EXPLANATION OF THE
1:500 000 HYDROGEOLOGICAL MAP 2326 POLOKWANE

By

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&

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FOREWORD

Groundwater in South Africa as a whole is under-utilised, although some local over-exploitation does occur. Groundwater schemes can be implemented quickly and cheaply, and are in particular 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, it is clear that 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. In an attempt to rectify this situation, groundwater information locked away in expert's minds and computer databases is being made available on maps. The first step in this program at the regional level is the preparation of the "General Hydrogeological Maps" at the scale of 1: 500 000.

The main purpose of the General 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 geohydrologist's 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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PREFACE

With the exception of air, water can, with little doubt, be defined as Man's most precious resource. It is said that to deny Man food, his body can sustain life for weeks, but refuse him water and 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 and 97% occurs underground (Johnson Division, 1975). Owing to the lack of perennial streams in the desert to semi-desert parts 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 in order to comprehend how and where groundwater occurs.

The Polokwane 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 borehole yield, 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 hopefully also be informative to planners, especially in the light of the Reconstruction and Development Programme, and it will play a constructive role in general groundwater education and groundwater awareness building.

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.

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DATA AND REPORTS

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Cover page: *The Kranskop Inselberg made up of reddish weathering sandstone and subordinate conglomerates of the Schilpadkop Formation, is a well known landmark along the N1 just past the Kranskop Toll Plaza (Photograph: WH du Toit).*

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ABBREVIATIONS

EC	Electrical conductivity
DWA	Department of Water Affairs
DWAF	Department of Water Affairs & Forestry
HARMEAN	Harmonic mean
NGDB	National Groundwater Data Base
Mamsl	metre above mean sea level
Mbgl	metre below ground level
TWQR	Target Water Quality Range
UNESCO	United Nations Educational, Scientific and Cultural Organisation
VSA	VSA Geoconsultants Group
WMS	Water Management System

SYMBOLS AND UNITS

Km^2	square kilometre
ℓ/s	litres per second
m	metre
Ma	million years
meq	milli-equivalents
mg/ℓ	milligrams per litre
mS/m	milliSiemens per metre
m^3	cubic metre
pH	logarithm of the hydrogen ion concentration in moles per litre
s	seconds

EXPLANATION OF THE 1:500 000 HYDROGEOLOGICAL MAP 2326 POLOKWANE

1 INTRODUCTION

1.1 General:

The **Polokwane Hydrogeological Map, sheet 2326,** scale 1:500 000, is a reconnaissance map and it is the first general synthesis of groundwater resources within this area.

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.

Groundwater occurrences are very heterogeneous in South Africa while the mapping standards, legend, etc demand a high degree of conformity. Not all 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 on a relatively small scale. The map and brochure can thus not replace detailed site investigations needed, when for example boreholes have to be sited or when site specific conditions must be determined.

Therefore **site-specific detailed investigations** will always be required 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 yield, aquifer type, groundwater quality, groundwater use and lithology. This brochure provides supplementary information for these topics and also 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 will transform to WUA's), management, pollution, utilization and future exploration.

A new **National Water Act (Act 36 of 1998)** was proclaimed in October 1998. A brief discussion is included under management 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 Data Base (NGDB) (recently replaced by the National Groundwater Archive) under the custody of the Department of Water Affairs (DWA).
- Water Management System (WMS), Department of Water Affairs (DWA).
- Existing data from the former homelands Lebowa and Venda.
- Available geohydrological reports.
- Existing information from various consultancies stationed in Limpopo Province.
- Field visits and borehole surveys.

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

RECORDS EVALUATED				
NGDB - 20677		WMS-14674		
Total Number of Borehole Yields	Total Number of Water-levels	Total Number of EC Measurements	Total Number of Nitrates and Fluorides 3348	Total Number of Complete Chemical Analysis
20677	6710	7225	4893	14674

2.2 Main map:

Polokwane hydrogeological map: scale 1: 500 000. The map sheet covers an area of approximately 71 130km². It represents the first general synthesis of the groundwater resources of the area bordered by latitudes 23º and 25º south and longitudes 26º and 30º east.

The lithostratigraphy of the region, based on the 1:1 000 000 Geological Map of South Africa and supplemented by the 1:250 000 geological map series, was used to sub-divide the mapped area into hydrogeologically relevant lithologic units which possess some degree of lithologic homogeneity and similarities in rock properties. These units are displayed as grey ornament on the map. An age symbol, displayed in black, has been assigned to these basic lithologies. The symbol consists of two or three letters, the first being the first letter of the lithostratigraphy (Erathem used up to the end of Namibian, thereafter System was used) as on the 1984, 1:1 000 000 Geological Map of South Africa and the second and third, where necessary, the author's choice. These lithologic 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 Data Base 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 was recommended as a suitable measure of centrality rather than the average. The median was also found to be a reasonable discriminator between hydrogeological regions and was easy to compute and interpret as a "typical" yield of a region. In order to provide sufficient resolution of the data to permit visual portrayal in a distinguishable manner, the borehole yield data was classified according to five groupings for each of the four classes of mode of groundwater occurrence. The five 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 also 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 lithologic 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.

Major groundwater abstraction points are shown on the map as filled red circles of various sizes representing the 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 Polokwane Hydrological map sheet 2326:

Two hydrogeological cross-sections, based on limited geological information and the author's own interpretation of the available information. The cross-sections display the third dimension and regional hydrogeological relationships discussed on the map as points 1-11. The static water level is included to show its relationship with surface topography.

Distribution of borehole data: scale 1: 2 000 000 represent available groundwater source information distribution. The yellow colour represents no data points, light pink represent 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: scale 1: 2 000 000, contour intervals relevant to the map at 400m. The elevation in the map area varies more or less between 400-2000mamsl.

Mean annual precipitation: scale 1: 2 000 000, 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: scale 1:1 500 00 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. 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 region to region and the brochure provides opportunities to reflect this variability. Included in the brochure are frequency diagrams on borehole yields and stiff diagrams giving information on groundwater chemistry for various lithology. These are guideline values with the accuracy 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 Polokwane 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 Polokwane map sheet namely:

- 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 Sand River it is depicted as two-layered (a/d) i.e. the upper aquifer being intergranular (a) and the bottom aquifer intergranular and fractured (d).

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 five sub-divisions were defined. On the Polokwane 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 lithologic ornaments and the chronostratigraphy by alphabetical symbols. Production ranges are defined as follows:

- High borehole yields, generally greater than 5ℓ/s, can be used for urban and rural water supply, industry or large-scale irrigation.

- Moderate borehole yields generally, 2ℓ/s - 5ℓ/s, can be used for urban and rural water supply to small towns, industry or small-scale irrigation.

- Low borehole yields generally, 0.5ℓ/s - 2ℓ/s, can be used for domestic and live stock watering supply to rural settlements, hospitals and health centres or small-scale irrigation at community vegetable gardens.

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

- Un-economical borehole yields generally, 0.0-0.1ℓ/s. Non-reticulated water supply for isolated households or for monitoring in certain cases. Suitability dependable on factors such as construction, objective of monitoring, location and geological setting.

