 1.7% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly corrosive (2%), slightly scaling (46.9%) and predominantly balanced (51%). The ZAR index indicates that 89.5% of the water is of a fair quality for irrigation (ZAR < 3).

There are a significant number of mines within the eastern occurrence of the unit. The activities associated with mines may influence groundwater negatively; therefore, mines are required by law to monitor, manage and mitigate the relevant activities to protect groundwater. The mines as depicted on Google Earth are Batlase, Dishaba, Thaba, Amandelbult, Swartklip, Redpath, Zondereinde, Tumela, Langpan, Vlaak Ore and Mantecu. The list may include more mines or shafts. The Northam Smelter Facility falls within the unit. Large towns include Northam, Swartklip, Amandelbult, Setaria, Sefikile, and Majuteng. Water schemes supplying water to these areas, use both ground and surface water.

No large-scale economic activities are within the western occurrence of the unit, activities include game and livestock farming and associated activities.

In 7% of the water samples, at least one element exceeds the maximum allowed limits for domestic use. For this unit the cation of concern is Magnesium followed by the anion Chloride that exceeds the maximum allowable concentration limit in 6.9% of the analysis.

7.2.3.7 CROCODILE RIVER FRAGMENT (Vco)

This unit occurs as a single cluster south of Thabazimbi within the south-centre section of the map sheet. It covers approximately 0.46% of the map area, (Figure 88). This fragment comprises deformed rocks from the Transvaal Supergroup; it is fault bounded; includes dolomites, quartzites, Shale and hornfels, which have undergone thermal metamorphism due to the intrusion of the Bushveld Ingenious Complex. It is most probably surrounded by large feeding channels (explanatory notes; Thabazimbi geological map sheet).

Stratigraphic, structural, geophysical, and metamorphic data show that the Crocodile River Fragment probably formed as a result of interference folding in the Transvaal Basin, prior to the intrusion of the Bushveld Complex. Folding took place along prominent pre-existing structural directions in the Kaapvaal Craton, notably the Murchison lineament and a north-west trending set of faults. The intrusion of the Bushveld Complex enhanced the intensity of folding, Hartzer (1989).

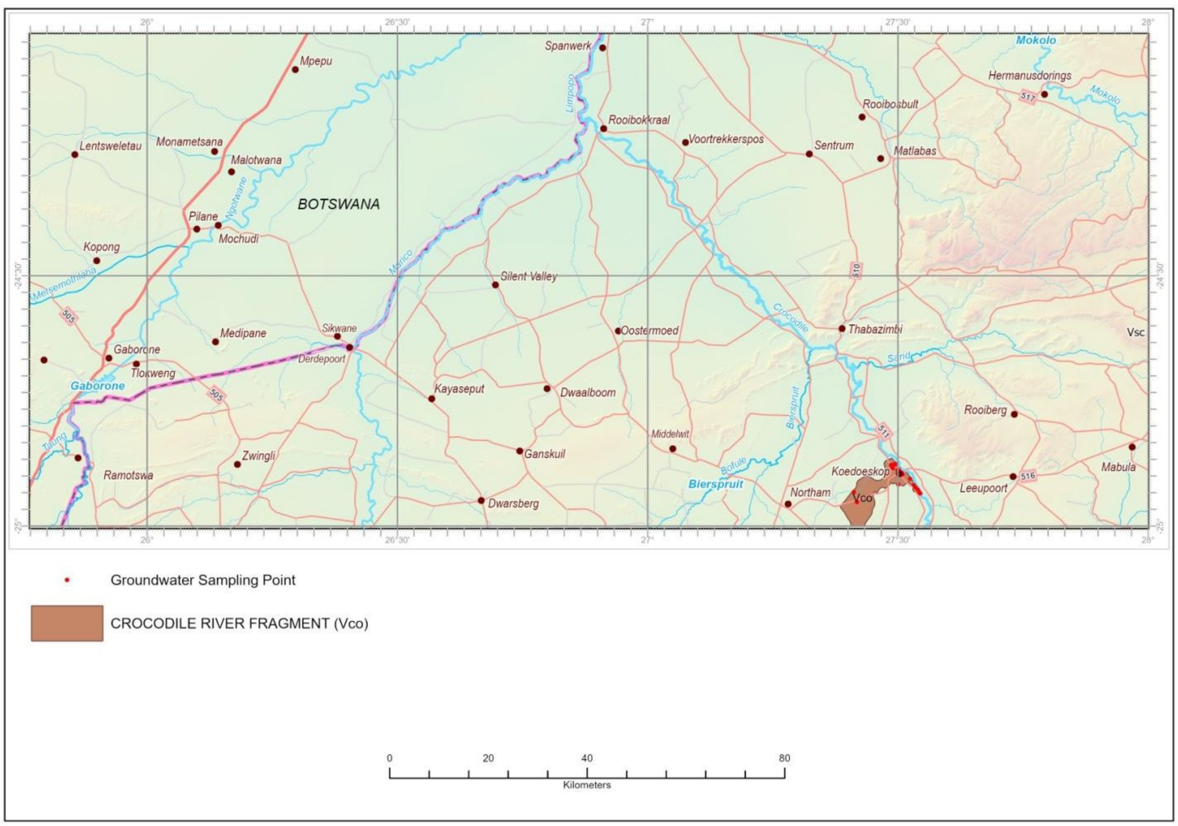


Figure 88: Geographical distribution of the Crocodile River Fragment (Vco) and the associated groundwater sampling points.

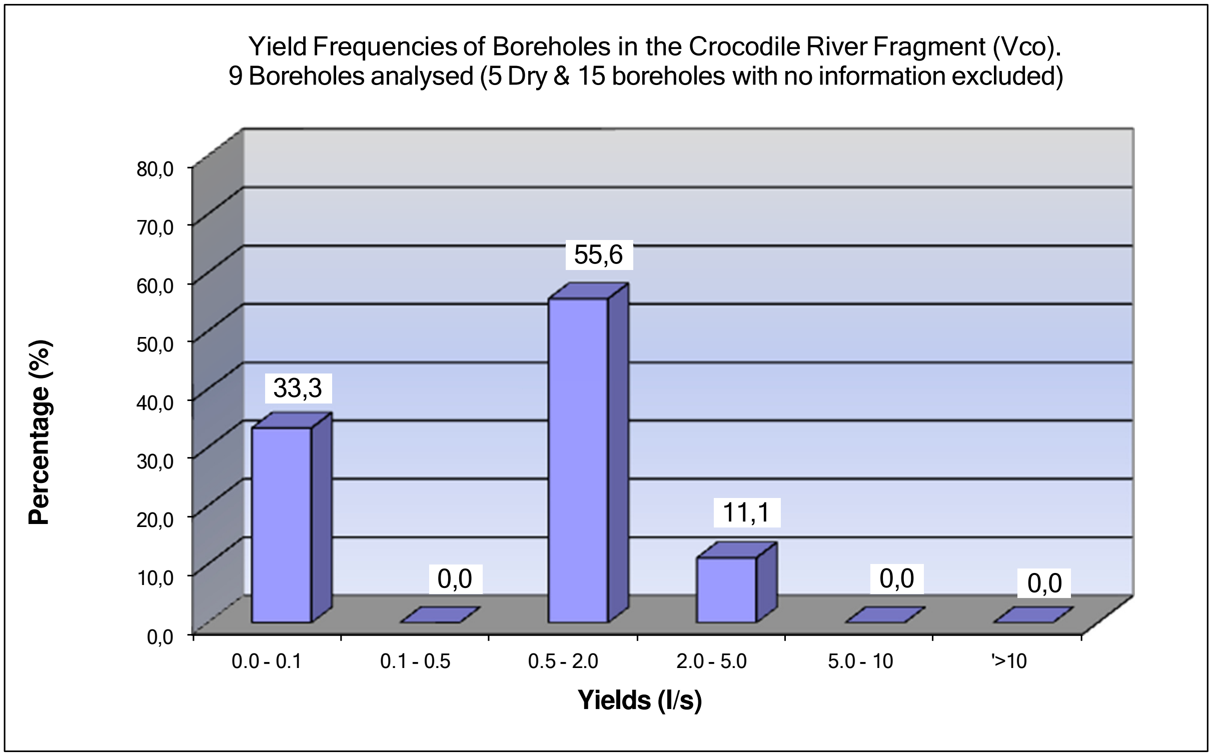


Figure 89: Yield frequency for Intergranular & fractured aquifers of the Crocodile River Fragment (Vco).

The yield frequency distribution indicates that 33.3% of the successful boreholes yield less than 0.1ℓ/s. A further 55.6% of the boreholes yield between 0.5ℓ/s and 2ℓ/s and 11.1% of the boreholes yield between 2ℓ/s and 5ℓ/s. None of the reported boreholes have yields exceeding 5ℓ/s, (Figure 89).

No information is available on borehole depths, water strike depths or abstraction. An accurate characterization could therefore not be done for this unit.

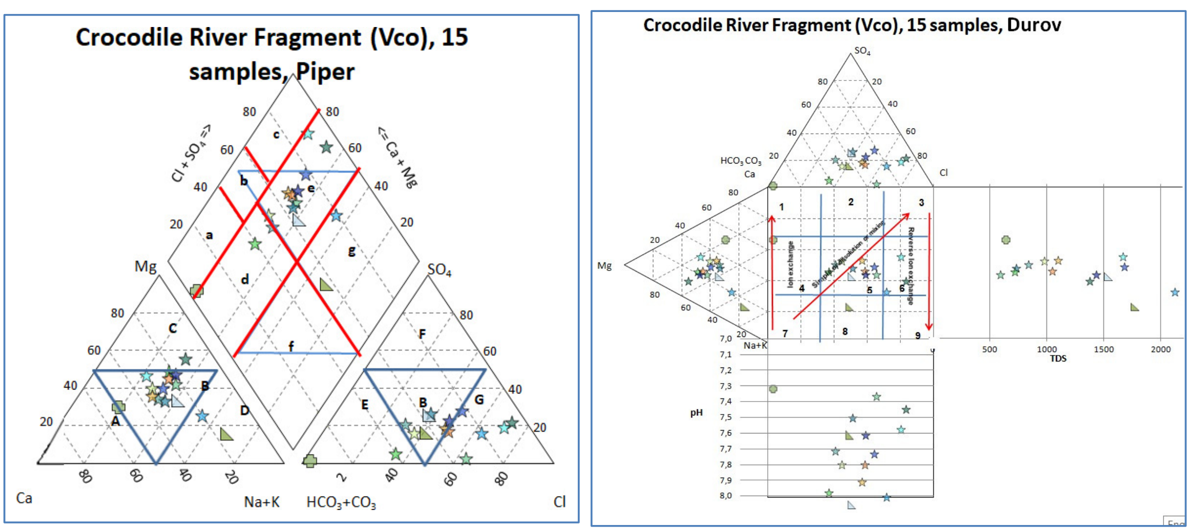


Figure 90: Trilinear diagrams, Piper and Durov for the Crocodile River Fragment (Vco).

The trilinear Piper diagram, (Figure 90) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions in order to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (86.7%), Weak acidic anions > Strong acidic anions (6.7%); Alkali >Alkali earths (13.3%); Strong acids > Weak acids (93.3%).

The groundwater in this unit classifies as:

- Mixed Calcium-Magnesium-Bicarbonate-Chloride type (59.8%);
- Sodium-Chloride type (13.4%);
- Calcium-Bicarbonate type (6.7%);
- Magnesium-Chloride type (6.7%);
- Calcium-Magnesium-Chloride type (6.7%);
- Calcium-Magnesium-Bicarbonate type (6.7%).

The trilinear Durov diagram defines the hydrochemical processes along with the water type:
- No dominant anion or cation indicates fresh recent recharge water exhibiting simple dissolution or mixing (66.6%), plot along the dissolution or mixing line,
- Anion discriminates and Na dominant indicates probable mixing or uncommon dissolution influences (20%),
- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (6.7%),
- Cl is the dominant anion and Na the dominant cation, indicative that the groundwater is related to reverse ion exchange of Na-Cl waters (6.7%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 51: Chemical statistics for the Crocodile River Fragment (Vco).

Element / Parameter	Statistics Drawn from a population of 20 data points for the Crocodile River Fragment (Vco)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	20	7,30	8,05	7,70	7,70	7,42	7,70	8,00	0,23	3,0%
Electrical Conductivity (mS/m EC)	20	61,9	320,0	146,7	182,6	82,6	190,0	275,8	77,2	42,3%
Total Dissolved Salts (mg/l TDS)	20	533,0	1936,0	1065,9	1267,5	642,0	1328,5	1880,9	483,0	38,1%
Calcium (mg/l Ca)	20	33,70	190,40	74,71	94,72	39,41	80,10	162,76	45,15	47,7%
Magnesium (mg/l Mg)	20	26,70	167,50	71,01	93,11	42,91	86,75	148,56	44,72	48,0%
Sodium (mg/l Na)	20	31,60	373,10	109,83	163,50	64,21	146,60	334,08	103,08	63,0%
Potassium (mg/l K)	20	1,48	10,10	3,41	4,58	2,12	4,03	8,41	2,56	56,0%
Chloride (mg/l Cl)	20	3,40	561,34	50,10	269,74	73,42	227,15	534,69	181,58	67,3%
Sulphate (mg/l SO_4)	20	2,00	347,80	23,89	132,37	13,45	127,20	215,55	85,70	64,7%
Total Alkalinity (mg/l) $CaCO_3$)	20	122,20	646,40	321,00	367,94	224,77	372,25	509,23	119,96	32,6%
Nitrate (mg/l N)	20	0,28	52,98	1,79	13,05	0,65	4,74	38,10	15,87	121,6%
Fluoride (mg/l F)	20	0,22	3,68	0,66	1,02	0,37	0,78	1,58	0,81	79,2%
Silicon as Si	20	1,04	35,00	8,65	21,56	6,86	24,05	31,68	10,48	48,6%
Iron (Fe)	0									
Manganese (Mn)	0									
Ortho Phosphate as Phosphorus as PO4	20	0,003	0,031	0,004	0,006	0,003	0,003	0,014	0,01	105,9%
ZAR	20	0,79	8,35	2,16	2,89	1,60	2,14	5,37	1,87	64,7%
LSI	20	Langelier Saturation Index (LSI)			Slightly Scaling		75,0%	Highly Scaling		0,0%
		Highly corrosive		0,0%	Slightly corrosive		0,0%	Balanced Corrosion		25,0%

Table 51 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is ideal to good (40%) and marginal in (60%) of the analysis in terms of the Electrical conductivity (EC) with values ranging between 61.9 and 320mS/m.

The Total Dissolved Solids (TDS) is acceptable in 40% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 20 samples indicates elevated concentrations of Nitrate (N >10mg/l) in 20% and Fluoride (F >1.5mg/l) in 10% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is predominantly slightly scaling (75%) and balanced (25%). The ZAR index indicates that 75% of the water is of a fair quality for irrigation (ZAR < 3).

The groundwater abstracted supply people in farmsteads and lodges; the water is also abstracted for livestock and game watering. Large-scale irrigation occurs in the eastern side of the unit. The water used for irrigation includes surface water from the Crocodile River and groundwater from the associated alluvial deposits around the river.

In 20% of the water samples from this unit, at least one element exceeds the maximum allowable limits for domestic use. The primary anions of concern are Nitrate, followed by Fluoride, which exceeds the maximum allowed concentration limit in approximately 10% of the samples.

7.2.3.8 GABORONE GRANITE (Zga)

The Gaborone Granite occurs as several annular plutons of granites of various types with quartz porphyries and quartz felsites within Botswana near Gaborone with extensions into the Thabazimbi map area, (SACS, 1980, p243).

The unit occurs southeast and west of the Derdepoort Border post (Figure *91*) and on either side of the Modipe Gabbro Complex. This unit covers approximately 1.1% of the map sheet area.