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

CLASS A				**CLASS B**				**CLASS C**				**CLASS D**			
INTERGRANULAR				HARD, CONSOLIDATED ROCK MATERIAL											
A water saturated zone, generally unconsolidated but occasionally semi-consolidated. Groundwater is stored and transmitted through intergranular interstices in porous and permeable medium.				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.											
				Where the principal water strike is in a fracture or in the 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.				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				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.			
Group	Typical borehole yield		Colour code	Group	Typical borehole yield		Colour code	Group	Typical borehole yield		Colour code	Group	Typical borehole yield		Colour code
	Range	ℓ/s			Range	ℓ/s			Range	ℓ/s			Range	ℓ/s	
a1	Un-economical	0.0-0.1		b1	Un-economical	0.0-0.1		c1	Un-economical	0.0-0.1		d1	Un-economical	0.0-0.1	
a2	Very low	0.1-0.5		b2	Very low	0.1-0.5		c2	Very low	0.1-0.5		d2	Very low	0.1-0.5	
a3	Low	0.5-2		b3	Low	0.5-2		c3	Low	0.5-2		d3	Low	0.5-2	
a4	Moderate	2-5		b4	Moderate	2-5		c4	Moderate	2-5		d4	Moderate	2-5	
a5	High	>5		b5	High	>5		c5	High	>5		d5	High	>5	
Alluvial deposits of limited extent along river terraces such as sand and gravel. Weathered crystalline rock with the principle water strike in the weathered intergranular zone				Sedimentary rocks of arenaceous origin. Acid volcanic rocks and other igneous rocks with very limited overlying residual weathered products.				Carbonate rocks including dolomite, limestone of marine origin				Sedimentary. Igneous and Metamorphic rocks with significant thicknesses of overlying saturated residual weathering.			
INTERGRANULAR				FRACTURED				KARST				INTERGRANULAR AND FRACTURED			

4 PHYSICAL ENVIRONMENT

4.1 General

The Polokwane hydrogeological map sheet which is bounded by latitudes 23°S and 25°S and longitude 30°E and the Botswana border to the west and northwest, covers an area of approximately 71 130km².

Approximately 2.5 million people (2002 figures with a yearly 2% increment) are resident in the area with only approximately 15% living in urban areas. The remaining 85% live in rural areas.

4.2 Terrain Morphology

The area can be divided into six main terrain morphological units (Kruger, 1983) see Figure 3, viz.:

- Plains with low relief
- Plains with moderate relief
- Lowlands, hills, and mountains with moderate and high relief
- Open hills, lowlands, and mountains with moderate and high relief
- Closed hills and mountains with moderate and high relief
- Tablelands with moderate to high relief

4.3 Climate

The climate is generally hot and dry in the plains, especially along the Limpopo Valley, becoming more moist and cooler in the more mountainous and plateau areas. The area receives 90% of its annual rainfall between October and March, generally in the form of convection thunderstorms.

Mean Annual Precipitation (MAP) (Figure 1), varies from approximately 380mm/a in the Limpopo Valley and the low relief plains in the area south of the Soutpansberg to about 1 500mm/a along the Drakensberg escarpment in the east. Rainfall occurrence over the largest part of this area is very erratic and unreliable resulting in long dry periods.

The mean annual evaporation (Figure 2) is high over most of the area and varies from 1778mm (70 inches) in the east to 2286mm (90 inches) in the west for Symons pans and 2032mm (80 inches) to 3048mm (120 inches) for Class 'A' pans (Schulze, 1984).