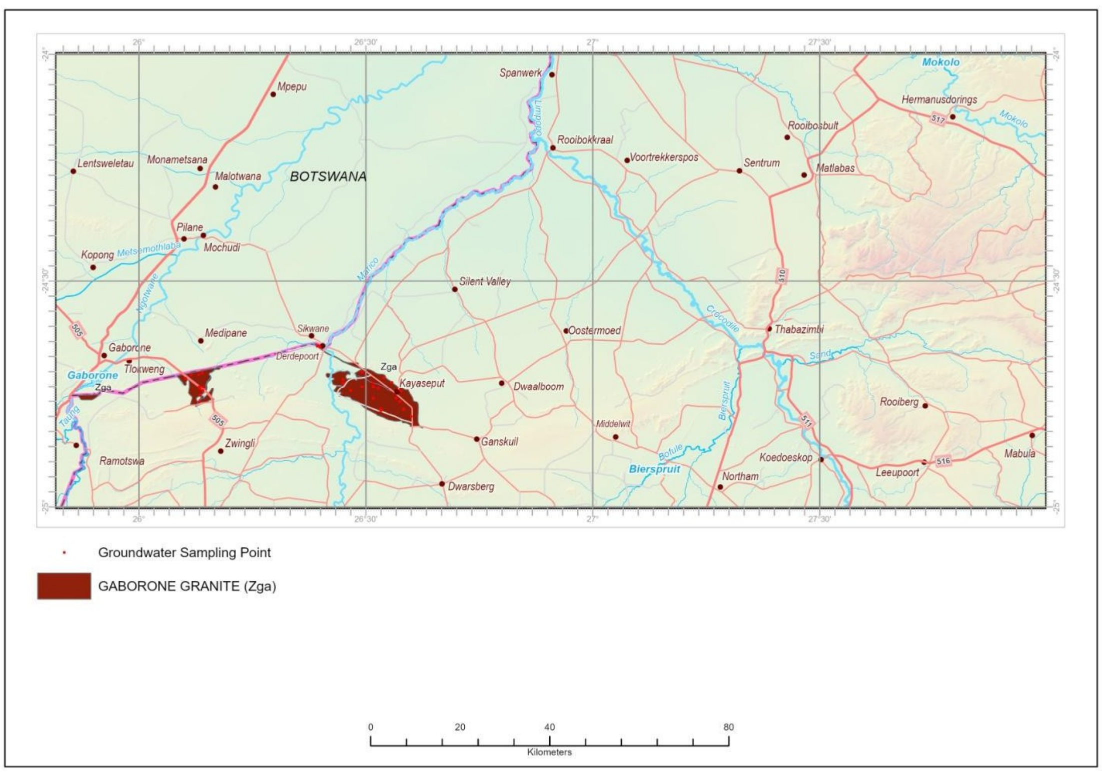


Figure 91: Geographical distribution of the Gaborone Granite (Zga) and associated groundwater sampling points.

Groundwater occurs mainly in faults and associated shear zones, fracture zones as well as dyke and fractured lithological contacts. The Gaborone granite has a low groundwater potential as 83.2% of the successful boreholes yield less than 2ℓ/s, (Figure 92).

The depth of weathering could be insignificant for groundwater exploration as fresh bedrock outcrop dominates as scattered hills.

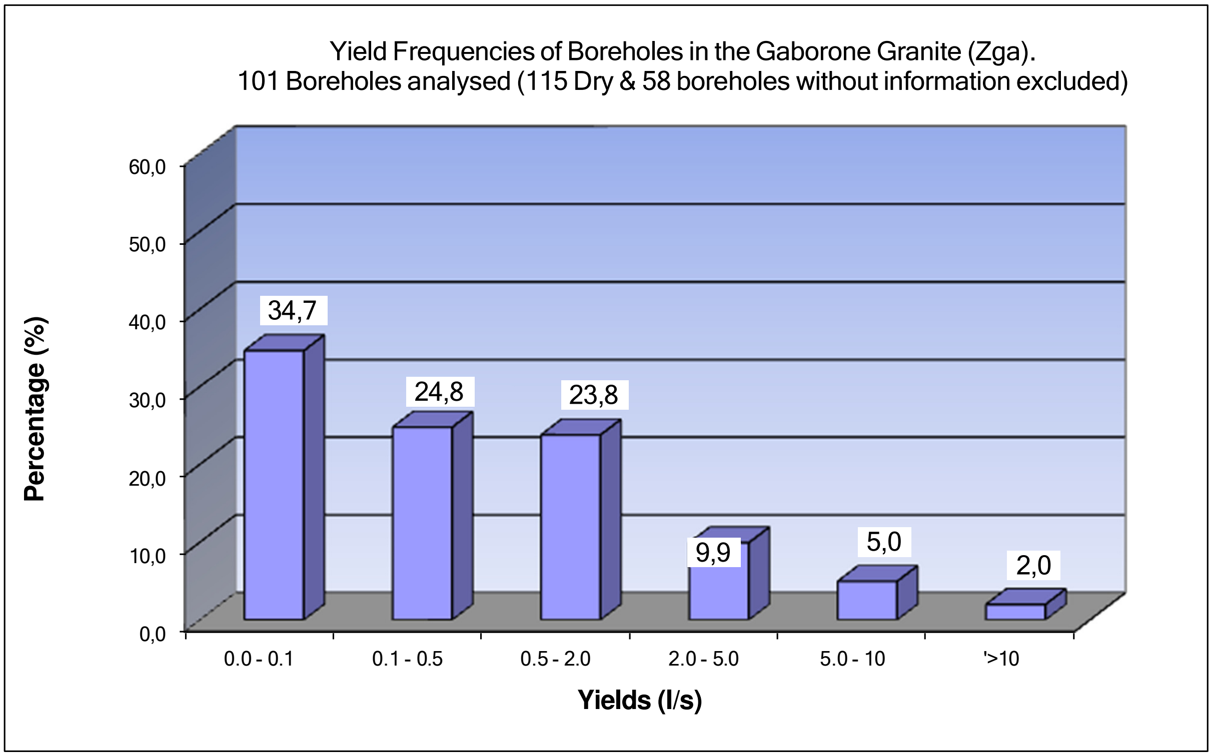


Figure 92: Yield frequency for the intergranular and fractured aquifers of the Gaborone Granite (Zga*).*

Statistics indicate that 59.5% of the successful boreholes yield less than 0.5ℓ/s. A further 23.8% of the boreholes yield between 0.5ℓ/s to 2ℓ/s, while 9.9% of the boreholes yield between 2-5ℓ/s. Only 7% of the boreholes yield more 5ℓ/s, (Figure 92).

No information is available on borehole depths, water strike depths or abstraction volumes. An accurate characterization of the unit could therefore not be done.

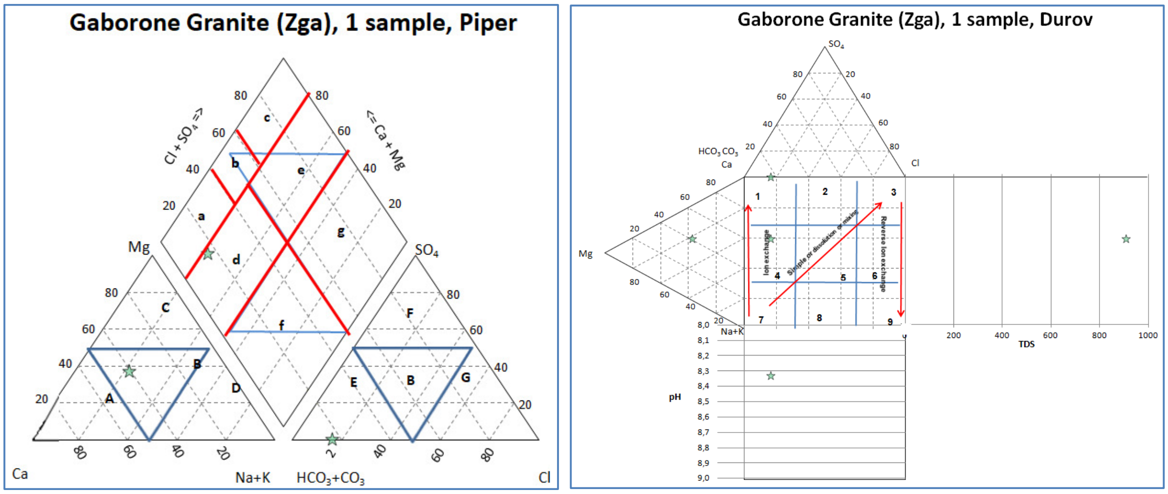


Figure 93: Trilinear diagrams, Piper, and Durov for the Gaborone Granite (Zga*).*

The trilinear Piper diagram, Figure 93 facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (100%), Weak acidic anions > Strong acidic anions (100%); Alkali >Alkali earths (0%); Strong acids > Weak acids (0%).

The groundwater in this unit is classified as a Mixed Calcium-Magnesium-Bicarbonate type.

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (100%),

Table 52: Chemical statistics for the Gaborone Granite (Zga).

Element / Parameter	Statistics Drawn from a population of 1 data point for the Gaborone Granite (Zga)									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	1	8,31	8,31	8,31	8,31	8,31	8,31	8,31		
Electrical Conductivity (mS/m EC)	1	103,5	103,5	103,5	103,5	103,5	103,5	103,5		
Total Dissolved Salts (mg/l TDS)	1	912,0	912,0	912,0	912,0	912,0	912,0	912,0		
Calcium (mg/l Ca)	1	96,10	96,10	96,10	96,10	96,10	96,10	96,10		
Magnesium (mg/l Mg)	1	53,30	53,30	53,30	53,30	53,30	53,30	53,30		
Sodium (mg/l Na)	1	59,10	59,10	59,10	59,10	59,10	59,10	59,10		
Potassium (mg/l K)	1	1,14	1,14	1,14	1,14	1,14	1,14	1,14		
Chloride (mg/l Cl)	1	30,90	30,90	30,90	30,90	30,90	30,90	30,90		
Sulphate (mg/l SO_4)	1	2,00	2,00	2,00	2,00	2,00	2,00	2,00		
Total Alkalinity (mg/l) $CaCO_3$)	1	460,00	460,00	460,00	460,00	460,00	460,00	460,00		
Nitrate (mg/l N)	1	24,18	24,18	24,18	24,18	24,18	24,18	24,18		
Fluoride (mg/l F)	1	0,41	0,41	0,41	0,41	0,41	0,41	0,41		
Silicon as Si	1	23,57	23,57	23,57	23,57	23,57	23,57	23,57		
Iron (Fe)	0									
Manganese (Mn)	0									
Ortho Phosphate as Phosphorus as PO4	1	0,023	0,023	0,023	0,023	0,023	0,023	0,023		
ZAR	1	1,20	1,20	1,20	1,20	1,20	1,20	1,20		
LSI	1	Langelier Saturation Index (LSI)			Slightly Scaling		100,0%	Highly Scaling		0,0%
		Highly corrosive		0,0%	Slightly corrosive		0,0%	Balanced Corrosion		0,0%

Table 52 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Limited analysis was available for accurate characterization. In terms of the Electrical conductivity (EC) the value is 103.5mS/m (good quality) and the Total Dissolved Solids (TDS) are acceptable in all the samples (TDS ≤ 1200mg/l).

For the single chemical analysis available the Langelier Saturation Index (LSI) indicates that the water is slightly scaling. The ZAR index indicates that the water is of a fair quality for irrigation (ZAR < 3).

Groundwater from the unit is used for the Madikwe game reserve with associated lodges and game watering.

7.2.3.8.1 UNNAMED HYPERITE

Hyperite is indicated on the 1974 Geological map sheet to occur within the area. The latest GIS digital coverage available from the Council for Geoscience that was used in compiling the hydrogeological map sheet does not include this lithological unit within the Thabazimbi map coverage. Coverage is therefore assumed to be minimal, and it will not have a significant influence on groundwater occurrences.

As no references could be found for Hyperite it was assumed to be Hypertite which typically refers to hypersthene-bearing norite, a type of igneous rock. The accompanying notes for the geological map sheet state the following: ''the Gaborone Granite is intrusive into basic and ultrabasic rocks, 'old granite' and hyperite along the Marico River and into the Kanye Volcanic Group and Modipe gabbro in Botswana''.

7.2.3.9 GRANITE AND GRANITE GNEISS, WESTERN TRANSVAAL BELT (Zjt)

The unit occurs within the north-western section of the map sheet; the surface coverage is approximately 23.3% of the map area which makes it the largest groundwater resource unit within the map area. On the 1: 500 000 hydrogeological map sheet this unit was grouped under the unnamed Swazian Rocks (Zz) hydrogeological unit.

Intrusive in the Swazian stratified rocks, the unit's composition is granitic to granodioritic, K- feldspar dominates with or without Plagioclase. It has a gneissose structure in many places with migmatitic phases developed around inclusions of primitive rock, (Visser D.J.J. 1989, p23). Scattered small occurrences of granite and gneiss are intrusive in the unit in the north-eastern section of the map. These scattered granite and gneiss outcrops has been grouped with this unit.

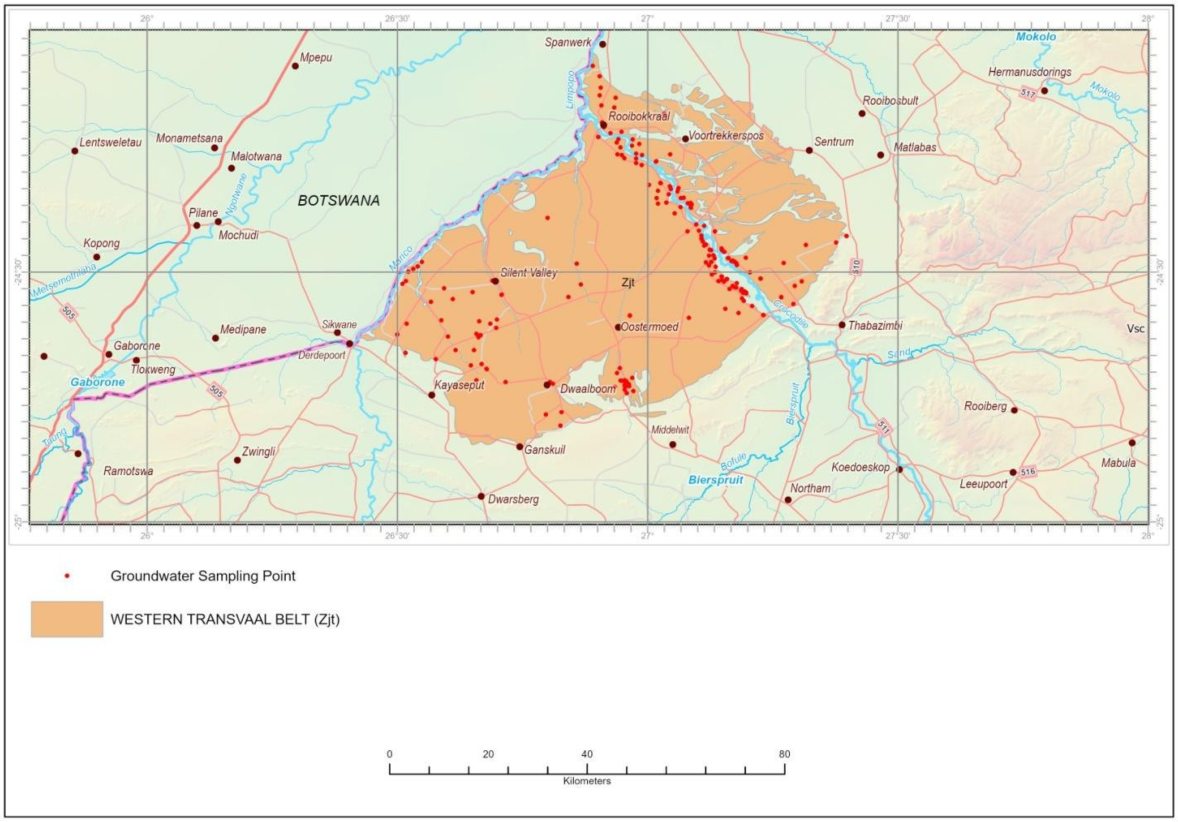


Figure 94: Geographical distribution of the Granite and Granite Gneiss, Western Transvaal Belt (Zjt).

Groundwater occurs in fault and associated shear zones and fractures related to quartz veins and pegmatites. Water also occurs to a limited extent along dyke contacts.

The groundwater potential of these granites and gneisses is generally low as approximately 80.5% of the successful boreholes yield less than 2ℓ/s, (Figure 95). Studies conducted by Vegter (1993) in the Silent Valley area indicated that recharge improved considerably in de-bushed areas. This was manifested in the significant rise in water levels in these areas. The topography underlying the unit is characterized by flat country.

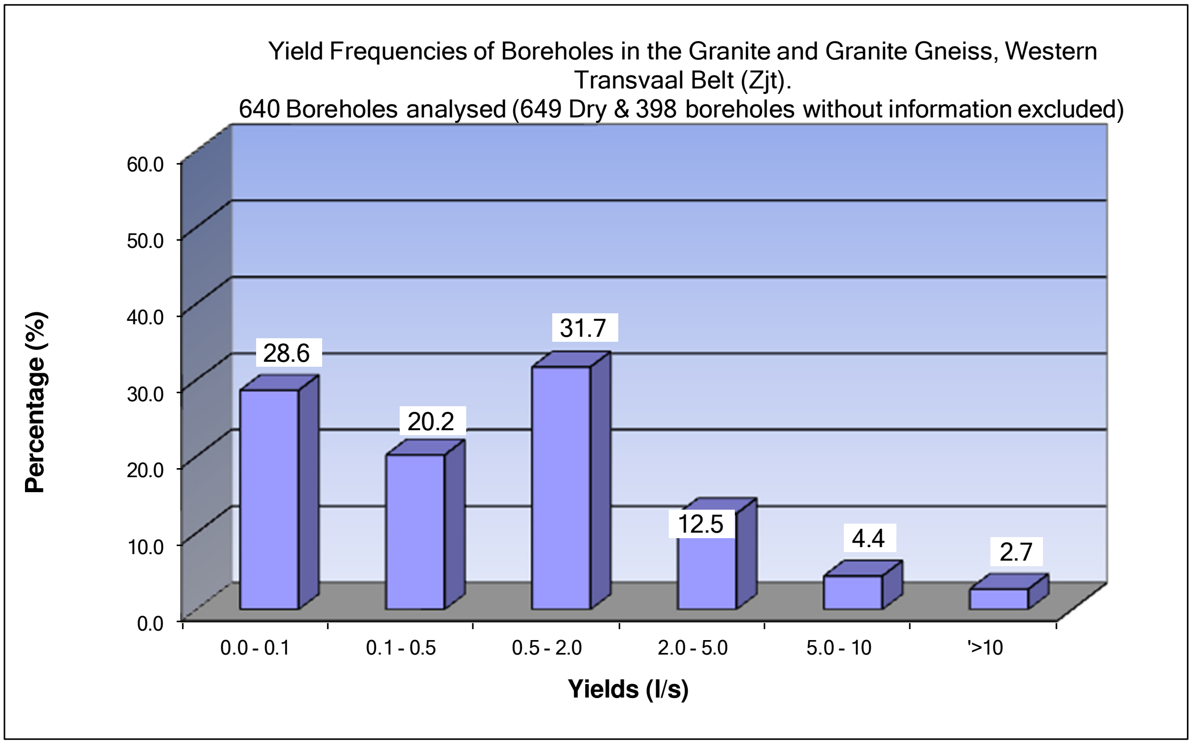


Figure 95: Yield frequency for the intergranular and fractured aquifers of the Granite and Granite Gneiss, Western Transvaal Belt (Zjt).

Statistics indicate that 48.8% of the successful boreholes yield less than 0.5ℓ/s. A further 31.7% of the boreholes yield between 0.5ℓ/s to 2ℓ/s, with 12.5% of the boreholes yielding between 2ℓ/s to 5ℓ/s. Only 7.1% of the boreholes yield more than 5ℓ/s, (Figure 95).

The static water level ranges from 6.51 meters below ground level (mbgl) to 55.9mbgl, with a median of 29.94mbgl and an average static water level of 28.89mbgl; (based on 56 data points). The maximum depth recorded is 198m, with an average depth of 77.5m and a median depth of 60m; (15 data points). The installation depths can give an indication of water strike depths; the maximum installation depth is 72m and the average is 40m (21 data points). The maximum abstraction derived from 8 pumping tests is 432 cubic meters per day (m³/day) and the average abstraction is 268.8m³/day.

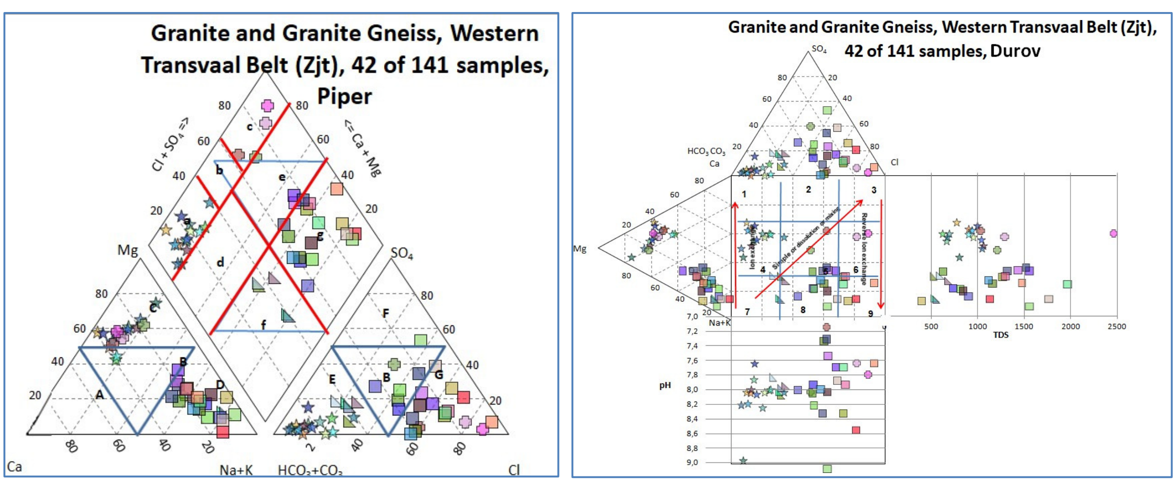


Figure 96: Trilinear diagrams, Piper, and Durov for the Granite and Granite Gneiss, Western Transvaal Belt (Zjt). 42 of 141 samples.

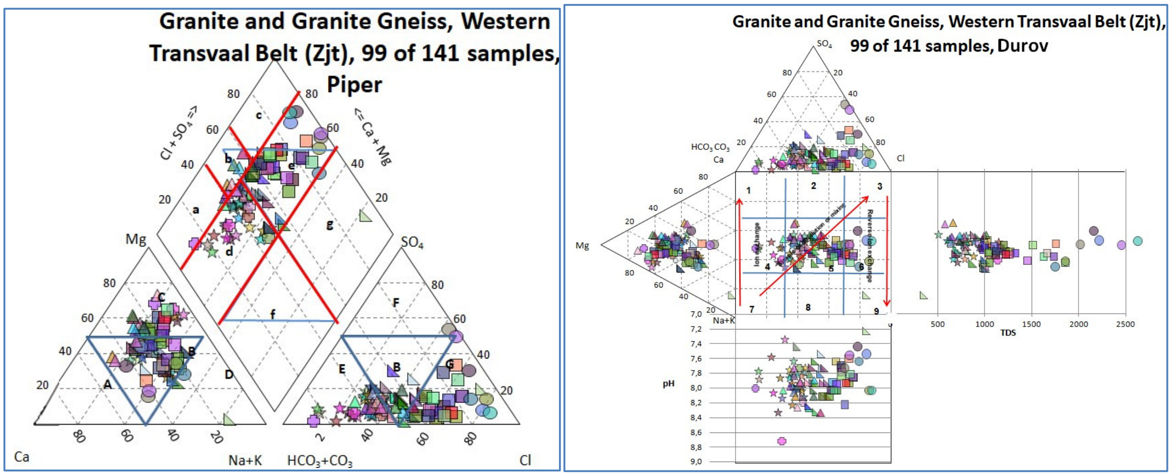


Figure 97: Trilinear diagrams, Piper, and Durov for the Granite and Granite Gneiss, Western Transvaal Belt (Zjt). 99 of 141 samples.

The trilinear Piper diagram, (Figure 96 & Figure 97) facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (83%), Weak acidic anions > Strong acidic anions (44%); Alkali >Alkali earths (17%); Strong acids > Weak acids (56%).

The groundwater in this unit classifies as:

- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with increased Sodium (20.7%);
- Magnesium-Bicarbonate type (20.7%);
- Magnesium-Chloride type (11.7%);
- Sodium-Chloride type (10.3%);
- Mixed Calcium-Magnesium-Chloride type (9%);
- Mixed Calcium-Magnesium-Bicarbonate type (6.9%);
- Magnesium-Bicarbonate-Chloride type (6.2%);
- Mixed Calcium-Magnesium-Chloride type with increased Sodium and Sulphate (4.7%);
- Mixed Calcium-Magnesium-Chloride type with increased Sodium (2.8%);
- Sodium-Bicarbonate type (2.8%);
- Sodium-Mixed-Bicarbonate-Chloride type (2.8%);
- Magnesium-Bicarbonate-Chloride type with increased Sulphate (0.7%);
- Sodium-Chloride type with increased Sulphate (0.7%);

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- No dominant anion or cation indicates fresh recent recharge water exhibiting simple dissolution or mixing (58.9%), plot along the dissolution or mixing line,
- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (17.1%),
- Anion discriminant and Na dominate indicative of possible mixing or uncommon dissolution influences (11.3%),
- Cl dominant anion and Na dominant cation, indicative of reverse ion exchange of Na-Cl waters (6.4%),
- Cl and Na dominate; frequently indicate endpoint down gradient waters through dissolution (3.5%),
- Cl and Na dominant, reverse ion exchange of Na-Cl waters (2.8%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 53: Chemical statistics for the Granite and Granite Gneiss, Western Transvaal Belt (Zjt).

Element / Parameter	**Statistics Drawn from a population of 202 data points for the Granite and Granite Gneiss, Western Transvaal Belt (Zjt)**									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	198	5,67	9,67	7,83	7,85	7,40	7,90	8,21	0,39	5,0%
Electrical Conductivity (mS/m EC)	198	35,0	1040,0	121,3	163,2	78,9	121,4	299,9	119,6	73,3%
Total Dissolved Salts (mg/l TDS)	185	228,0	6441,0	903,2	1147,0	624,8	996,0	1861,6	721,5	62,9%
Calcium (mg/l Ca)	184	3,10	458,00	48,77	84,89	31,53	70,65	138,98	64,72	76,2%
Magnesium (mg/l Mg)	184	1,90	434,40	46,48	86,29	34,59	74,30	133,80	58,86	68,2%
Sodium (mg/l Na)	184	0,03	1246,50	2,25	130,59	33,68	83,40	267,33	150,90	115,6%
Potassium (mg/l K)	184	0,15	41,80	2,30	4,85	1,20	3,82	8,28	5,01	103,3%
Chloride (mg/l Cl)	185	11,00	3802,60	69,29	238,19	29,90	111,70	538,90	386,38	162,2%
Sulphate (mg/l SO_4)	185	2,00	917,10	22,02	76,09	10,32	42,40	163,06	122,48	161,0%
Total Alkalinity (mg/l) $CaCO_3$)	189	31,00	757,20	303,44	374,50	239,24	351,40	576,00	134,59	35,9%
Nitrate (mg/l N)	198	0,02	135,73	0,72	13,77	0,46	4,49	40,62	22,73	165,1%
Fluoride (mg/l F)	185	0,04	4,90	0,50	0,91	0,30	0,71	1,65	0,69	75,1%
Silicon as Si	170	0,84	50,42	21,58	29,26	16,82	30,67	39,69	9,47	32,4%
Iron (Fe)	20	0,000	0,979	0,002	0,064	0,001	0,005	0,064	0,22	337,8%
Manganese (Mn)	20	0,000	0,090	0,001	0,010	0,001	0,001	0,025	0,02	213,7%
Ortho Phosphate as Phosphorus as PO4	167	0,003	0,712	0,005	0,018	0,003	0,005	0,019	0,08	428,7%
ZAR	184	0,00	15,33	0,07	2,54	0,65	1,60	5,59	2,52	99,4%
LSI	175	Langelier Saturation Index (LSI)			Slightly Scaling		**76,6%**	Highly Scaling		**0,0%**
		Highly corrosive		**0,0%**	Slightly corrosive		**3,4%**	Balanced Corrosion		**20,0%**

Table 53 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is ideal to good (64.6%), marginal in (30.8%) and unacceptable (EC > 370mS/m) in 4.5% of the analysis in terms of the Electrical conductivity (EC) with values ranging between 35 and 1040mS/m; the 90th percentile is 299.9mS/m.

The Total Dissolved Solids (TDS) is acceptable in 69.2% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 202 samples indicates elevated concentrations of Nitrate (N >10mg/l) in 18.2%; Fluoride (F >1.5mg/l) in 14.6%; Chloride (Cl > 600mg/l) in 8.6%; Sodium (Na > 400mg/l) in 3.8%; Magnesium (Mg > 200mg/l) in 3.3% Calcium (Ca > 300) in 2.2% and Sulphate (SO4 >600mg/l) in 1.6% of the analysis.

The Langelier Saturation Index (LSI) indicates that the water is slightly corrosive (3.4%); predominantly slightly scaling (76.6%) and balanced (20%). The ZAR index indicates that 71.7% of the water is of a fair quality for irrigation (ZAR < 3).

Groundwater is predominantly used for livestock and game watering. Domestic use includes farmsteads and lodges. Large scale irrigation is along the Limpopo and Crocodile Rivers. Water for irrigation includes a combination of surface and groundwater from the rivers and the associated alluvial deposits. Scattered throughout the unit is irrigation fields associated with dry land farming that was observed using Google Earth imagery. Some rural villages or settlements falls within this unit namely Dwaalboom, Adriaanshoop and Setaria. The water supply to the Dwaalboom settlement is from groundwater, the Adriaanshoop and Setaria settlements are supplied from a combination of groundwater and surface water.

In 18.2% of the water samples, at least one element exceeds the maximum allowed limits for domestic use. For this unit the anion of concern is Nitrate followed by Fluoride that exceeds the maximum allowable concentration limit for domestic use in 14.6% of the analysis.

7.2.3.10 MODIPE GABBRO COMPLEX (Zme)

This groundwater resource unit is mainly situated in Botswana and occurs on the South African side in a small area west of the Derdepoort Border Post (Figure 98). It is amongst others, represented by a series of prominent south-south-east to north-north-west to north-west isolated hills with elevations up to ±160m. Some isolated hills are also occurring within the western section of the unit that continues into Botswana. In the south-central section of the unit a hill with an estimated elevation of up to 340m occurs. Most of the game lodges occur near these hills. The rest of the unit is characterized by plains covered by quaternary sand and soil. The unit covers approximately 1.34% of the map area.

The rocks of the complex have not been studied in detail, but in the Derdepoort area reportedly consist mainly of gabbro with associated norite, gabbronorite, pyroxenite, wehrlite, dunite, serpentinite, anorthosite and bands of magnetite (Jansen et al., 1974). Granite associated with the Gaborone granite Complex is intrusive into this unit.