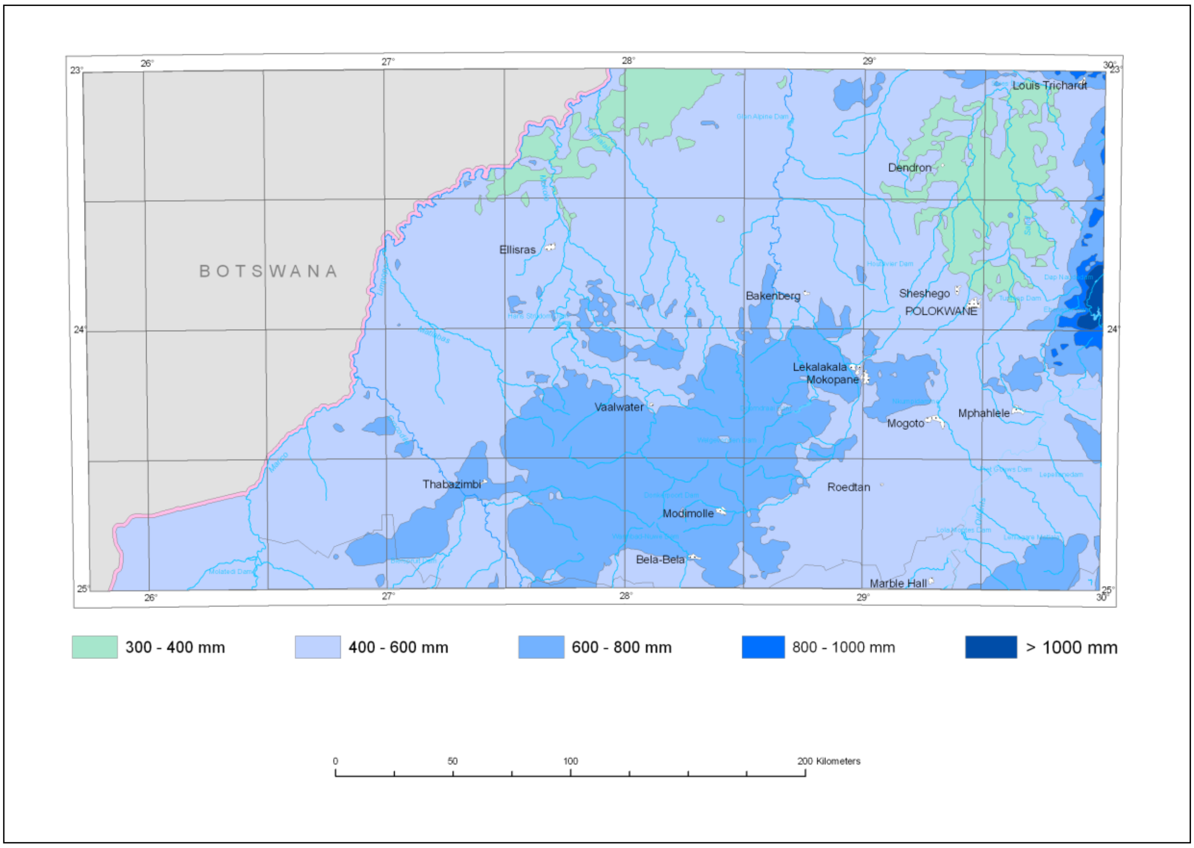

Figure 1: Mean Annual Precipitation

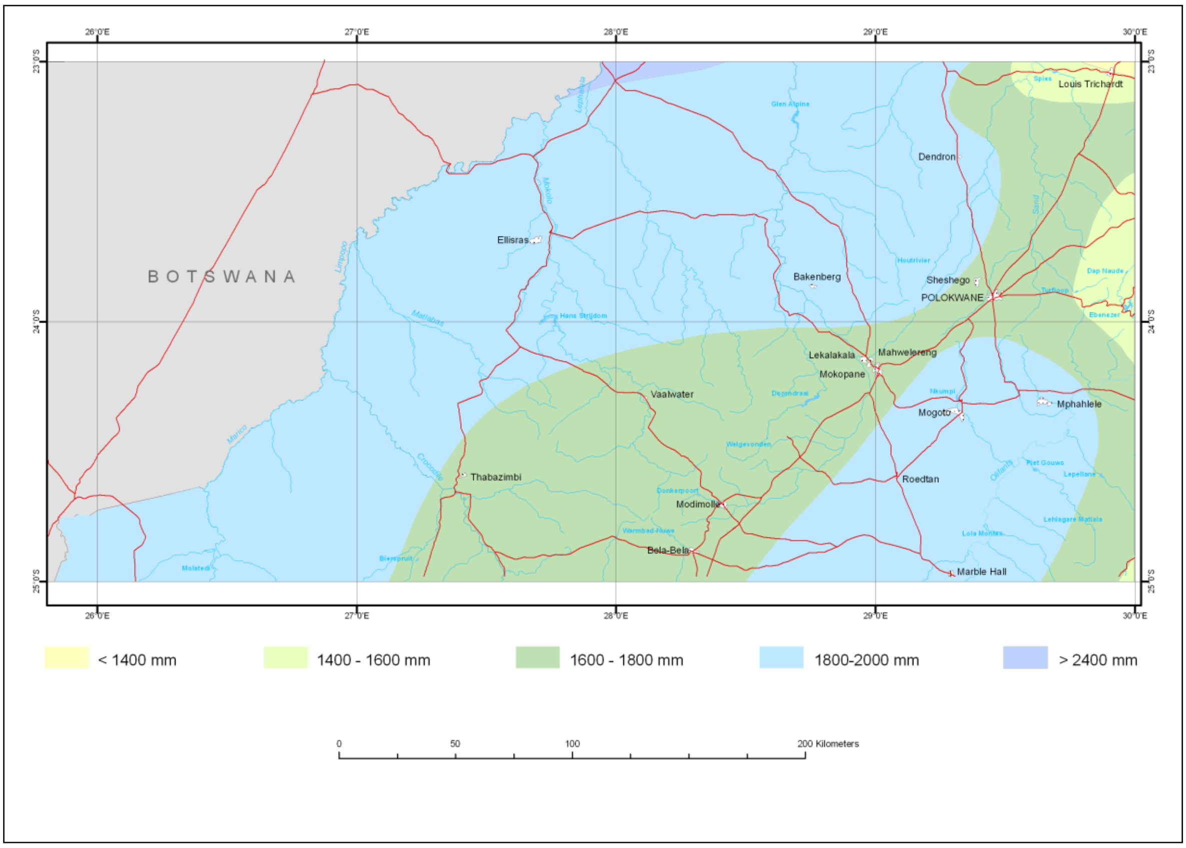

Figure 2: Mean annual evaporation.

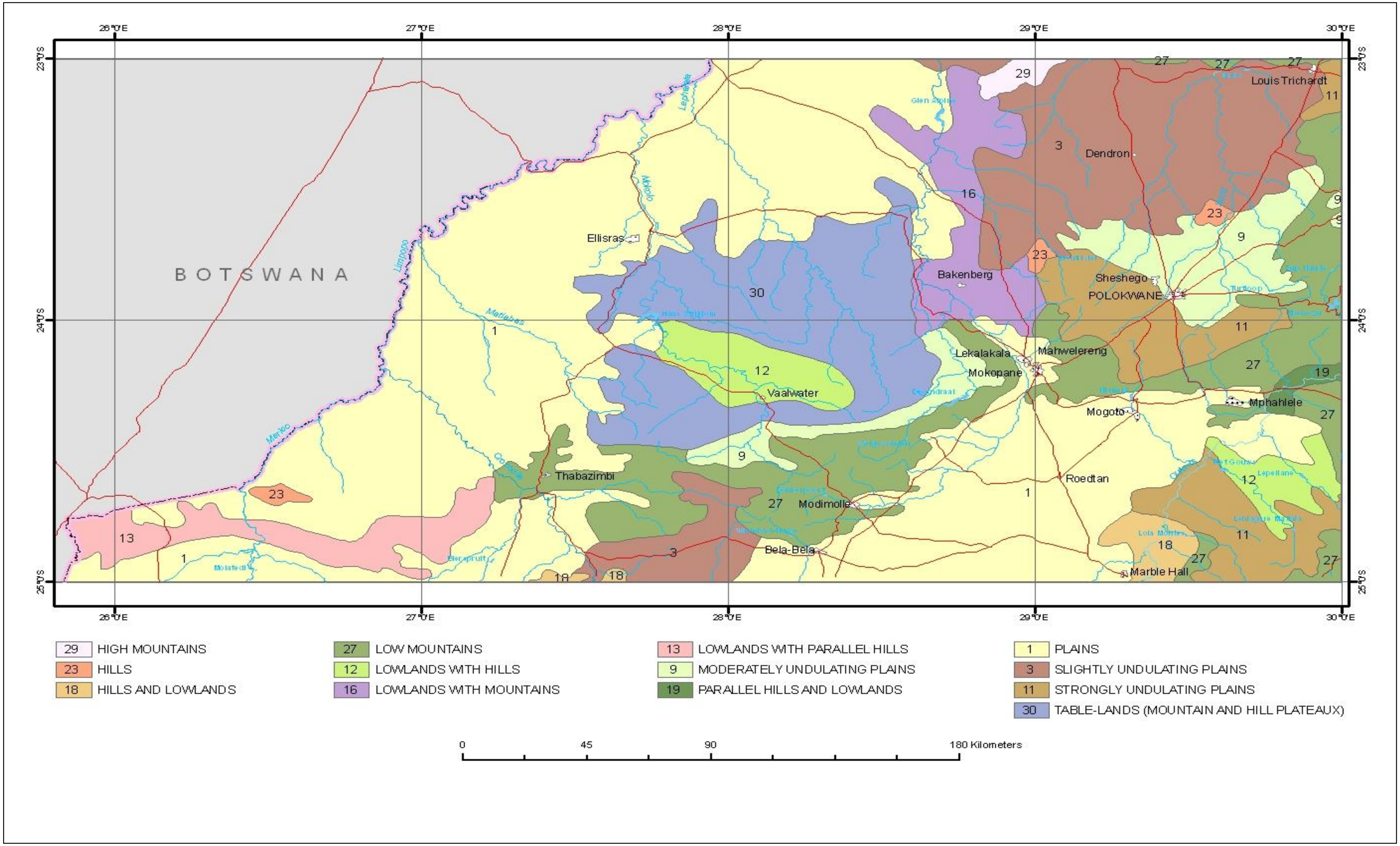

Figure 3: Terrain Morphology (Kruger, 1983)

Table 3: Explanation for Figure 3, 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	
	11	Slightly undulating plains		
Lowlands, hills and mountains with moderate to high relief	12	Lowlands with hills	low - medium 0 - 2	50 - 80%
	13	Lowlands with parallel hills		
	16	Lowlands with mountains		
Open hills, lowlands and mountains with moderate and high relief	18	Hills and lowlands	medium 0.5 - 2	20 - 50%
	19	Parallel hills and lowlands		
Closed hills and mountains with moderate and high relief	23	Hills	medium 0.5 - 2	< 20%
	27	Low mountains		
	29	High 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*

4.4 Surface Hydrology

The area can be divided into **two main drainage regions** i.e. the Limpopo system (A) which drains approximately 75% of the area, and the Olifants system (B). Rivers of the Limpopo and Olifants systems flow mainly north-wards and east-wards respectively. Figure 4 shows the location of the two main surface water drainage basins as well as the major dams.

The **major dams** together with their storage capacities are depicted in Table 4. Only the Limpopo, Olifants, and Crocodile Rivers can be considered as perennial, although it is not unusual for these rivers to stop flowing in exceptionally dry years. Mode and irregular frequency of precipitation combined with high evaporation rates results in droughts and periodical flows in most of the smaller rivers and streams. Interaction between surface and groundwater in river systems is seasonal with rivers either gaining or losing water from and to groundwater. This interaction is dependant on factors such as the water level of the river, depth of erosion channel and type of river bed material, structural geology, riparian vegetation, abstraction points near the river and the static water level in the vicinity of the river.