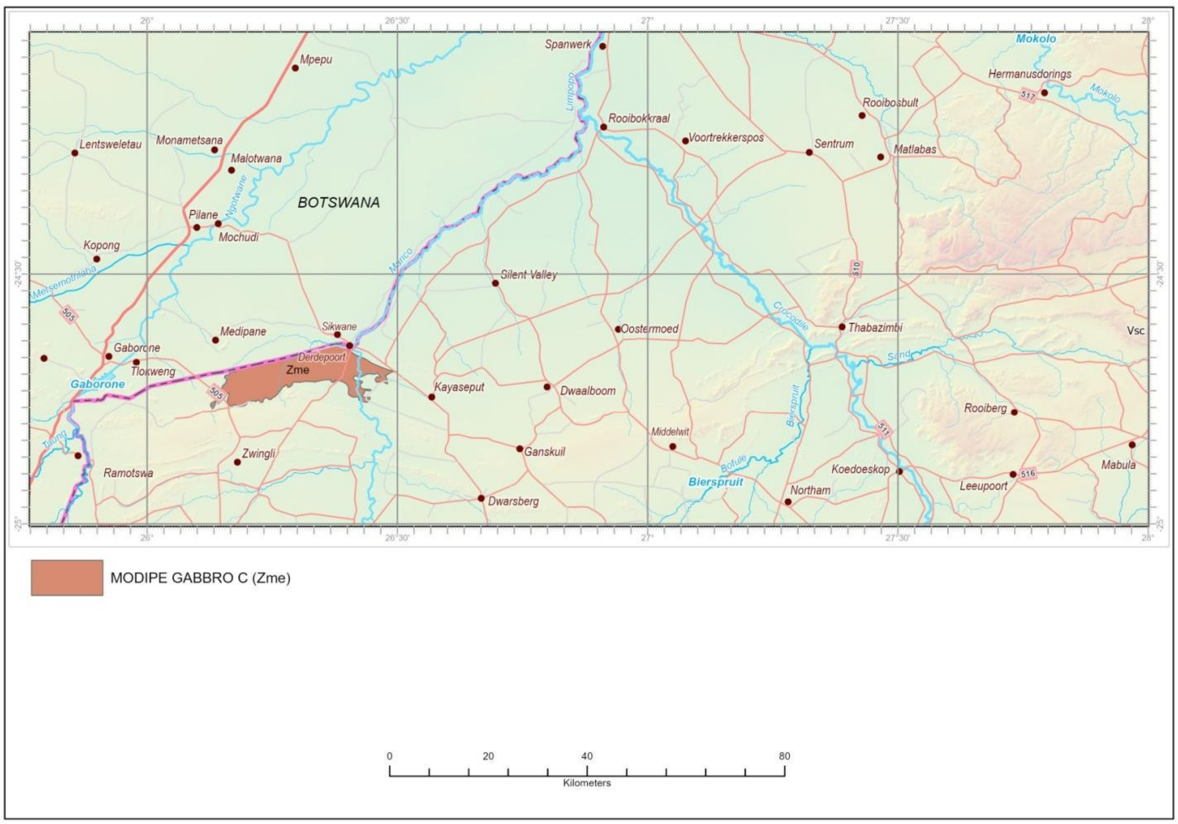


Figure 98: Geographical distribution of the Modipe Complex (Zme).

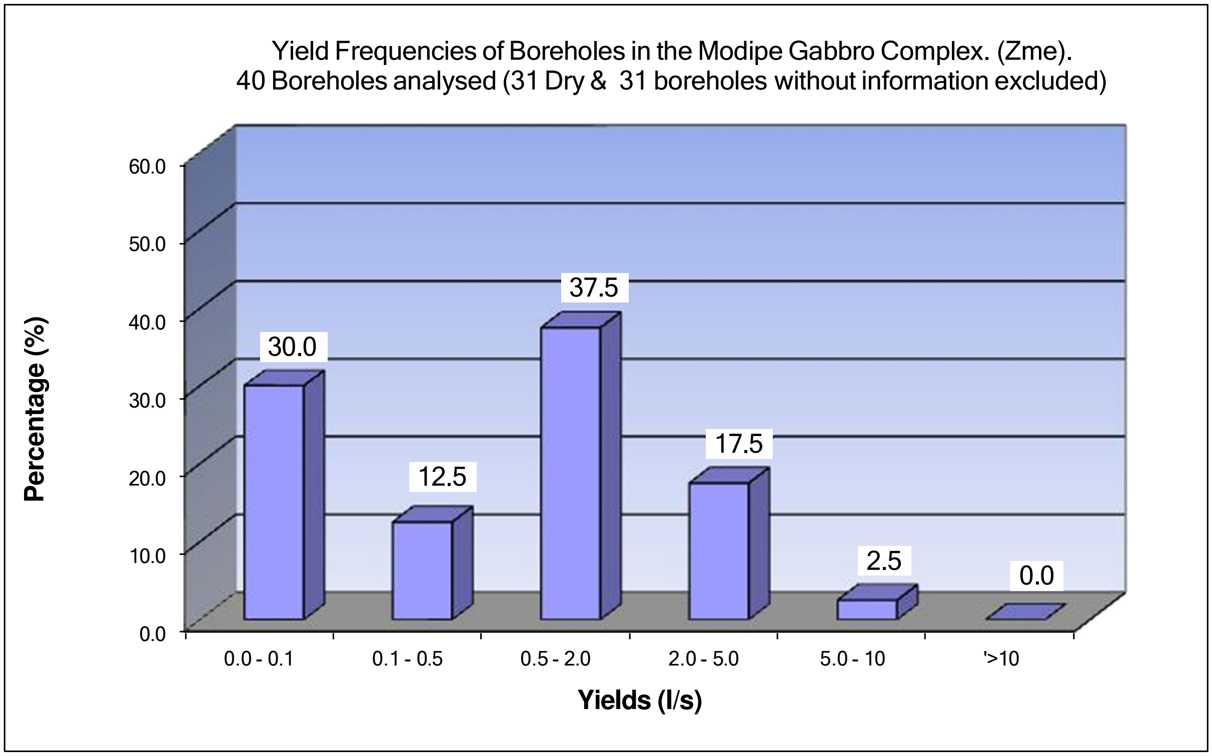


Figure 99: Yield frequency for the intergranular and fractured aquifers of the Modipe Gabbro Complex (Zme).

The statistics of 40 borehole resources indicate that 42.5% of the successful boreholes yield less than 0.5ℓ/s. A further 37.5% of the boreholes yield between 0.5ℓ/s to 2ℓ/s, while 17.5% of the boreholes yield between 2 to 5ℓ/s. Only 2.5% of the boreholes are yielding more than 5ℓ/s, (Figure 92).

No information is available on borehole depths, water chemistry, water strike depths or abstraction volumes. Therefore, an accurate characterization could not be completed for this groundwater resource unit.

The groundwater is used for the Madikwe game reserve with associated lodges and game watering.

7.2.3.11 SWAZILAND SYSTEM (BASIC TO ULTRABASIC ROCKS OF THE AREA CORRELATED WITH ARCHAEAN & JAMESTOWN COMPLEXES) (Zsj)

The oldest rocks within the Thabazimbi map sheet are represented by the groundwater resource unit named ‘Basement rocks of the area correlated with Archaean Complex & Jamestown Complex (Zsj)’. The explanatory notes of the Thabazimbi geological map sheet correlated the rocks of the occurrence with that of the Jamestown Igneous Complex that is part of the Baberton Mobile Belt and the Swaziland Group. The rock types indicated on the geological map sheet includes Gneiss, granulite, schist, talc schist, quartzite, arkose, banded iron stone, diorite, amphibolite, serpentinite and lava. The unit covers approximately 0.95% of the map sheet and occurs as scattered ‘xenoliths’ within the Granite and Granite Gneiss, Western Transvaal Belt, (Figure 100).

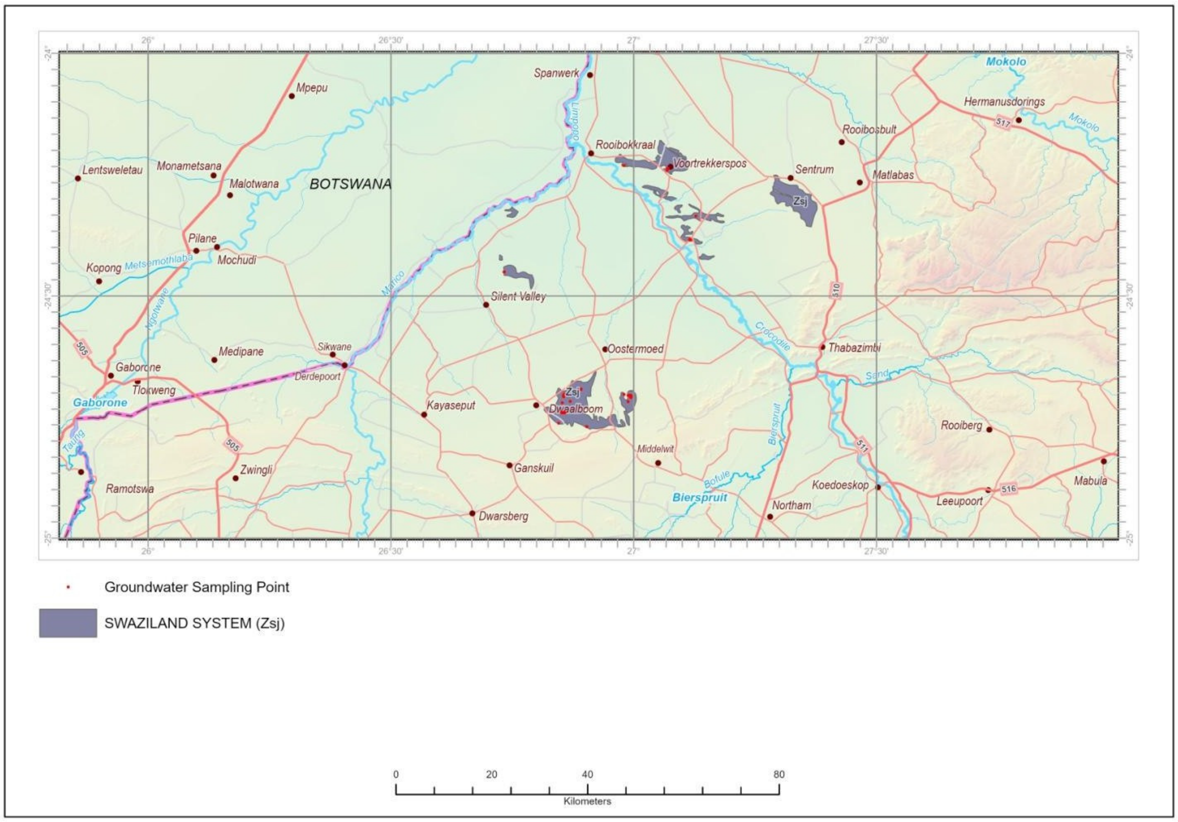


Figure 100: Geographical distribution of the Swaziland System (Basic to ultrabasic rocks of the area correlated with Archaean & Jamestown Complexes (Zsj).

Due to the wide range of rock types, drilling targets in the search for groundwater will be site dependent. Fault zones, geological contacts and deep weathered zones can be targeted in the search for groundwater. The area is covered extensively with Tertiary to Quaternary overburden that consists of Kalahari sand, black soil, red soil, and surface limestone. Alluvium is limited to the larger rivers such as the Limpopo and Crocodile River. See the section on the intergranular aquifers, namely, Tertiary-Quaternary Alluvial Deposits (Q) for more information.

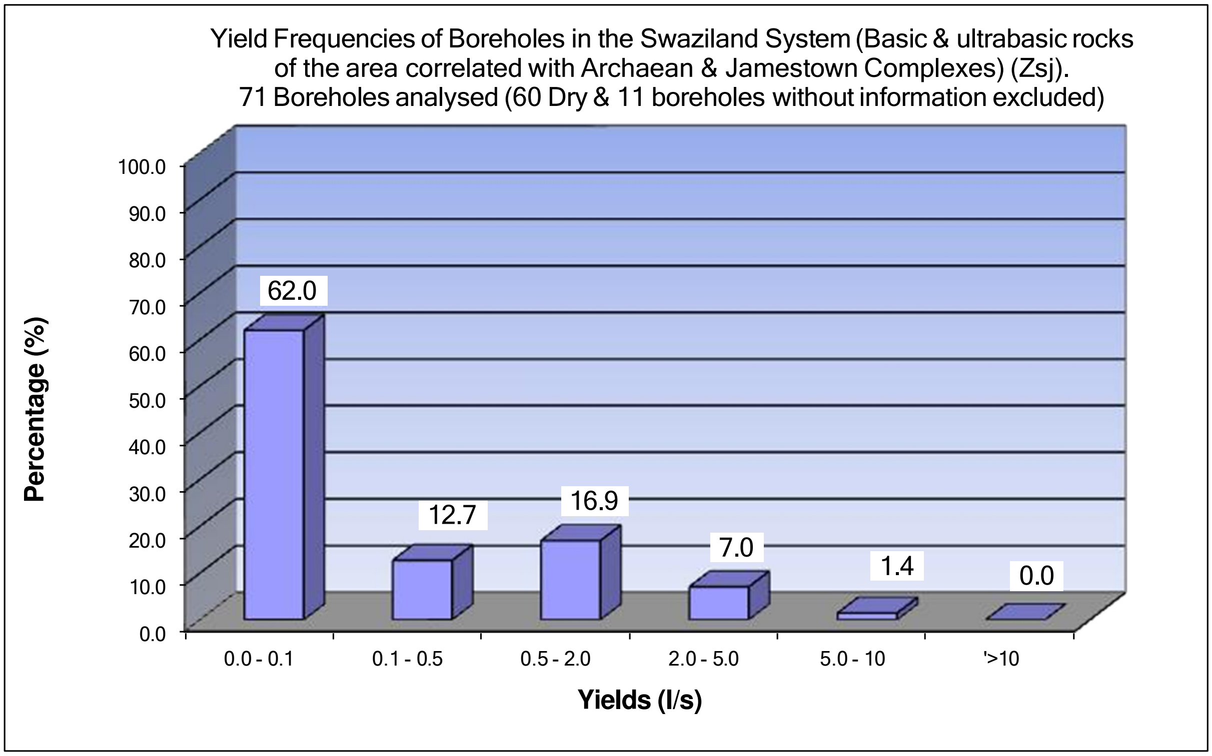


Figure 101: Yield frequency for the intergranular and fractured aquifers of the Swaziland System (Basic & ultrabasic rocks of the area correlated with Archaean & Jamestown Complexes) (Zsj).

Statistics from 71 groundwater resources indicate that 62% of the successful boreholes yield less than 0.1ℓ/s. A further 12.7% boreholes yield between 0.1ℓ/s to 0.5ℓ/s, while 16.9% of the boreholes are yielding between 0.5ℓ/s to 2ℓ/s. Only 7% of the boreholes yield between 2ℓ/s to 5ℓ/s and 1.4% are yielding more than 5ℓ/s, (Figure 101).

No information is available on borehole depths, water chemistry, water strike depths or abstraction volumes; an accurate characterization could therefore not be done.

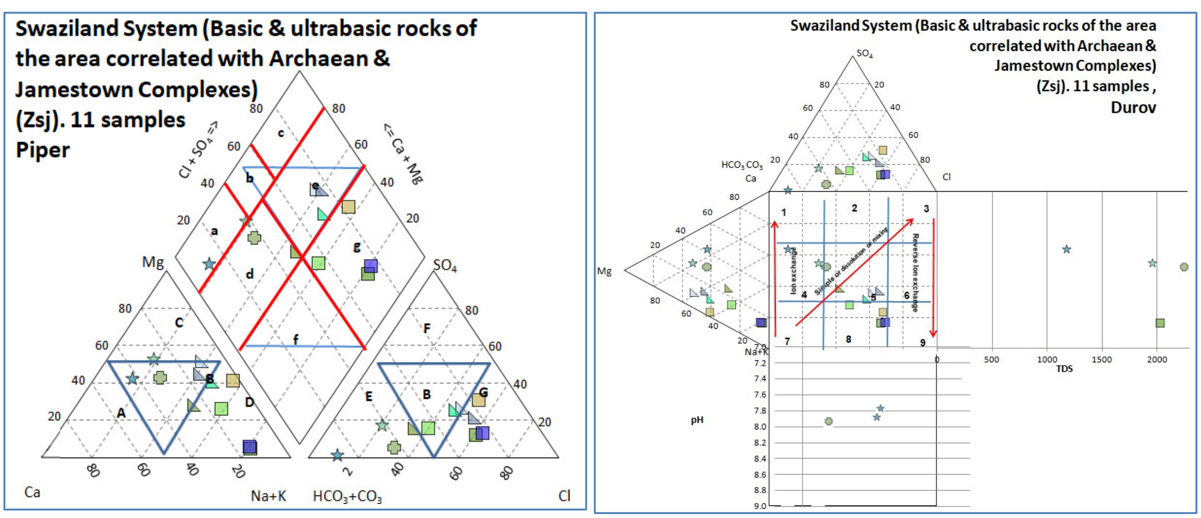


Figure 102: Trilinear diagrams, Piper, and Durov for the Swaziland System (Basic & ultrabasic rocks of the area correlated with Archaean & Jamestown Complexes) (Zsj).

The trilinear Piper diagram, Figure 102 facilitates the visualization of water chemistry through the representation of the concentrations of major cations and anions to classify the major hydrochemical facies. The first evaluation on the chemical dominance is as follows: Alkali earths > Alkali (63.6%), Weak acidic anions > Strong acidic anions (27.3%); Alkali >Alkali earths (36.4%); Strong acids > Weak acids (72.7%).

The groundwater in this unit classifies as:

- Sodium-Chloride type (36.3%);
- Mixed Calcium-Magnesium-Bicarbonate-Chloride type with increased Sodium and Sulphate (18.2%);
- Mixed Calcium-Magnesium-Bicarbonate type with increased Sodium (18.2%);
- Magnesium-Bicarbonate type (9.1%);
- Mixed Calcium-Magnesium-Bicarbonate type (9.1%).
- Mixed Calcium-Magnesium-Chlorite type (9.1%);

The trilinear Durov diagram defines the hydrochemical processes along with the water type:

- No dominant anion or cation indicates water exhibiting simple dissolution or mixing (45.5%), plot along the dissolution or mixing line,
- Anion discriminates and Ca dominant indicating mixed water or water exhibiting simple dissolution (18.2%),
- Cl is the dominant anion and Na the dominant cation, indicative that the groundwater relates to reverse ion exchange of Na-Cl waters (36.4%),
- Some samples exhibit high TDS values that may be indicative of long residence times in the aquifer allowing reactions to be complete.

Table 54: Chemical statistics for the Swaziland System (Basic & ultrabasic rocks of the area correlated with Archaean & Jamestown Complexes) (Zsj).

Element / Parameter	**Statistics Drawn from a population of 11 data points for the Swaziland System (Basic & ultrabasic rocks of the area correlated with Archaean & Jamestown Complexes) (Zsj).**									
	Total samples	Minimum Value	Maximum Value	Harmonic mean value	Arithmetic mean Value	10th percentile	50th percentile (median)	90th percentile	Standard Deviation	Coefficient of Variation
pH	11	7.78	8.34	8.11	8.12	7.90	8.20	8.30	0.18	2.2%
Electrical Conductivity (mS/m EC)	11	43.2	295.7	95.4	137.1	45.4	101.2	224.0	80.8	58.9%
Total Dissolved Salts (mg/l TDS)	11	362.0	2296.0	872.3	1155.0	601.0	1294.0	1843.0	592.9	51.3%
Calcium (mg/l Ca)	11	18.80	58.50	39.31	44.28	24.45	51.30	53.30	12.75	28.8%
Magnesium (mg/l Mg)	11	4.90	159.30	24.93	66.01	13.16	49.60	125.00	50.12	75.9%
Sodium (mg/l Na)	11	14.00	408.20	67.60	178.31	30.60	164.80	352.99	126.71	71.1%
Potassium (mg/l K)	11	0.96	6.07	3.31	4.28	3.14	4.45	5.96	1.49	34.8%
Chloride (mg/l Cl)	11	9.00	479.90	55.74	192.07	35.10	165.00	347.50	145.51	75.8%
Sulphate (mg/l SO_4)	11	2.00	377.10	16.11	112.81	13.90	87.10	198.80	110.19	97.7%
Total Alkalinity (mg/l) $CaCO_3$)	11	185.89	513.30	321.39	349.90	214.90	344.40	459.20	98.16	28.1%
Nitrate (mg/l N)	11	0.07	91.27	0.45	27.99	0.12	14.08	72.01	33.01	117.9%
Fluoride (mg/l F)	11	0.20	3.27	0.61	0.95	0.45	0.67	1.22	0.82	86.1%
Silicon as Si	11	11.33	23.19	17.65	18.86	12.12	21.45	23.03	4.55	24.1%
Iron (Fe)	2	0.003	0.005	0.004	0.004	0.003	0.004	0.005	0.001	35.4%
Manganese (Mn)	2	0.001	0.044	0.002	0.023	0.006	0.023	0.040	0.03	133.8%
Ortho Phosphate as Phosphorus as PO4	11	0.003	0.022	0.005	0.008	0.003	0.005	0.020	0.01	87.7%
ZAR	11	0.43	11.26	1.78	4.29	0.75	3.12	7.76	3.30	76.8%
LSI	11	Langelier Saturation Index (LSI)			Slightly Scaling		**63.6%**	Highly Scaling		**0.0%**
		Highly corrosive		**0.0%**	Slightly corrosive		**0.0%**	Balanced Corrosion		**36.4%**

Table 54 gives a summary of the physical properties, the major anions, cations, and some of the minor elements. Where the coefficient of variation is above 100%, the 90th percentile, the maximum value and standard deviation will give an indication of the scale of the problem. The overall water quality is ideal to good in (54.5%) to marginal (EC < 370mS/m) in (45.5%) of the analysis in terms of the Electrical conductivity (EC) with values ranging between 43.2 and 295.7mS/m.

The Total Dissolved Solids (TDS) is acceptable in 45.5% of the samples, (TDS ≤ 1200mg/l). An evaluation of the major cations and anions from 11 samples indicates elevated concentrations of Nitrate (N >10mg/l) in 36.4%; Fluoride (F >1.5mg/l) in 9.1% and Sodium (Na > 400mg/l) in 9.1% of the samples.

The Langelier Saturation Index (LSI) indicates that the water is predominantly slightly scaling (63.6%) and balanced (36.4%). The ZAR index indicates that 36.4% of the water is of a fair quality for irrigation (ZAR < 3).

The water abstracted supply people in rural farmsteads and lodges; the water is also abstracted for livestock and game watering. Large scale irrigation is along the Limpopo and Crocodile Rivers. Water for irrigation is from surface water pumped from the rivers or from groundwater found within the associated alluvial deposits.

In 36.4% of the water samples, at least one element exceeds the maximum allowed limits for domestic use. For this unit the anion of concern is Nitrate.

8. SPRINGS AND ARTESIAN BOREHOLES

8.1 Hot Springs

Of the 90 (Kent, 1968) known hot springs in the Republic of South Africa, none occurs on the Thabazimbi Hydrogeological map sheet.

8.2 Cold Springs

Springs are natural exit points where groundwater emerges from an aquifer and flows across the surface as surface water. Interflow, on the other hand, refers to the lateral movement of water within the unsaturated (vadose) zone, which eventually returns to the surface or enters a stream, (Wikipedia).

Not much documentation / information could be obtained regarding the occurrence of cold springs within the map area. On the DWS report portal one report could be obtained regarding springs. The investigation was done in 1969 by Steyn, M.J., within the carbonate (dolomite) formations around Thabazimbi. The following findings and information from the report:

- Various springs were reported but no coordinates or detailed information was provided, for instance farm names were mentioned but no farm numbers were provided. For springs in the dolomite in Karst Region 10: (the area from Delmas to Zeerust), more information is available. There is also a report by Fleisher, J.N.E. (1979) called. 'An analysis of springs in the Dolomite aquifer South-Western Transvaal'. A comment that may apply to the dolomite within the Thabazimbi map sheet is as follows: spring flow was reported to be dependent on rainfall i.e. decreasing / ceasing during periods of low / no rainfall and increasing / resuming after periods of high rainfall.

The springs reported by Steyn in 1969 were as follows: (note farm numbers were obtained from the relevant topographical map sheets)

- Grootfontein 352KQ - east of Thabazimbi,
- Waterval 443KQ - east of Thabazimbi: Water flow from the dolomites into the Sondagsriver, at the time of reporting the yield measured was 0.42l/s. North of the dolomite the river did not flow,
- Zandspruit 449KQ or 451KQ – east of Thabazimbi: It was reported that a borehole was drilled near a cave-no mention was made regarding the presence of a spring,

- No springs occur in the dolomite north-west of Thabazimbi,
- Witfontein 296KQ – west of Thabazimbi: one spring was reported that was flowing from the dolomite southwards,
- Holfontein 361KQ – west of Thabazimbi: one spring was reported flowing from the dolomite northwards.
- e-WULAAS registered spring at coordinates of latitude S-24.49434º and longitude E 27.90771º; daily registered abstraction is 168.5m³/day. Underlain by sedimentary rocks of the Waterberg Supergroup. It is located on the southern side of the plateau.
- e-WULAAS registered spring at coordinates of latitude S-24.48444º and longitude E 27.91778º; daily registered abstraction is 171.1m³/day. Underlain by sedimentary rocks of the Waterberg Supergroup. It is located on the southern side of the plateau.
- The geological map sheet indicates various other springs on the southern and western side of the Waterberg plateau, but no information could be obtained regarding the occurrences.

8.3 Artesian boreholes

The definition of an artesian borehole is a borehole that penetrated a confined aquifer in which the Piezometric surface is above ground level. This will result in water being discharged from the borehole without being pumped. The definition of a confined aquifer is a water bearing formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations. Thus, a confined groundwater aquifer is generally subject to pressure greater than atmospheric, (DWS Groundwater Dictionary). In addition to the above the confined water bearing formation must be exposed to recharge at some distance away and the formation needs to permeable to enable the flow of the water within the aquifer from the recharged area to the outlet point. The Piezometric pressure or hydraulic head at the point of recharge that will be represented by the static water level needs to be at a higher altitude than the surface area at the discharge point.

Artesian conditions that include outflow or the rate of outflow at a borehole may be seasonal due to the Piezometric pressure head at the recharge point being lowered by drought. To explain to a layman, it can be best illustrated by using a bend pipe with one end higher than the other; when water is added to the higher point it will flow out at the lower point at a yield equal to inflow. In a geological context the pipe is filled with material with small openings and cracks. The dominant forces that will determine the outflow rate and volume are inflow volume, hydraulic pressure, (difference in height), as well as permeability, (connection between openings).

From the evaluation of static water levels available for the map sheet a single artesian borehole was identified. The information available is as follows:

- Welgevonden 186 KQ: the borehole located next to the Bulge River and underlain by the Kransberg Subgroup. It is near the surface outcrop / contact of the Cleremont Formation. No confirmation is available if the available information is correct.

9. GROUNDWATER RELATED MATTERS

9.1 The National Water Act (Act 108 1998)

The **National Water Act** (Act 108 of 1998) replaces the old Water Act (Act 56 of 1956). Water resources are now recognised as scarce and unevenly distributed national assets. The most important implications to groundwater users are that groundwater is now considered as part of the larger **hydrologic cycle** and that **ownership** thereof is not private but belonging to all South Africans. The meaning of this is that landowners with strong groundwater sources or with a river occurring on his or her property do not have the right to use the water without authorization.

The Act makes provision for the separation of power between different spheres of government. The **Minister of the Department of Water and Sanitation is the custodian** (trustee) of water resources on behalf of the National Government, with the responsibility to provide a framework for the protection, to promote equitable access to water, to facilitate social and economic development, to protect aquatic and associated ecosystems and their biological diversity, and management of water resources for the country. It must be managed in an integrated manner according to the principles of the Act (sustainability, equity, and efficiency). It must also meet international obligations.

The Act allows the Minister to delegate most of his or her powers and duties to departmental officials, water management institutions, advisory committees, and water boards. The framework to achieve the principles and purpose of the Act is the National Water Strategy (NWS). To manage water resources on local level, Catchment Managing Agencies (CMAs) and Water User Associations (WUAs) must be established. These institutions must operate under the framework of the NWS and DWA guidelines.

The CMA is responsible for a water allocation plan within their catchments and a Catchment Water Strategy (CWS) that is similar to some extent to the NWS. The WUA is responsible for a few functions such as the protection of water resources and to prevent water wastage. All South Africans should be able to participate in water management and participate meaningfully in decisions on water matters that affect them. In 2016 the minister of Water and Sanitation approved the establishment of 9 CMAs, due to the complicity DWS had to develop documents for the establishment of these CMAs. CMAs will be representative of and facilitate the involvement of communities and other stakeholders in decision making.

At present the Department of Water and Sanitation is responsible for administering all aspects of the Act on the Minister's behalf. As regional CMA's (19 CMAs are planned) and other local water management institutions are established the Department will delegate or assign water resource management responsibilities to these institutions over time. In the longer term the Department's role will mainly be to develop national policy and a regulatory framework to govern the way other institutions manage the water resources. The Department will maintain general oversight of these institutions' activities and how well they perform.

The National Water Act is important because it provides a framework to protect water resources against over-exploitation and pollution as demand and stress on the environment is increasing. The Act must ensure that there is water for social and economic development for the present and the future. It's also important because it recognises that water belongs to the whole nation for the benefit of all people. The only right to water ensured by the National Water Act is referred to as the reserve. Other users who are not falling under Schedule 1 must register their use or apply for a license. Aspects that will be considered before allocating water to users in a catchment, will be water needed for strategic purposes such as Eskom, inter catchment water transfers and international obligations.

9.1.1 Water user registration and licenses

Licensing of water use is compulsory reserving the right to the minister of DWS to publish a notice in the Government Gazette requiring all existing and potential water users except Schedule 1 users to apply for licenses. The application for a Water User's License does not differentiate between users of surface or groundwater. The notice is revised on a 5-year basis and published in the Government Gazette.

Schedule 1 users are relatively low water users such as reasonable domestic household supplies, non-commercial small gardens, livestock watering for subsistence use, (not feeding pens), storing and using run-off water from a roof, emergencies e.g., firefighting, recreation e.g., swimming, angling.

- The use is not excessive in relation to the available source and needs of other users.
- A Catchment Management Agency (CMA) may limit the taking of water in terms of Schedule 1 (Schedule 3(2) (e) of the Act.
- Water users in this category can commence with their activities without informing the Department.

Continuation of existing lawful use: Existing Lawful Water Use (ELU) means the use of water authorization by or under any law that took place at any time for a period of two years before the commencement of the NWA, 1998. An Existing Lawful Water Use, with any conditions attached, is recognised but may continue only to the extent that it is not limited, prohibited, or terminated by this Act.

- No license is required to continue with Existing Lawful Water Use until a responsible authority requires a person claiming such an entitlement to apply for a license.
- If a license is issued it becomes the source of authority for water use.
- If a license is not granted the use is no longer permissible.
- This authorization requires a registration with the Department in other words these users must inform DWS of their usage and DWS will verify if the use is legal.

General Authorization: General permission has been granted by the Minister for other slightly larger uses from certain less stressed sources. This permission has been given by means of general authorisations published in the Government Gazette. A general authorisation is only applicable to specific rivers or catchments and is not applicable to the whole country. The users must report on their water use but due to the small volumes they are not required to be licensed, this includes users such as small-scale farmers in low stressed areas.

- This authorization requires registration with the Department prior to exercising the water use(s).