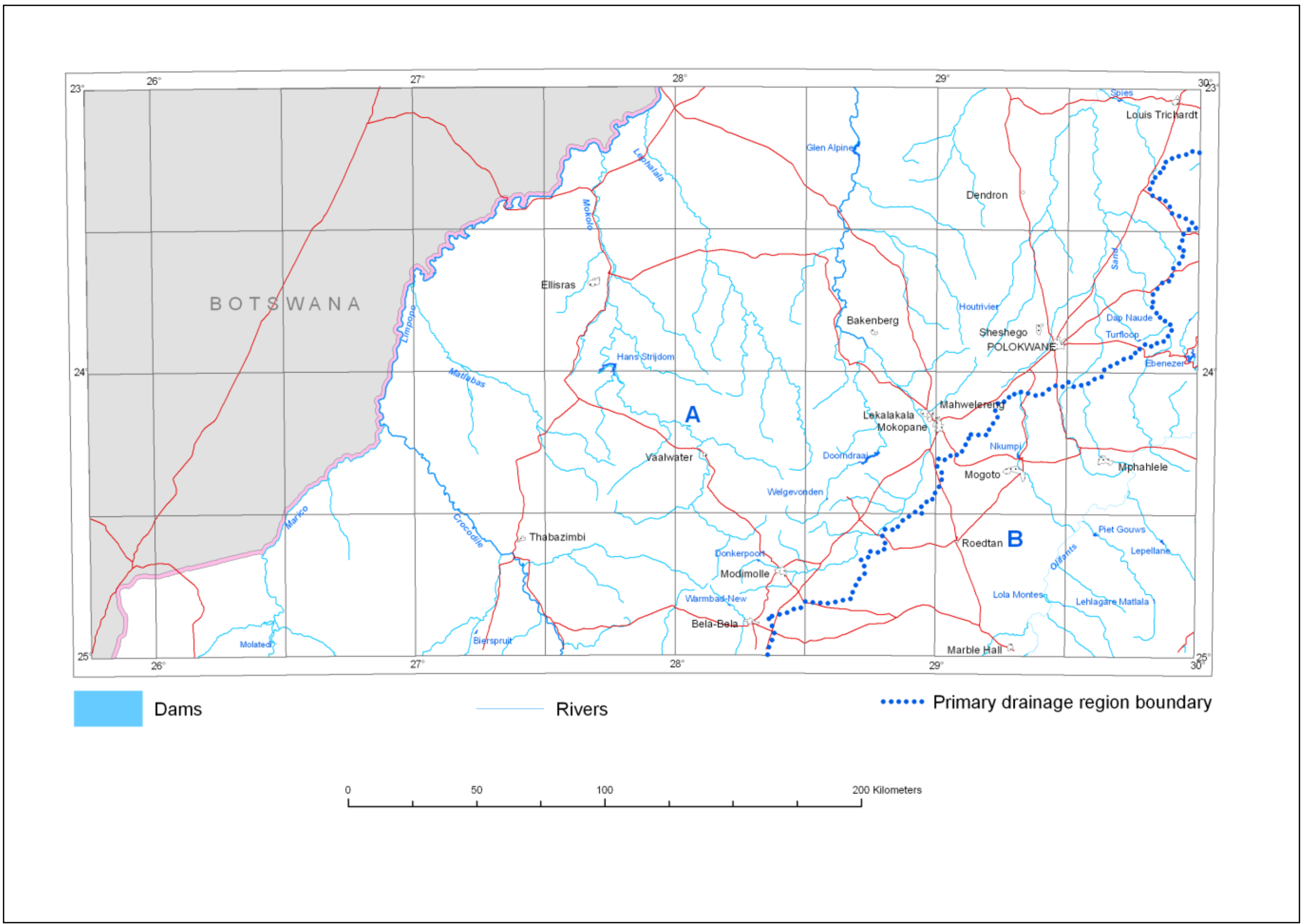

Figure 4: Drainage regions and major dams (HRU, 1981)

Table 4: Major dams, drainage basin, supplying river and storage capacity (HRU, 1981)

DAM NAME	DRAINAGE BASIN	RIVER	STORAGE CAPACITY (Mm^3)
Glen Alpine	A6	Mogalakwena	24
Mokolo	A4	Mokolo	157
Doorndraai	A6	Sterk	40
Molatedi	A3	Marico	30
Warmbad	A2	Buffelspruit	1
Dap Naude	B8	Broederstroom	2
Ebenezer	B8	Letaba	67
Flag Bashilo formerly Arabie	B5	Olifants	100

5 GEOLOGY

5.1 Regional geology

The geology occurring on the Polokwane Hydrological map sheet area spans the length of the South African geological history and contains most of the major stratigraphic groups in the country. A simplified map geological map (Figure 5) was compiled from the following 1: 250 000 published geological map sheets and explanatory booklets (Council for Geosciences):

- 2326 Ellisras
- 2328 Pietersburg
- 2426 Thabazimbi
- 2428 Nylstroom

The major stratigraphic units formed the basis for the delineation of the hydrological units that were chosen according to geohydrological similarities. The boundaries of the hydrological units do not always follow the geological boundaries. The major stratigraphic groups are as follows:

- The Basement Complex
- Granite intrusives
- Ventersdorp Supergroup
- Transvaal Supergroup
- Bushveld Complex
- Soutpansberg Group
- Waterberg Group
- Karoo Supergroup
- Quaternary

The Basement Complex

The Basement Complex occurs in the northern and eastern portions of the map and consists essentially of gneiss, banded gneiss, granite gneiss with infolded xenoliths of mafic to ultra-mafic material and migmatite associated with leucocratic granite [Goudplaats gneiss (Zgo)], greenstones [Bandelierskop Complex (Zga) and Pietersburg Group (Zp)], undifferentiated metamorphic rocks [Mount Dove Group (Zbo), Malala Drift Group (Zba), Gumbu Group (Zbg)], intrusive layers and lenses of ultramafic and anorthositic to gabbroic rocks [Messina Suite (Zbm)], migmatite gneiss [Hout River Gneiss (Rho)] and Unnamed Swazian Rocks (Zz) in the western part of the map. The Pietersburg Group (Zp) occurs within the gneiss (Zgo and Rho) as a southwest striking belt of steeply folded material ranging from ultra-mafic to mafic lavas, acidic lavas, arenaceous sediments and chemical sediments such as banded iron formation and chert. The sequence was subjected to low-grade (green schist facies) metamorphism.

The Central Zone of the Limpopo Mobile Belt strikes east-northeast across the northern part of the map sheet and forms part of the Basement Complex. It is bounded in the south by major faults i.e. Abbottspoort, Melinda and Vivo faults which have exposed deeper levels of the earths crust, hence the high grade of metamorphism of the rocks that prevails within the belt.

Granite intrusives

The Basement Complex has been intruded by numerous younger granites such as Geyser (Rge), Hugomond (Rhu), Matok (Rma), Moletsi (Rmo), Lunsklip (Rlu), Uitloop (Rui), Utrecht (Rut), Gaborone (Rga), Matlala (Rat), and Turfloop Granite (Vtu). Other intrusives include the Unnamed Vaalian Rocks (Vz) of Vaalian to Randian age and the Modipe Complex (Zmo) comprising gabbro of Swazian Age represented in the south-western part of the map.

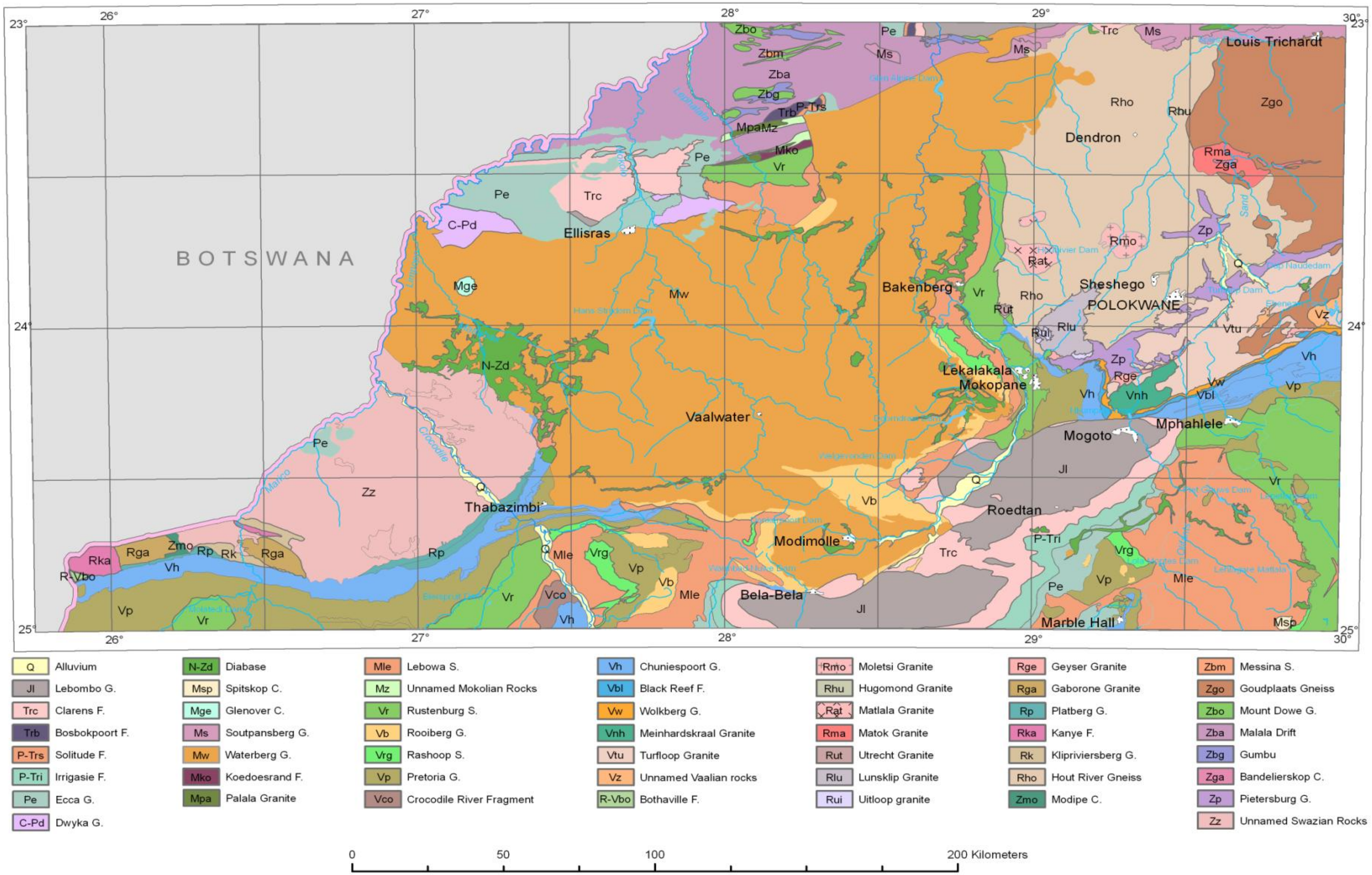

Figure 5: Simplified regional geology of the map area.

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 (Rga) intruded into this acid lava.

Transvaal Supergroup

The Transvaal Supergroup occurs as steeply dipping strata striking approximately east-west across the map sheet and folded about the Bushveld Complex. The Sequence consists of a basal quartzite, shale and basalt layer [Wolkberg Group (Vw)] followed by a period of chemical sediment deposition consisting of a lower banded iron formation and chert layer [Black Reef Formation (Vbl)] followed by a thick sequence of dolomite with interlayered chert [Chuniespoort Group (Vh)]. The Crocodile River Fragment (Vco) in the centre of the southern portion of the map is currently included under the Malmani Subgroup a subdivision of the Chuniespoort Group. Chemical deposition of the Chuniespoort Group was followed by cyclic episodes of quartzite and shale deposition [Pretoria Group (Vp)]. A capping of acidic lava [Rooiberg Group (Vb)] marks the end of Transvaal deposition and the beginning of the intrusion of the Bushveld Complex.

Bushveld Complex

The Bushveld Complex is the largest known igneous intrusive of which the northern, western, and eastern lobes are present in the south and central part of the map sheet. It consists of a lower layered ultra-mafic unit, a middle massive gabbro unit, and an upper-layered mafic unit [Rustenburg Layered Suite (Vr)] capped by a red granite and granophyre unit [Lebowa Granite Suite (Mle) and the Rashoop Granophyre Suite (Vrg)]. Intrusive into the Lebowa Granite Suite (Mle) is the Spitskop Complex (Msp) consisting predominantly of alkaline rocks with a wide range of composition. The Palala Granite (Mpa) located intermittently along the Abbottspoort and Melinda faults, is related to the Bushveld Complex.

Soutpansberg and Waterberg Groups

The Bushveld Complex intrusion was followed by the deposition of the Soutpansberg (Ms) and Waterberg (Mw) Groups. The Waterberg Group includes the Koedoesrand Formation (Mko).

The Soutpansberg Group is considered slightly older than the Waterberg Group and was deposited in the fault-bounded troughs of the Limpopo Mobile Belt to form the Soutpansberg and Blouberg mountain ranges of today.

The Waterberg Group was deposited in the basin formed by sagging of the cooling Bushveld Complex intrusion.

The Soutpansberg Group differs from the Waterberg Group in that the former has a larger basaltic lava component in an otherwise essentially sedimentary sequence of sandstone and conglomerate.

In the south-western part of the map a plug consisting of carbonatites and biotite pyroxenite intruded the Waterberg Group, named Glenover (Mge) after the farm on which it occurs. In the centre of the northern part a series of unnamed Mokolian Rocks (Mz) intruded the Soutpansberg Group.

Diabase dykes and sills

Diabase dykes and sills (N-Zd) are pervasive throughout the whole region. Most dykes are generally related to two main igneous events. The older dykes are thought to be of Bushveld Complex age and the younger dykes are generally of late and post Karoo age. The latter dykes were the feeder conduits to the Karoo basalt suggesting that the basalt outpouring probably covered the whole map sheet area prior to Gondwana break-up and their later removal by erosion.

Karoo Supergroup

The Karoo Supergroup was deposited in a vast intracratonic basin with the maximum depth in the south and in a few satellite basins to the north. It represents the final major episode of deposition before the break-up of Gondwanaland. It is divided in a few geographical areas with two occurring on the map sheet, namely the Springbok flats area and the coal fields north of Lephalale (Ellisras). Deposition in the Springbok flats is believed to have occurred within a shallow inland depression, shallower in the north and deeper to the south. In the northern occurrence deposition was formed in fault bounded troughs of the Limpopo Mobile belt. The Supergroup consists of lower diamictite of probable glacial origin [Dwyka (C-Pd)] overlain by shale (at places carbonaceous), mudstone, and sandstone horizons [Ecca Group (Pe)], Permian-Triassic (P-Tr) formations consisting of the Solitude (P-Trs) and Irrigasie Formation (P-Tri), Triassic (Tr) formations consisting of the Bosbokpoort (Trb) mudstone and siltstone grading into an upper sandstone layer Clarens Formation (Trc) and capped by a thick sequence of basalt [Lebombo Group (Jl)].

Quaternary

The youngest strata are thin sequences of Quaternary to Tertiary Aeolian Kalahari sand (not shown on map) and alluvial sand deposits (Q) along the major drainages in the area.

5.2 Structural geology

Dykes and sills

In the north-eastern sector of the map sheet (Figure 6) dykes occurring within the Swazian rocks and granitic intrusives of Radian and Vaalian age have a predominant north-easterly orientation. Fewer dykes occur in the Hout River Gneiss. These dykes have a predominantly east-northeast and northwest strike whereas dykes in the unnamed Swazian age rocks extending south into the lower formations of the Transvaal Supergroup have a more prominent north-westerly orientation. Fewer dykes occur in the Swazian rocks north of the Melinda fault. These dykes as well as the dykes occurring within the Palala shear zone are trending east-northeast, a direction parallel to the Zoetfontein and Melinda fault zones. Fewer dykes occur within rocks of the Transvaal and Karoo Supergroups. Dyke intrusions in sedimentary rocks of the Waterberg Group are predominantly trending west-northwestwards and to a lesser extend north-northeast-wards. Diabase sills are mainly limited to the Nebo Granite and Waterberg and Soutpansberg Groups.