Users who need to be licensed: Section 21 of the Act lists water use that must be licensed. Existing and potential water users must ensure that they comply and are familiar with the requirements of the Act. The following table was obtained from the E-WULAAS web site at: https://www.dws.gov.za/ewulaas/WUA.aspx

The following activities constitute water uses and require authorization in terms of Section 21 of the NWA:

Table 55: The following activities constitute water use and require authorization in terms of Section 21 of the NWA:

Water Use	Example
Section 21 (a) Taking water from a water resource.	Abstracting water from a river or borehole for the following purposes: - domestic use - irrigation - watering of livestock - industrial - mining - water bottling, etc.
Section 21 (b) Storing water.	Raw water containment facilities constructed in-stream and in off-channel dams.
Section 21 (c) Impeding or diverting the flow of water in a watercourse.	Construction of structures/facilities within surface water resources, e.g. weirs, bridges, pipelines, etc.
Section 21 (d) Engaging in a stream flow reduction activity.	Plantation of forestry species (Eucalyptus, Pine and Wattle).
Section 21 (e) Engaging in a controlled activity identified as such in section 37(1) or declared under section 28(1) of the NWA.	Irrigation with water containing waste, artificial recharge of aquifer, modification of atmospheric precipitation and in-stream power generation activities.
Section 21 (f) Discharging waste or water containing waste into a water resource.	Discharging of water containing waste into a surface water resource, e.g. discharging treated effluent into a river or a wetland.
Section 21 (g) Disposing of waste in a manner which may detrimentally impact on a water resource.	Disposal of effluent into a water containment facility, dust suppression and stockpiles.
Section 21 (h) Disposing of waste in a manner which contains waster from or which has been heated in any industrial or power generation process.	Discarding of industrial/power generation waste water or water which has been heated.
Section 21 (i) Altering the bed, banks, courses or characteristics of a watercourse.	Construction of structures/facilities within surface water resources, e.g. weirs, bridges, pipelines, etc. Introduction of unnatural characteristic to the resource.
Section 21 (j) Removing, discharging or disposing of water found underground if it is necessary of the efficient continuation of an activity or for the safety of the people.	Extraction of water from underground workings for safe continuation of activities.
Section 21 (k) Using water for recreational purpose.	The use of surface water resources for fishing, boating, etc.

If the user receives water from a local government or any other bulk supplier there is no need to register. The local government or any other bulk supplier must register. All licenses will be issued with conditions to ensure that the water use authorized by the license does not have a negative impact on the water resource or other water users. These conditions will be negotiated with the water user wherever possible. Conditions can include a time-period and the monitoring of quantity and quality.

9.1.2 The Reserve

The only right to water ensured by the National Water Act is referred to as the reserve. The Minister is required to determine the RESERVE for all, or part of any significant water resource unit. A water resource unit is usually a catchment area, or it can be smaller to differentiate between different hydrological settings, or it can be "hotspots". Hotspots are regions within a catchment that are completely different due to pollution or usage that can be related to industry or mining.

The reserve must be (set aside) before water is allocated for other uses. The reserve includes basic human needs (currently 25liter/person/day) and the ecological reserve needed to sustain ecosystems within the water resource unit such as the aquatic, riparian and their associated biological diversity ecosystems.

9.1.3 Resource Directed Measures

The National Water Act of 1998 places an emphasis on the protection of water resources for their sustainable utilisation. This is reflected in the subsequent development of Resource Directed Measures (RDM) by The Department of Water and Sanitation, which consists of three important aspects, namely: classification of each major resource unit, setting the reserve; and determination of resource quality objectives. The objective is to balance protection and development by assessing as accurately as possible how much water can be abstracted from a system before the reserve is affected.

The framework to achieve this objective of protecting water resources while optimising their utilisation in a sustainable and equitable manner is provided in the National Water Resource Strategy (NWRS).

The NWRS adopts two complementary strategies to achieve this balance:

- Resource Directed Measures (RDM) that undertake to protect water resources by setting goals and objectives for the desired condition of water resources in aquatic ecosystems,
- Source Directed Controls (SDC) specify criteria for controlling water resource use activities and their impact on aquatic ecosystems.

The core of the RDM, and the basis of water resource management in South Africa, is the determination of a Management Class (MC). The MC is defined in terms of the resource quality that must be maintained.

Resource quality: includes the water quantity and quality, as well as the "character and condition of in-stream and riparian habitats, and the characteristics, condition and distribution of the aquatic biota" (DWAF 2003).

Management Classes are determined using the Water Resource Classification System (WRCS). The overall objective of the WRCS is to classify water resources in terms of:

- Class I (minimally used),
- Class II (moderately used),
- Class III (heavily used)

Based on the MC for each significant water resource, the Reserve, and the resource quality objectives (RQOs) for that resource are prescribed.

A class is allocated to each resource unit representing the level of protection required for the water resource and to state the extent to which the water can be used. The classification is used to define the present status of the resource unit and to define the state towards which the water resource needs to be managed to be sustainable (future state). The classification process involves stakeholder participation and consultation, as users must know the current state.

Users must decide the future state of the water resources, as development and usage must be balanced against the degradation of the environment. During the **resource quality objectives** future quality and quantity of the source and conditions of the aquatic and riparian ecosystems are provided as an **environmental statement.** The minister of DWS is responsible to set the reserve. Basic human needs are set at 25 liter/person/day, and the ecological reserve is determined by investigation groundwater/surface interactions. Management of the resource units will be an ongoing process with emphasis on pollution prevention, emergency spillage and rehabilitation, monitoring quality and quantity, monitoring abstraction and compliance of licensed water users. Availability and demand must be managed in an integrated manner to maintain the resource quality objectives.

9.1.4 Monitoring

Monitoring, recording, assessing and dissemination of information on water resources are critically important for achieving the objectives of the act. According to the DWS' records there are currently 46 monitoring sites falling within the Thabazimbi map of which only 4 are active (Table 56). Of the 46 monitoring sites 11 are equipped with Autographic recorders, 4 with electrical data loggers, 2 with dip meters, and the rest have no monitoring equipment.

Table 56: Monitoring boreholes on the Thabazimbi map.

Location	Site number	Latitude	Longitude	Status	Monitoring status	Date start	Date end	Monitoring equipment
Frankfort	A2N0101	-24.47278	26.71944	Unused	Not Active	19770420	19680724	Autographic Recorder
Frankfort Thabazimbi	A2N0102	-24.74944	26.73306	Unused	Not Active	19800902	19690526	Autographic Recorder
Dwaalboom	A2N0002	-24.71667	26.81667	Unused	Not Active	19600520	19680715	Autographic Recorder
Potchefstroom	A2N0012	-24.53194	26.97917	Unused	Not Active	19600523	19680903	Autographic Recorder
Van Wykskraal	A2N0745	-24.42889	27.09306	Unused	Not Active	19890615	19690203	Autographic Recorder
Faure Makoppa	A2N0746	-24.42444	27.09778	Unused	Not Active	19850506	19691006	Autographic Recorder
De Put Northam	A2N0508	-24.98333	27.28306	Unused	Not Active	19570719		
De Put Northam	A2N0507	-24.98306	27.28306	Unused	Not Active	19550315	19770421	No equipment
De Put Northam	A2N0500	-24.96667	27.28306	Unused	Not Active	19530623	19770401	No equipment
Skool Northam Koedoesdoorns	A2N0506	-24.95000	27.28306	Unused	Not Active	19550117	19770401	No equipment
De Put Northam	A2N0509	-24.98306	27.28333	Unused	Not Active	19570911		
Leeukop Rustenburg	A2N0522	-24.96667	27.28333	Unused	Not Active	19620204		
Skool Northam Koedoesdoorns	A2N0505	-24.95000	27.28333	Unused	Not Active	19530529	19690221	Autographic Recorder
De Put Northam	A2N0510	-24.95000	27.28333	Unused	Not Active	19530623	19630910	Autographic Recorder
Donkerpoort	A2N0004	-24.60000	27.35000	Unused	Not Active	19680307		
Kopje Alleen Thabazimbi	A2N0512	-24.88306	27.36667	Unused	Not Active	19641201	19770501	No equipment
Thabazimbi-Myn	A2N0074	-24.63306	27.36667	Unused	Not Active	19691110	19770401	No equipment
Buffelshoek	A2N0058	-24.65917	27.37917	Unused	Not Active	19600518	19760518	No equipment
Haakdoorndrift	A2N0766	-24.71250	27.40056	Unused	Not Active	19770401	19770401	No equipment
Thabazimbi-Kwaggahoek	A2N0076	-24.59167	27.40806	Unused	Not Active	19680724	19760610	No equipment
Thabazimbi-Kwaggahoek	A2N0079	-24.59167	27.40806	Unused	Not Active	19690526	19760428	No equipment
Thabazimbi	A2N0077	-24.59139	27.40806	Unused	Not Active	19680715	19810113	No equipment
Thabazimbi-Kwaggahoek	A2N0075	-24.59139	27.40833	Unused	Not Active	19680903	19760501	No equipment
Thabazimbi-Kwaggahoek	A2N0078	-24.59139	27.40833	Unused	Not Active	19690203		
Thabazimbi	A2N0080	-24.59139	27.40833	Unused	Not Active	19691006	19700904	Autographic Recorder
Grootkuil	A2N0094	-24.77528	27.41194	Unused	Not Active	19770421		
Elandskuil	A2N0764	-24.74583	27.41333	Unused	Not Active	19770401	20090922	Electr Data Logger
Grootkuil	A2N0768	-24.76056	27.41500	Unused	Not Active	19770401	20120524	Electr Data Logger
Haakdoorndrift Thabazimbi	A2N0007	-24.71667	27.41667	Unused	Not Active	19690221	20210323	Dip meter
Wachenbietjiedraai	A2N0060	-24.65000	27.41667	Unused	Not Active	19630910	20090811	Electr Data Logger
Middeldrift	A2N0759	-24.79639	27.42667	Unused	Not Active	19770501		
Grootkuil	A2N0769	-24.78306	27.43167	Unused	Not Active	19770401		
Middeldrift	A2N0758	-24.79417	27.43528	Unused	Not Active	19760518		
Aapieskraal	A2N0767	-24.79667	27.45083	Unused	Not Active	19770401		
MATSULAAN	A4N0508	-24.22124	27.46778	In use	Active	20080916		
Rietfontein	A2N0770	-24.85333	27.48417	Unused	Not Active	19760610		
Rietfontein	A2N0771	-24.86139	27.49806	Unused	Not Active	19760428		
Olifantskop	A2N0104	-24.87250	27.49917	Unused	Not Active	19810113		
Liverpool	A2N0772	-24.90556	27.53000	Unused	Not Active	19760501		
Haakdoornboom	A4N0500	-24.16667	27.83306	Unused	Not Active	19700904		
RHENOSTERPOORT	A4N0512	-24.48514	27.83912	In use	Active	20090804	20090922	Electr Data Logger
Hanover	A4N0515	-24.09262	27.90186	In use	Active	20131107	20120524	Electr Data Logger
HANOVER	A4N0507	-24.09054	27.90429	Artesian	Active	20080916	20210323	Dip meter

It is recommended that the 42 non-active sites are re-activated. One of the active site is listed as artesian.

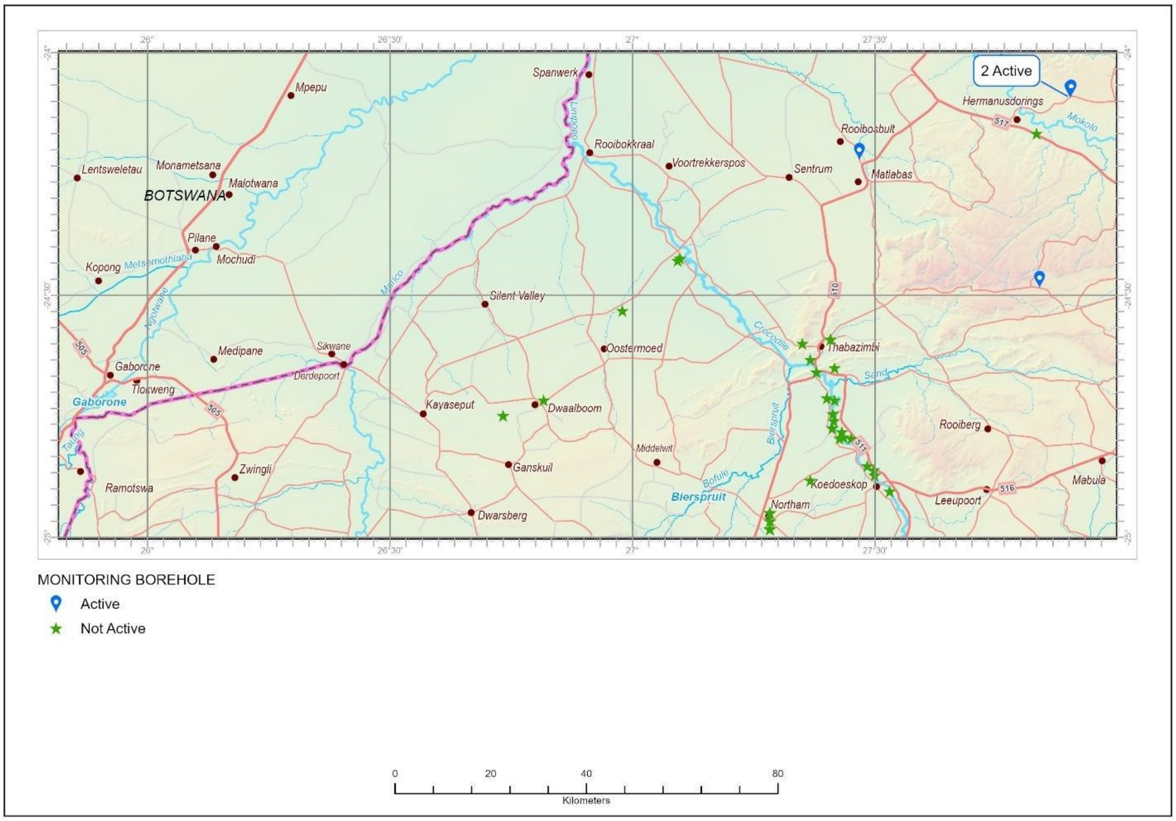


Figure 103: DWS monitoring boreholes on Thabazimbi map.

DWS is responsible for setting up National water monitoring systems that will facilitate the continued and coordinated monitoring of various aspects of water resources. This is achieved by collecting relevant information and data through established procedures and mechanisms from a variety of sources. These include organs of state, water management institutions, and water users. Monitoring aspects such as quantity, quality, use, and rehabilitation are some of the important ones. As part of the water user license, users can be required to supply information on abstraction, water levels, and quality on a time frequency negotiated between DWS and the license holder. The NWA is not the only Act requiring monitoring as it is also part of the environmental requirements for various other industrial, mining, sewerage, and landfill management.

9.2 Groundwater recharge, storage, and movement

Vegter (1995) states that groundwater recharge is dependent in the first instance on rainfall. He considers recharge to be involved in the absorption and addition of water to the zone of saturation. Recharge to groundwater resources on the Thabazimbi map sheet is dependent on effective rainfall defined as the fraction of rainfall that will infiltrate to the saturated zone after evaporation, transpiration, run-off, and inception loss. Recharge may also occur from rivers or dams with controlling factors such as open fracture zones and type of bedding material underlying the surface water bodies. The infiltration potential will be influenced by various aspects such as the type of underlying material, the absence or presence of hard pan surfaces, duration of surface water availability, grain size and distribution

The map area is in general a "dry" region; the major rivers are the Limpopo River and tributaries namely Ngotwane, Marico, Crocodile, Matlabas and Mokolo Rivers. Recharge to the alluvial aquifers associated with the rivers relate to the level of the surface water level in the rivers. To ensure sustainability of the aquifers water is released from surface dams at times to recharge the aquifers along the Mariko and Crocodile River. The same is applied for the lower Mokolo that are sustained by the regular releases from the Mokolo Dam.

Recharge must be seen as a seasonal occurrence mostly when the rivers flow during the rainy season. In some cases, groundwater is "lost" to rivers through seepage and springs thus contributing to base flow. Please note that recharged water "lost" to base flow has not been taken into consideration. However, depending on the circumstances, it has been observed that dams, especially earth dams, are major local contributors to groundwater recharge. Water level responses to rainfall events sometimes show a time lapse, as the percolation of water through the unsaturated zone to the saturated zone takes time.

Surface water percolates through the unsaturated weathered zone into the saturated zone, where all available pore spaces and fractures are filled with water. Structural features such as faults, fractures, joints, and bedding planes often serves as conduits for groundwater movement rather than storage. In dolomitic formations, structural features such as fractures enhance the percolation of water that may result in the formation of large cavities due to solution processes. Solution cavities significantly increase the storage capacity in dolomite as fresh dolomite is fine- grained and dense with minimal storage capacity.

Unconfined aquifer storage occurs in unconsolidated alluvial deposits along rivers and in the weathered zone in certain areas. Specific yield (indication of storage capacity) can be expressed as the volume of water that will drain under gravity from a saturated rock of unit volume. It is usually quoted as a percentage of the total volume. The volume of water stored in the weathered zone and alluvial deposits decreases with the decrease in the static water level.

In solid rock, water is stored within micro pores and fractures. Igneous and metamorphic rocks generally provide limited storage, whereas sedimentary rocks typically offer greater storage capacity. It is important to note that borehole yield is a function of an aquifer's permeability rather than an indication of the total volume of water in storage or its long-term sustainability. The sustainability of groundwater extraction is determined through the interpretation of scientifically conducted borehole pumping tests

Groundwater on the Thabazimbi map sheet generally flows in the same direction as surface water. The groundwater level often mimics the topography, causing groundwater divides to approximately align with the surface water divides. However, extensive groundwater abstraction can alter the natural flow pattern by creating a cone of depression around extraction points. Once pumping ceases, natural groundwater flow is restored as water levels recover

Some irrigation farmers along the Limpopo River dug trenches along the river that act as earth dams. This may contribute to recharge along the river. Where artificial recharge from earth dams is planned, sufficient sub-surface storage must be available. In suitable areas a local elevated water level zone will form under the recharged area migrating slowly through preferential pathways into the rest of the aquifer as it is not a closed system. Natural recharge in the map area is controlled by factors such as amount and frequency of rainfall, vegetation cover, soil type, topography, slope, geology, depth to water level and others.

Vegter (1995) produced a recharge map for the Water Research Commission covering the whole of South Africa. The four 1:250 000 maps covering the 1:500 000 Polokwane Hydrogeological map, were cut from the Vegter recharge map (1995) and pasted in this document,). The recharge- related numbers obtained on the Vegter map for Thabazimbi, was used to determine the estimated mean recharge for the Thabazimbi map sheet.

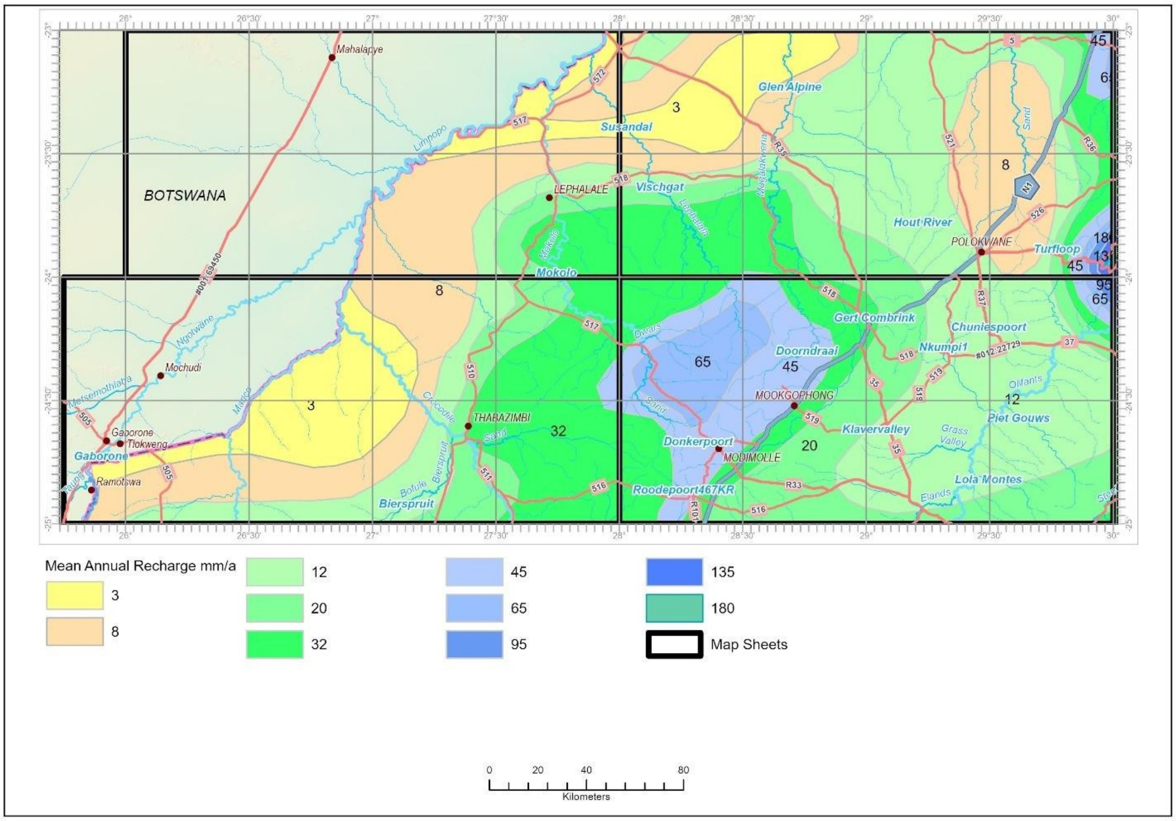


Figure 104: Mean annual recharge in mm for the four, 1:250 000 maps that is the upgrade for the 1:500 000 Polokwane hydrogeological map (after Vegter, 1995). Thabazimbi map area is at the bottom left.

Table 57: Mean annual recharge calculated for Thabazimbi map (after Vegter, 1995).

Recharge in zone (mm/annum)	Recharge in zone (m/annum)	Zone area (km²)	Zone area (m²)	Recharge in zone (m³)	Recharge in zone (Mm³/annum)
3	0.003	3947.788	3947788000	11843364	11.843364
8	0.008	3931.587	3931587000	31452696	31.452696
12	0.012	2678.607	2678607000	32143284	32.143284
20	0.02	1981.300	1981300000	39626000	39.626
32	0.032	4867.919	4867919000	155773408	155.773408
45	0.045	147.445	147445100	6635029.5	6.6350295
		17554.646			277.4737815

Vegter divided the Thabazimbi map into 6 mean recharge zones each with an allocated mean annual recharge value in millimeters (mm). Although the recharge is expressed quantitatively, it should be seen as depicting broad trends rather than laying claim to accurate regional recharge figures, (Vegter, 1995). However, these values were used to calculate the mean annual recharge volume for each zone. The volume for each zone was added to determine the total mean annual recharge volume for the Thabazimbi map, which amounts to 277.474 million cubic meters per annum (277.474Mm^3/annum), (Table 57).

Another approach to estimating recharge is by utilizing data from the Department of Water and Sanitation's (DWS) GRAII project. However, in a 2024 email, DWS stated that the GRAII data has not been verified, and its use is not recommended without special permission.

Specialist hydrogeological reports accompanying e-WULAAS in the Thabazimbi area were made available by DWS. The groundwater data were abstracted from these reports and used as additional information to compile the brochure and the relevant sections for the map such as median yield and chemical data. In relation to recharge the mining applications typically estimate recharge using numerical groundwater models, while smaller applications, such as farms, rely on localized recharge calculations or published values. These calculations are often based on the Chloride mass balance method; Vegter's recharge values, Harvest Potential values, the GRAII dataset, or a combination of the above. In addition to these methods, other techniques that can be used to estimate recharge include the water balance approach, the water table fluctuation method, Darcy's Law, isotopic tracer studies, and soil moisture balance assessments. Each method varies in applicability depending on data availability, scale, and site-specific hydrogeological conditions.

An alternative method for determining annual recharge or rather "safe abstraction," as referred to in the document, is the Harvest Potential approach proposed by A. Seymour and P. Seward (1995). Similar to Vegter's method, the Thabazimbi map area was divided into several safe abstraction zones. These zones have a minimum and a maximum volume (similar to the GRAII set that refers to the minimum and maximum volume as 'dry' and 'wet' to take into consideration seasonal fluctuations in rainfall). Table 60 represent the minimum and maximum volume (m^3/km^2/annum) that can be safely abstracted without depleting the aquifer. These values were used to calculate a minimum and maximum total annual volume for the Thabazimbi map sheet. In practice the average total annual volume is mostly used.

9.3 Borehole siting

Table 58 depicts the different geophysical survey techniques / methods that were used in the past in the search for geological features that might relate to the occurrence of groundwater. The choice of technique / method for each of the different hydrogeological resource units is based on the proven track records of the application in each unit. This relates to the geological and hydrogeological setting and the expected groundwater target in each unit. The instruments / technique / method used must be as such to detect natural differences in the subsoil. The data obtained must be interpreted to identify and evaluate geological features e.g. dykes, deep weathered/fracture zones, fault zones, joints, contact zones etc. that are known to relate to groundwater occurrences in each unit.

The table can be used as guidance as technology is evolving at a rapid rate with new instruments / techniques / methods becoming available.

Table 58: Geophysical survey techniques that can be employed in each resource unit.

GROUP/FORMATION	HYDRO-GEOLOGICAL UNIT	CATEGORY	1a	1b	2a	2b	3	4	5
Tertiary - Quaternary alluvial deposits	Q	A	***	**	**			**	**
Clarens Formation	Trc	B	*	**	**	**	***		**
Irrigasie Formation	P-Tr	B	*	**	***	**	***		
Ecca Formation	Ppe	D	**	**	***	***	***		
Undifferentiated Waterberg Supergroup	Mw	B	*	***	***	*	***		
Vaalwater Formation	Mva	B	*	***	***	*	***		
Cleremont Formation	Mcl	B	*	***	***	*	***		
Kransberg Sub-Group	Mkr	B	*	**	**	**	***		**
Aasvoëlkop Formation	Mas	B	*	***	***	*	***		
Alma Formation	Mag	B	*	***	***	*	***		
Swaershoek Formation	Ms	B	*	**	**	**	***		
Undifferentiated Pretoria Group	Vpg	B	*	**	***	***	***		
Smelterskop Formation	Vsk	B	*	**	***	***	***		
Daspoort Formation	Vdp	B	*	**	***	***	***		
Timeball Hill Formation	Vti	B	*	**	***	***	***		
Malmani with Pilanesberg dyke intrusion system	Mpd	C	*	**	**	**	***	*	*
Malmani Subgroup	Vma	C	*	**	**	**	***	*	*
Black Reef Formation	Vbr	B	*	**	***	***	***		
Crocodile River Fragment	Vgo	B	*	**	**	**	***		
Nebo Granite	Mn	D	***	**	**	*	**		
Rustenburg Layered Suite	Vrs	D	**	**	***	**	***		
Diabase	N-Za	D	**	**	***	**	***		
Undifferentiated/unnamed Ventersdorp Group	Rvz	D	**	**	***	**	***		
Gaborone Granite	Zga	D	**	**	***	**	***		
Granite and Gneiss of the Western Transvaal Belt	Zjt	D	**	**	***	**	***		
Modipe Gabbro Complex	Zmc	D	**	**	***	**	***		
Swaziland System	Zsj	D	**	**	***	**	***		

The geophysical method is listed as follows:

- 1a Electrical Resistivity
- 1b Electrical Resistivity – profiling
- 2a Electromagnetic - EM-34
- 2b Electromagnetic - Genie SE / Stratagem / Max-Min Slingram
- 3 Magnetic
- 4 Gravity
- 5 Seismic

The rating for its successful application is as follows:

- *** Essential
- ** Useful
- * Not essential

Geological targets associated with groundwater occurrence are described for most hydrogeological units in Chapter 7. The success of identifying these targets is enhanced by incorporating additional scientific tools such as aerial photographs, LANDSAT images, Terra ASTER satellite imagery, geological and hydrogeological maps, existing data for the area, and aeromagnetic surveys. Experienced geohydrologists also consider visible indicators such as vegetation patterns, topography, soil variations, and other surface features during field surveys. The value of a geohydrologist's expertise, particularly their understanding of geology and data interpretation techniques, cannot be overstated.

While geophysical methods are widely used in groundwater exploration, the use of these methods does not always guarantee successful water strikes (boreholes with water). This is not due to flaws in the instruments themselves since they are based on well-established natural laws, but rather to incorrect interpretations, influences on the response of the instruments not taken into account or natural subsurface conditions that are not favorable for groundwater. For example, when targeting a diabase dyke, differences in magnetic susceptibility between the host rock and the dyke can often produce a detectable anomaly. However, if the contact zone is fused together without secondary fracturing, the borehole may yield no water despite the correct identification of the geological target.

Other factors that influence the effectiveness of geophysical methods include limitations in the area available for surveys, (such as small yards), where no discernible geological features associated with groundwater occurrence are present. Additionally, man-made interferences, such as power lines and other infrastructure, are often unavoidable in urban or semi-urban environments. These interferences can lead to incorrect data interpretation, as anomalies may not be related to natural geological phenomena, thereby reducing the effectiveness of the instruments. A further concern is the growing use of inexpensive, unverified instruments operated by individuals lacking the necessary geological or geophysical expertise. This trend further undermines the reliability of geophysical surveys.

9.4 Groundwater management

The new Water Act states that the **Minister of the Department of Water and Sanitation is the custodian** (trustee) of water resources on behalf of the National Government, with the responsibility to provide a framework for the protection, use, development, conservation, and management of water resources for the country. It must be managed in an integrated manner according to the principles of the Act (sustainability, equity, and efficiency).

To manage water resources on local level, Catchment Managing Agencies (CMAs) and Water User Associations (WUAs) must be established that operate under the framework of the NWS and DWS guidelines. The CMA is responsible for a water allocation plan within their catchments and a Catchment Water Strategy (CWS) that is like the NWS. The WUA is responsible for a few functions such as the protection of water resources and to prevent water wastage.

At present the **Department of Water and Sanitation is responsible** for administering all aspects of the Act on the Minister's behalf as no CMA's or WUA is yet in operation within the map area.

Over-exploitation of groundwater resources can be prevented and controlled through sound groundwater management practices.

Part of the license requirements can be that water users must monitor abstraction and quality at all levels that includes local authorities i.e. the Lephalale (Ellisras); Thabazimbi, Ramotshere (Zeerust), Moses Kotane (Mogwase area), Bela Bela (Warmbaths) and Modimolle (Nylstroom) Local Municipalities; Mining i.e. Batlase, Dishaba, Thaba, Amandelbult, Swartklip, Redpath, Zondereinde, Tumela, Langpan, Vlaak Ore and Mantecu. The list may include more mines or shafts. The Northam Smelter Facility and the Mamba Cement manufacturing plant falls within the map sheet. Other users that require licenses include places where petroleum products are sold or stored, lodges, large scale irrigation farms.

During the period or at the renewal date of the water user license DWS can request monitoring data from license holders. As licensing is compulsory, holders should familiarize themselves with the license requirements as the license can be cancelled. Regular or continuous measurements of groundwater level fluctuations together with accurate abstraction and rainfall measurements all displayed on one graph, is a sure way of keeping one's finger on an aquifer's pulse. Over-pumping can be detected in advance and the necessary precautionary measurements (reduction in abstraction, water restrictions etc.) taken to prevent borehole failure at critical times. Long-term accurate measurements of groundwater levels, abstraction, and rainfall are essential in the accurate assessment of recharge and storage of an aquifer and subsequent compilation and/or refining of a groundwater management model.