Faults and shear zones

Major fault zones occurring in the north-western sector of the map sheet (Figure 6) have a predominantly east to northeast orientation and includes the Boleme fault with a downthrow to the north and a vertical displacement of approximately 50m, the Eenzaamheid fault with an estimated 250m vertical displacement, the Constantia fault with an estimated maximum displacement of 160m, the Daarby fault with a maximum displacement of 300m, the Zoetfontein fault with a downthrow to the north and the Melinda fault that extends northeast towards the Blouberg. Minor faulting occurs mainly in the rocks of the Karoo Supergroup with a predominantly north-easterly trend. In the northern part of the map, the Sunnyside shear is exposed and characterized by strong planar mylonitic fabric parallel to the strike of shearing. Minor shear zones include the easterly trending Beaufort and Abbottspoort zones. The 10km wide Palala shear zone occurs along the southern boundary of the central zone of the Limpopo Mobile Belt. It is possible that it continues under the Waterberg outcrop into the Blouberg area.

In the north-eastern sector of the map sheet faults occur mainly within the rocks of the Soutpansberg Group. The predominant strike directions are east-northeast and northwest. Within the basement rocks and later granitic intrusions the north-eastern fault near Matok is the most prominent feature. Minor shear zones include the north-easterly Boyne shear and a zone located at Matok that occurs within the granitic intrusions of Randian and Vaalian age.

In the south-eastern sector of the map sheet major fault zones include the east-west striking Zebediela fault and the north-easterly Welgevonden fault. South-easterly to north-westerly trending faults includes the Boschpoort and Droogekloof faults. Fault zones within the Wolkberg Group and Bushveld Complex is mostly of a north-easterly orientation and includes the Wonderkop, Sekhukhune, Steelpoort and Ysterberg faults respectively.

In the south-western sector of the map sheet, one of the most important structural aspects is the Thabazimbi-Murchison Lineament (TML) with faulting the main structural feature. This faulting has controlled the northern margin of the Transvaal basin, the northern extension of the Bushveld Complex and the southern margin of the Waterberg Group. This part of the TML is characterised by complex faulting involving primarily the Transvaal Supergroup and to a lesser extent the granite of the Bushveld Complex (Council of Geosciences).

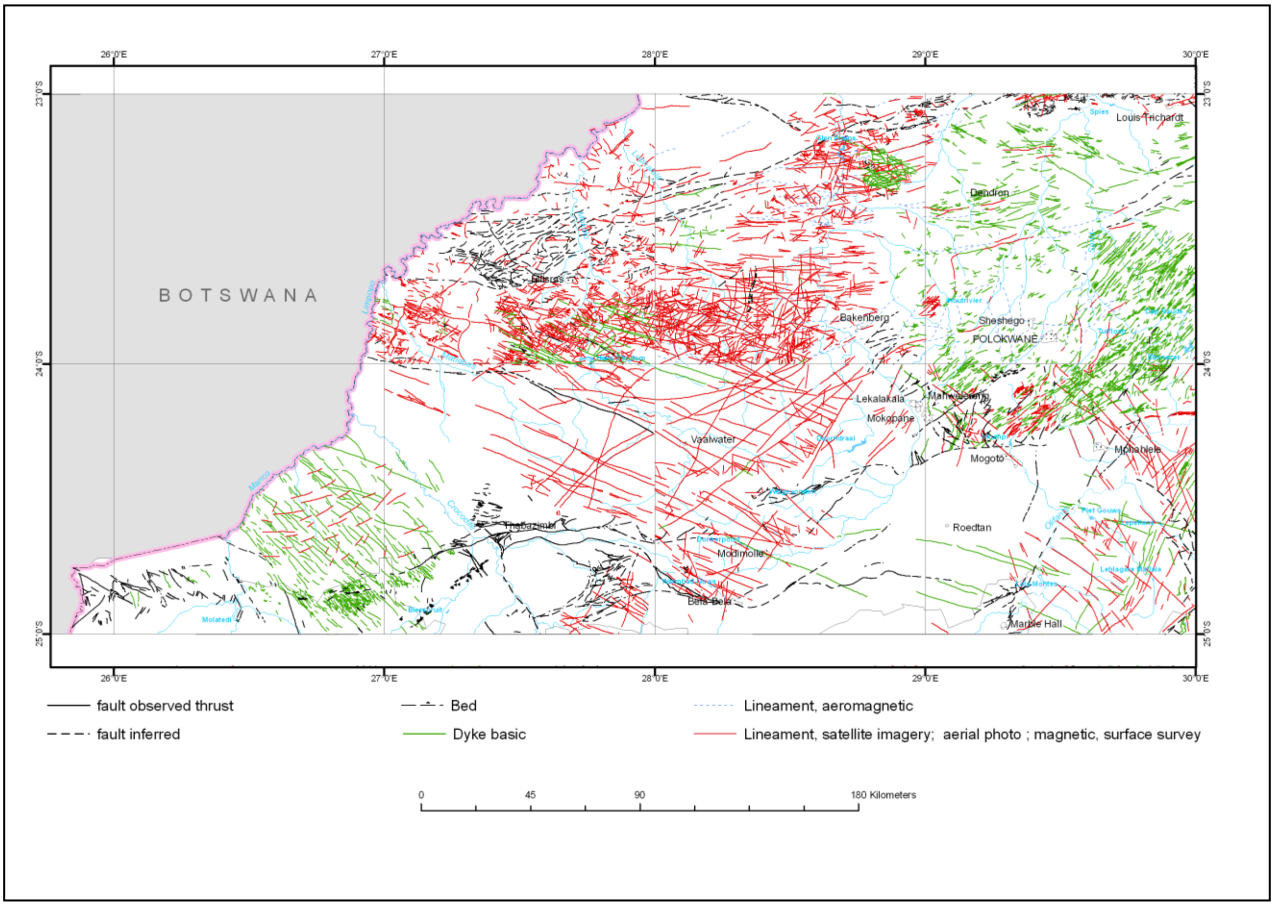

Figure 6: Inferred and observed geological lineaments.

6 GENERAL HYDROCHEMISTRY

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.

In order to characterise and compare the chemical composition of groundwater in the various rock formations, complete chemical analysis of 4508 groundwater samples, taken during the period from 1968 to 2008, was utilized.

The accuracy of the chemical analysis was checked by the plausibility of the electrical conductivity (EC) and chemical analysis, electro neutrality (E.N). The calculation used for the 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%.

Due to the large number of groundwater samples, a basic method of general characterisation of water composition known as the Kurlov method (Kurlov, 1928) was used. It is based on the relative concentration (meq/l) of major cations and anions. The harmonic mean was calculated for each of the parameters needed for the stiff diagrams.

Some major water types are listed below with some examples of occurrence. Detailed hydrochemical classification of the individual formations is undertaken in chapter 7.

- **Calcium Magnesium bicarbonate water**

Bicarbonate water is usually characterised by a high content of HCO_3^- and Ca^{2+}/Mg^{2+} with Mg^{2+} being dominant in groundwater associated with dolomitic aquifers. Groundwater encountered in Goudplaats Gneiss (Zgo), Mount Dove Group (Zbo), Malala Drift Group (Zba), Gumbu Group (Zbg), Hout River Gneiss (Rho), Chuniespoort Group (Vh), Waterberg Group (Mw), Lebombo Group (Jl) and Alluvial Deposits (Q) adjacent to the middle part of the Crocodile River, can be classified as calcium-magnesium-bicarbonate water.

- **Sodium bicarbonate water**

This type of water is generally related to the movement of groundwater from intensive recharge areas and normally indicates a cation exchange process. It is dominated by a high content of Na^+ and HCO_3^-. Sodium-bicarbonate water has a limited occurrence in the study area. It was only encountered in the Alluvial Deposits (Q) of the Nyl, Crocodile, and Limpopo Rivers and some fault zones of the Lebombo Group (Jl) and Karoo sedimentary rocks (Pe, P-Tri, and Trc).