It is equally important to monitor the quality of the groundwater on a regular basis to detect any deterioration in the water quality in advance. The frequency of sampling for chemical analysis depends on the water usage (human, agricultural, industrial) and vulnerability of the aquifer to pollution or other influences but should be analysed at least once or twice a year for macro, tracer, and microbiological constituents. Further information on this can be obtained from Resource Quality Services (formerly the Institute for Water Quality Studies).

In the license application no distinction is made between surface water or groundwater use as it is all part of the hydrological cycle. From a hydrogeological point of view conjunctive use of groundwater and surface water is recommended. During summertime when evaporation is at its highest resulting in high losses, surface water should be utilized extensively with groundwater only supplementing any shortages. During wintertime groundwater should be utilized extensively which could be recharged again during summertime. Evaporation losses should be at their lowest during wintertime. Surface water could thus only supplement shortages during this period.

For water level monitoring, observation boreholes are developed, especially where large well fields are established. A thorough knowledge of the geology of the terrain and an understanding of the anticipated groundwater flow, are requirements for the correct positioning of observation boreholes. The Department of Water and Sanitation manage 46 monitoring boreholes in the map area of which some are equipped with electronic data loggers within the map sheet area (Figure 103 & Table 56). The data are available on request from the Department's National Groundwater Archive (NGA) in Pretoria.

9.4.1 Groundwater contamination and pollution

Groundwater contamination is defined as the introduction of any substance into groundwater by the action of man. Pollution is defined as the direct or indirect alteration of the physical, chemical, or biological properties of a water resource to make it:

a) Less fit for any beneficial purpose for which it may be expected to be used.
b) Harmful or potentially harmful:
  - To the welfare, health or safety of human beings,
  - To any aquatic or non-aquatic organisms,
  - To the resource quality, or to property,

(Source: National water Act, Act No 36 of 1998).

Pollution is one of the greatest threats of our time. Groundwater is, like surface water, very vulnerable to pollution. It is very difficult and expensive to rehabilitate an aquifer once it is polluted. In the environmental Act the principle of polluter pays for the rehabilitation is followed. Managers of companies responsible for the degradation of the environment can be held responsible even after a long time.

In the modelling of pollution mitigation sources, pollution sources are classified at first according to their geometry. Point sources are sources such as waste disposal, underground storage tanks, septic tanks and sewage works. These sites should be selected with utmost care, continuously monitored, and reported on by groundwater pollution specialists to protect vulnerable aquifers. The establishment or closure of such sites is strictly controlled by the Department of Water and Sanitation to protect the water resources of the country. Selling and storage points of petrol, diesel, chemicals, and fertilizers are widespread with waste disposal and sewerage works mostly confined to the larger towns and some of the smaller settlements within the map area. In the rural areas of the map a common problem is high concentrations of Nitrates which have been introduced into the water through pit-latrines and cattle-kraals. High nitrates occur in the Matlabas areas. The occurrences are displayed as an inset on the main map sheet.

Line sources are possible pollution sites such as sewage pipelines and railway lines (use of weed killing chemicals). Aerial sources are industrial, mining and irrigation areas with a big aerial discharge of contaminants. These sources are also widespread throughout the area. Mining activities occurring predominantly south of Thabazimbi are all potential sources of pollution if not properly managed.

9.4.2 Groundwater utilization

Groundwater over a large section of the map sheet is in many cases the only source of supply, especially for farms, small to large rural villages and settlements (±34) and game reserves. Water in these rural areas, not taking into account the numerous settlements is predominantly used for game, livestock, homesteads and some lodges. Water use associated with rural settlements is predominantly for domestic use although small scale commercial activities and livestock farming do occur. For the rural settlements and some of the smaller town's groundwater can be the only source of water. In other areas, conjunctive use of surface and groundwater supply is in demand.

Large scale irrigation is along the Crocodile River. The source of water is surface water from the river and groundwater from the associated alluvium and underlying fractured bedrock. The groundwater abstracted from deep fractures associated with geological lineaments such as fault zones forms a small percentage of the total use. Water releases from dams (Roodekopjes, Klipvoor and Vaalkop) are used to manage and sustain water flow in the rivers and recharge to the associated alluvium aquifers. Without these measures, irrigation will be negatively affected.

Irrigation along the Marico River does occur predominantly within the South African side of the border. The irrigation along this river is on a smaller scale than along the Crocodile River. In this system, the Molatedi Dam are managed to sustain irrigation. The smaller-scale irrigation practices can be attributed to the Madikwe game reserve that occurs along a large section of the river. Farming in the area seems to lean towards game farming as some of the irrigation fields are not used anymore, (Google Earth imagery evaluation).

Irrigation along the stretch of the Limpopo River within the map area is at the confluence of the Crocodile and Marico Rivers with small patches of irrigation to the north.

No large-scale abstraction occurs from the **Matlabas River** and associated alluvial aquifers. The finding was that the alluvium associated with the river is of minor significance as an aquifer. Strong boreholes in these areas relate to structural geology.

Large scale irrigation occurs along the Mokolo River and one of its tributaries, i.e. the perennial river Sterkstroom. As it is upstream from the Mokolo Dam (Hans Strijdom Dam), water releases from the dam only benefits the section of the river below the dam which falls within the Lephalale map sheet. Within the lower section of the river the managed release of surface water sustain irrigation from the river and associated alluvium aquifers up to sections within the Limpopo River. Water supply for irrigation upstream from the dam is from surface water in wet periods and groundwater in dry periods.

The nearby Bulge River Fault zone may enhance the occurrence of groundwater. Interflow from the mountains underlain by rocks of the Waterberg Supergroup may sustain surface flow in the river long after rainfall events.

The large towns (Thabazimbi and Regorogile) are supplied by groundwater sources, (1.46Mm³/annum) and surface water, (2.56Mm³/annum). Mining towns such as Setaria, Amandelbult and Swartklip are supplied by surface and groundwater resources, but no volumes are available. Other towns such as Northam are supplied by surface water sources 1.46Mm³/annum while other smaller towns are only supplied by groundwater (Leeupoort and Rooiberg). Surface water supply is managed by Magalies Water. Magalies Water is a Schedule 3B state owned enterprise (SOE) in terms of the Public Finance Management Act (PFMA), which is accountable to the government of South Africa through the Minister of the Department of Water and Sanitation (DWS).

Water supply to mines and large industries within the map area is from surface and groundwater sources. The volumes used were not available.

Due to water shortages in the Mokolo catchment, the Mokolo Crocodile Water Augmentation Project (MCWAP 2A) was initiated to transfer water from the Crocodile catchment to the Mokolo catchment. The available surface water to the urban node (Lephalale Local Municipality) with the completion of MCWAP 2A will be 13.88Mm³/annum in the year in 2040 or 38.03Ml/day.

Table 59: Localities where large-scale groundwater abstraction (>400 000 M³/a) are taking place.

LOCALITY/AREA	APPROXIMATE ABSTRACTION (10^6 m³/a)	
	DOMESTIC	AGRICULTURAL
No large-scale abstraction areas/localities occur on the Thabazimbi map sheet		

9.4.2.1 Harvest potential

The information for the Harvest potential was obtained from the Groundwater Harvest Potential of The Republic of South Africa, A. Seymour, and P. Seward 1995. The harvest potential is the maximum amount of groundwater that can be abstracted per square kilometer per annum in South Africa without depleting the aquifers, (DWS groundwater dictionary). The Harvest Potential method was developed to provide a first estimate of the national sustainable groundwater resource. It considers recharge, storage, and time periods between recharge events. For the largest sections of the map, the harvest potential is between 5 000 and 15 000m³/km²/annum. Within the

Thabazimbi map sheet, 5 harvest potential zones are depicted in Figure 105. Using the values and the aerial extent of each zone the harvest potential for the Thabazimbi map sheet was calculated. The safe abstraction is 147.790 million cubic meters per annum (Mm³/a) (Low) to 265.445Mm³/annum (high) with an average of 280.513Mm³/annum.

Table 60: Safe abstraction for Thabazimbi derived from Harvest Potential (A. Seymour and P. Seward, 1995).

Zone m³/km²/annum	Zone Areal extent km²	Minimum safe abstraction m³	Maximum safe abstraction m³	Minimum safe abstraction Mm³	Maximum safe abstraction Mm³
2 000 - 5 000	3940	7880000	19700000	7.880	19.700
5 000 - 10 000	5350	26750000	53500000	26.750	53.500
10 000 - 15 000	5058	50580000	75870000	50.580	75.870
15 000 - 25 000	1757	26355000	43925000	26.355	43.925
25 000 - 50 000	1449	36225000	72450000	36.225	72.450
Totals	**17554**	**147790000**	**265445000**	**147.790**	**265.445**
			Average:	**206.618**	

The total safe abstraction using the Harvest potential arrives at amounts of 206.618 million cubic meters of water annually. This is a considerable amount of water if one considers that the total area covered by the Thabazimbi map, is approximately only 17554 km².

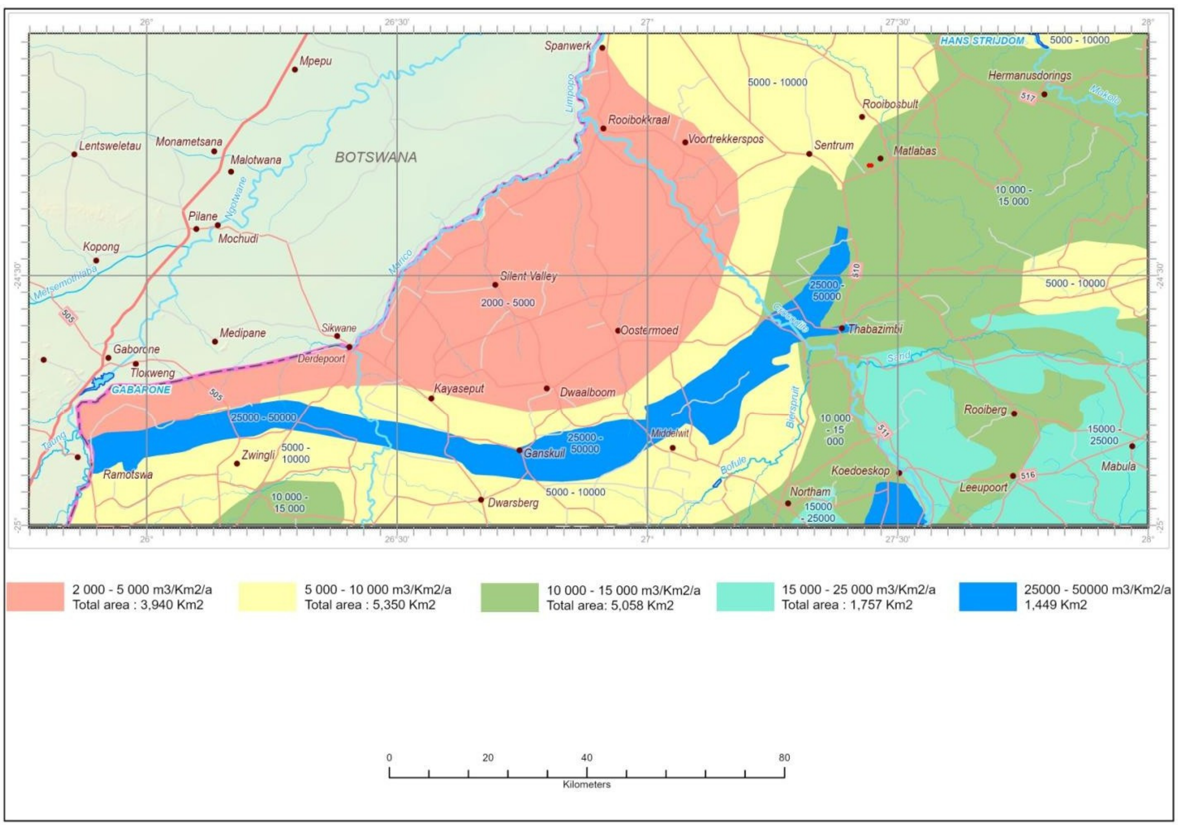


Figure 105: Harvest potential depicting safe abstraction on the Thabazimbi map area, (A. Seymour and P. Seward, 1995).

9.5 Future groundwater and associated projects

The growing population and development in South Africa are bound to put the country's scarce water resources under tremendous pressure in years to come. As many of the aquifers in South Africa are past the development phase management and intervention measures will start to dominate the groundwater industry. To be able to maintain water supply to the relevant sectors in South Africa, the country should invest in groundwater resource management and protection. Management is considered a strong groundwater database, monitoring rainfall and water levels, updating recharge estimates, research into mitigation actions such as artificial recharge, legal enforcements to protect aquifers from over exploitation and most importantly pollution. The private sector is already willingly or legally contributing to management by submitting data to DWS i.e. quarterly monitoring data.

The following possible subjects are suggested:

Monitoring Stations: Upgrades and Maintenance

- Investigate the current network of monitoring stations, including water level and meteorological stations.
- Upgrade and maintain stations where necessary to ensure accurate and continuous data collection.
- Assess the possible effects of environmental changes and large-scale abstraction on natural conditions and implement a monitoring framework.
- Recognize that long-term data collection is critical for scientifically measuring and quantifying the impacts of climate change.

Sanitation Audit and Improvements

- Conduct an audit of sanitation practices, identifying areas where improvements are required. On municipal level the IDP documents do address some of these. The methodology needs to be uniformly applied between the different spheres of Government to address sanitation. The framework of the Catchment Managing Agencies (CMAs) includes sustainability. As such, recommendations on mitigation measures should form part of management of the catchments with the Local or District Municipality or the implementing agent.
- Regular audits and investigations into the effectiveness of large sewage plants need to be done by DWS and/or CMA officials. The recommendations should be enforced by the relevant authorities to prevent pollution.
- Address high nitrate levels and bacteriological pollution, which are known to occur in rural communities. The slogan prevention is more effective than rehabilitation that needs to be applied.
- Investigate and mitigate sources of *e-coli* contamination, which have been detected in some groundwater sources. The bacteria were even detected in the water from groundwater resources where the water strike depth were deemed too deep (>30m) to be affected by bacterial pollution.

Groundwater Recharge and Artificial Recharge

- Investigate the feasibility of artificial recharge interventions in areas experiencing high abstraction rates.
- Assess the recharge potential in these areas; assess the potential increase in recharge by considering hydrogeological conditions and water availability.

Data Management and National Groundwater Archive (NGA)

- Invest in the National Groundwater Archive (NGA) to improve data accessibility and integrity.
- Ensure extensive use of the e-WULAAS system to maintain an up-to-date database.
- Incorporate all legally required groundwater data submissions into the NGA.
- Ensure that Hydrocensus data obtained through the WULA process include accurate geographic coordinates.
- Before capturing data, verify existing records to prevent duplication.
- If new sources are identified, ensure the inclusion of borehole logs, pump test results, and chemical analysis certificates in the documentation.
- Require geohydrological reports from consultants working for government or semi-government entities to be submitted to the Department of Water and Sanitation (DWS).
- Link municipal water source asset registers to the groundwater database for better resource management.

Water Use License Applications (WULA) and Compliance Monitoring

- Ensure that WULA approvals include conditions for quarterly water level measurements and chemical analysis where required.
- Incorporate this data into the NGA to support long-term monitoring efforts.
- Align measurement dates within specific timeframes to facilitate regional water level trend analysis.

Capacity-building and awareness

- Develop capacity-building programs for local authorities and stakeholders on groundwater monitoring and data management.
- Enhance public awareness and community participation in groundwater protection initiatives.
- Establish partnerships with research institutions to improve methodologies for groundwater assessment and recharge strategies.

Groundwater research projects

- Application of remote sensing techniques (LANDSAT imagery, etc.) for early identification of potential groundwater target areas.

- Due to limited available information on the potential of the dolomite aquifers west of Thabazimbi, a research project can be initiated.

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