- **Sulphate water**

SO_4^{2-} and Ca^{2+} or Mg^{2+} and occasionally Na^+ dominate this type of water. The sulphate water is usually associated with groundwater encountered in lavas and gypsum deposits as found for example in the Lebombo Group (Jl) of the Springbok Flats. A limited number of samples indicating the same water type were found in the sandstone/conglomerate formation of the Waterberg Group (Mw).

- **Chloride water**

The anion chloride dominates this type of water. The cation content is variable. Where Ca^{2+} and Mg^{2+} are dominant, water is related to reverse ion exchange (replacement of Na^+ with Ca^{2+} and Mg^{2+}). These types of water are found in the Lebombo Group (Jl) northwest of Roedtan, alluvial deposits (Q) along the Crocodile River, Karoo sedimentary rocks (Trc, P-Tri, & Pe), Waterberg

Group (Mw), and Mount Dove- (Zbo), Malala Drift- (Zba) and Gumbu Groups (Zbg). A predominance of Na^+ and Cl^- indicates an end point of discharge or stagnation of water. This type of water is encountered in Karoo sedimentary rocks (Trc, P-Tri, & Pe), riverbed deposits along the Mogol, Limpopo and Matlabas Rivers (Q), Pretoria Group (Vp) shales and some granite intrusions.

Table 5 provides some guidelines on the suitability of water quality based on electrical conductivity measurements for domestic, livestock and irrigation purposes. This table should be read together with Figure 7 to determine the suitability of water for the various user groups. The ranges in this table differ slightly from the indicated ranges on the inset map and Tables 6 to 9.

Table 5: Guidelines for groundwater quality and suitability (DWA, 1996)

ELECTRICAL CONDUCTIVITY RANGE (mS/m)	**SUITABILITY**		
	DOMESTIC	**LIVE STOCK**	**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 - 300	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
300 - 450	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
>450	Totally unacceptable	Tolerable - may be refused by animals not accustomed to the water	Generally unacceptable

Other problem chemical species, which occur in the area covered by the map sheet, include nitrate and fluoride (Figure 7). Nitrate and nitrite concentrations reported as N greater than 10mg/l can cause methaemoglobinaemia (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.

6.1 Aquifer Hydrochemistry

Data obtained from the National Water Quality Database (WMS) was utilised for hydrochemical data analysis and interpretation. The data points were plotted and sorted for each aquifer unit. The data is presented under each aquifer unit depicted as a stiff diagram showing the major anions and cations. Additionally to this Tables 6 to 9 summarize statistics for easy comparison between units. The quality ranges for classes is from the South African National Standards for domestic water use (SANS 241, 1999) document. Table 6 shows the harmonic mean derived for various parameters in each of the aquifer units. Tables 7 to 9 display a summary of the major parameters divided in three classes (ideal, acceptable and maximum allowed as per SANS 241 limit ranges) with an additional column reflecting values exceeding the maximum allowed limit range for each of the units and thus regarded as water of unacceptable quality for domestic use. Eight of the units did not have any chemistry data available for analysis. They are the Solitude Formation (P-Trs), Koedoesrand Formation (Mko), Unnamed Vaalian rocks (Vz), Uitloop Granite (Rui), Hugomond Granite (Rhu), Geyser Granite (Rge), Modipe Complex (Zmo) and Bandelierskop Complex (Zga). Where the concentration displayed in Table 6 exceeds the maximum allowed limit (SANS 241, 1999), they are displayed in bold red.

Table 6: Hydrochemistry of the Polokwane Map Area

Aquifer Unit	**Total sampled points**	**Total samples**	**E.N. ≤ ±10%**	**Total samples used in analysis**	**pH**	**EC**	**NO_3**	**F**	**TAL as ($CaCO_3$)**	**Na**	**Mg**	**SO_4**	**Cl**	**K**	**Ca**
						mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
SANS 241					**4-10**	**370**	**20**	**1.5**		**400**	**100**	**600**	**600**	**100**	**300**
Category A: Intergranular aquifers															
Q	283	364	182	136	7.3	74.6	0.1	0.51	173.6	43.9	13.2	22.3	54.6	2.9	26.8
Category B: Fractured aquifers															
Trb	2	2	1	1	8.7	66.4	0.02	1.2	319.8	83.4	29	13.4	12.6	13.2	18.8
P-Trs	No data														
Pe	42	60	32	28	7.2	121.5	0.59	0.57	23.4	126.8	14.1	22.3	145.5	5.6	55.6
C-Pd	13	32	28	11	8.1	167.8	0.04	1.89	192.9	308.2	1.5	65.4	297.8	4.6	10.5
Mge	8	9	2	2	7.9	115.5	0.75	**2.11**	199.8	81.7	58.1	41.8	87.8	6.0	59.6
Ms	15	25	18	14	8.1	62.2	0.09	0.19	116.3	41.4	10.4	19.5	48.0	1.6	28.9
Mw	1426	1818	945	719	7.8	50.4	0.22	0.31	87.0	30.5	10.5	11.2	33.1	2.2	18.1
Mko	No data														
Mpa	17	24	9	7	8.2	178.1	4.83	0.95	301.7	176.0	63.6	47.3	195.3	1.9	83.1
Mz	13	25	3	3	8.2	184.6	3.21	0.95	164.0	190.7	21.3	93.7	322.9	6.4	55.3
Vb	39	143	59	25	7.6	26.4	0.08	0.57	86.6	22.1	1.8	6.4	10.6	2.4	16.2
Vrg	4	9	6	2	7.5	15.0	0.77	0.63	58.0	11.8	2.9	3.7	6.0	3.3	8.5
Vp	1	1	1	1	7.2	14.5	0.02	**2.16**	68.6	15.8	3.5	2.0	3.0	0.6	8.4
Vh	3	7	5	3	8.1	66.1	0.85	0.27	287.1	18.3	40.2	13.3	12.3	0.8	47.1
Vbl	17	47	29	9	8.2	19.6	0.07	0.12	85.0	2.0	9.7	3.1	3.2	1.1	15.9
Vw	2	2	1	2	8.3	34.9	0.16	0.15	166.2	5.4	14.2	3.5	7.7	2.7	42.4
Rp	23	25	12	14	7.9	109.0	2.46	0.28	302.1	41.7	51.0	26.9	65.9	3.1	54.5
Category C: Karst aquifers															
Vh	88	152	58	38	7.9	68.4	0.16	0.19	258.7	7.3	41.2	4.5	11.2	1.0	50.0
Category D: Intergranular and fractured aquifers															
Jl	1305	2006	446	218	7.8	78.8	0.48	0.21	74.2	35.9	10.2	15.0	36.7	1.8	20.4
Trc	353	537	292	220	7.7	46.5	0.21	0.18	91.2	33.2	4.8	5.8	31.1	3.2	16.5
P-Tri	84	112	90	70	7.9	166.1	0.3	0.69	239.7	192.1	8.1	21.4	241.4	5.4	35.4
Pe	73	91	79	67	7.9	161.3	0.11	1.49	224.0	142.0	5.3	29.3	169.8	9.1	23.9
N-Zd	119	198	107	79	7.9	95.3	0.28	0.54	194.7	55.2	12.9	15.3	54.8	1.5	36.8
Msp	12	22	11	11	8.2	61.3	0.14	0.36	293.9	31.7	10.7	8.8	9.6	6.3	30.4
Ms	62	129	52	37	8.0	50.4	0.12	0.21	212.0	25.8	10.3	6.2	18.4	0.4	12.6
Mle	626	1147	398	347	7.9	38.8	0.14	0.81	102.4	36.5	4.2	7.9	20.0	2.0	15.4
Vr	740	1344	495	411	8.1	104.4	0.32	0.23	246.8	51.8	31.2	24.3	57.6	1.0	44.3
Vp	401	251	128	163	7.8	57.2	0.19	0.29	172.8	14.9	22.8	11.4	16.7	1.0	25.0

Table 6: Hydrochemistry of the Polokwane map

Aquifer Unit	Total sampled points	Total samples	E.N. ≤ ±10%	Total samples used in analysis	pH	EC	NO_3	F	TAL as ($CaCO_3$)	Na	Mg	SO_4	Cl	K	Ca
						mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
SANS 241					**4-10**	**370**	**20**	**1.5**		**400**	**100**	**600**	**600**	**100**	**300**
Vco	15	15	9	9	7.8	164.7	2.26	0.59	340.9	131.4	81.6	41.1	202.5	2.9	75.2
Vnh	2	2	1	2	8.1	60.8	0.14	0.41	237.5	54.6	20.9	20.9	17.8	2.1	37.2
Vtu	186	352	136	117	8.1	57.6	0.38	0.48	189.0	35.2	14.5	8.9	31.9	1.7	27.5
Vz	No data														
Rat	52	95	37	30	8.2	125.1	0.26	0.95	297.3	148.5	27.0	21.4	77.6	5.3	34.2
Rga	5	6	0	1	8.3	103.5	24.2	0.41	460.0	59.1	59.1	4.0	30.9	1.1	96.1
Rut	7	9	7	7	8.3	109.3	0.27	0.57	291.5	134.9	18.1	30.9	104.0	2.3	44.4
Rui	No data														
Rlu	63	91	30	28	8.0	31.2	0.26	0.89	80.1	24.7	3.2	6.7	10.7	1.3	14.3
Rmo	55	112	35	28	8.1	72.6	0.34	0.9	231.9	87.8	15.6	17.0	53.6	4.7	28.7
Rma	54	95	24	21	8.1	202.8	5.72	1.32	239.3	255.8	47.8	63.8	320.7	10.5	53.6
Rhu	No data														
Rge	No data														
Rp	5	5	2	2	8.0	111.3	4.98	0.85	463.6	140.5	37.0	27.0	67.7	2.7	49.5
Rka	3	5	1	3	8.2	80.5	0.09	0.4	392.0	59.6	48.4	30.3	19.4	1.5	56.0
Rk	4	8	3	3	8.0	93.5	0.14	0.55	73.5	96.6	3.3	14.0	45.3	1.2	31.9
Rho	1399	3184	1877	1034	8.2	103.5	0.59	0.32	288.8	97.1	36.3	22.3	86.1	6.9	33.0
Zmo	No data														
Zbm	1	1	0	1	8.0	98.3	13.8	0.65	343.5	56.6	58.5	13.0	63.8	9.0	58.9
Zgo	507	995	469	294	8.1	84.0	3.2	0.2	287.8	62.6	38.8	13.3	55.4	5.0	26.8
Zbg	13	21	10	9	8.1	90.9	0.97	0.62	229.2	106.6	26.5	34.0	105.7	4.8	37.1
Zba	329	580	198	121	7.7	161.3	0.34	0.7	67.7	121.0	21.0	38.4	157.4	3.6	65.9
Zbo	28	40	14	12	8.3	111.9	0.81	0.84	337.7	99.1	51.0	20.1	107.3	6.6	56.1
Zga	No data														
Zp	68	109	24	23	8.2	66.5	0.33	0.36	240.5	35.9	26.4	10.3	19.4	1.3	34.6
Zz	197	367	172	125	7.9	133.3	0.63	0.61	307.9	83.7	56.2	25.8	90.4	2.8	48.1
Total	8764	14674	6538	4508											

Table 7: Summarized Chloride, Nitrate and Sulphate concentration ranges within aquifer units

Aquifer Unit	Number of samples	Chloride Cl (mg/l)				Nitrate and nitrite (presented as N) (mg/l)				Sulphate SO4 (mg/l)			
		Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable
Limit Ranges		100	200	600	>600	6	10	20	>20	200	400	600	>600
Category A: Intergranular aquifers													
Q	159	44.7%	23.3%	24.5%	7.5%	79.9%	7.5%	9.4%	3.1%	92.5%	5.7%	1.9%	0%
Category B: Fractured aquifers													
Trb	1												
Pe	28	14.3%	28.6%	39.3%	17.9%	60.7%	14.3%	10.7%	14.3%	78.6%	10.7%	0%	10.7%
C-Pd	11	0%	9.1%	81.8%	9.1%	72.7%	18.2%	0%	9.1%	100%	0%	0%	0%
Mge	2	50%	0%	50%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Ms	13	46.2%	46.2%	7.7%	0%	69.2%	0%	23.1%	7.7%	92.3%	7.7%	0%	0%
Mw	747	35.3%	13.8%	27.7%	23.2%	56.9%	11.4%	18.1%	13.7%	91.3%	4.6%	1.5%	2.7%
Mpa	6	0%	33.3%	33.3%	33.3%	16.7%	16.7%	16.7%	50%	83.3%	0%	0%	16.7%
Mz	3	0%	0%	100%	0%	33.3%	0%	0%	66.7%	66.7%	33.3%	0%	0%
Vb	24	79.2%	8.3%	4.2%	8.3%	91.3%	4.3%	4.3%	0%	95.8%	4.2%	0%	0%
Vrg	2	50%	0%	50%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Vp	1												
Vh	3	66.7%	0%	0%	33.3%	100%	0%	0%	0%	66.7%	0%	0%	33.3%
Vbl	12	91.7%	0%	8.3%	0%	91.7%	0%	0%	8.3%	100%	0%	0%	0%
Rp	14	42.9%	35.7%	21.4%	0%	100%	0%	0%	0%	92.9%	7.1%	0%	0%
Vw	2	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Category C: Karst aquifers													
Vh	34	79.4%	2.9%	11.8%	5.9%	73.5%	14.7%	2.9%	8.8%	94.1%	0%	2.9%	2.9%

Table 7: Summarized Chloride, Nitrate and Sulphate concentration ranges within aquifer units

Aquifer Unit	Number of samples	Chloride Cl (mg/l)				Nitrate and nitrite (presented as N (mg/l)				Sulphate SO4 (mg/l)			
		Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable
Limit Ranges		100	200	600	>600	6	10	20	>20	200	400	600	>600
Category D: Intergranular and fractured aquifers													
Jl	352	37.5%	12.8%	29.3%	20.5%	36.9%	11.6%	19.6%	31.8%	80.4%	12.2%	4.0%	3.4%
Trc	226	42.0%	17.7%	28.3%	11.9%	68.9%	9.3%	12.9%	8.9%	93.8%	2.2%	1.3%	2.7%
P-Tri	71	4.2%	31.0%	42.3%	22.5%	70.4%	7.0%	15.5%	7.0%	88.7%	7.0%	4.2%	0%
Pe	70	5.7%	5.7%	51.4%	37.1%	63.8%	7.2%	10.1%	18.8%	84.3%	7.1%	1.4%	7.1%
N-Zd	81	23.5%	34.6%	32.1%	9.9%	56.8%	17.3%	17.3%	8.6%	93.8%	2.5%	0%	3.7%
Msp	7	100%	0%	0%	0%	85.7%	0%	14.3%	0%	100%	0%	0%	0%
Ms	38	81.6%	10.5%	5.3%	2.6%	76.3%	10.5%	5.3%	7.9%	97.3%	2.7%	0%	0%
Mle	347	56.8%	14.7%	19.6%	8.9%	73.5%	8.6%	11.0%	6.9%	95.7%	3.2%	0.9%	0.3%
Vr	411	33.1%	17.8%	33.6%	15.6%	40.9%	12.2%	25.5%	21.4%	88.8%	8.3%	1.7%	1.2%
Vp	129	52.7%	10.9%	18.6%	17.8%	72.9%	10.9%	9.3%	7.0%	89.9%	2.3%	1.6%	6.2%
Vco	9	11.1%	33.3%	33.3%	22.2%	44.4%	11.1%	22.2%	22.2%	100%	0%	0%	0%
Vnh	2	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Vtu	120	65.0%	22.5%	11.7%	0.8%	75.0%	13.3%	8.3%	3.3%	98.3%	1.7%	0%	0%
Rat	30	20%	26.7%	26.7%	26.7%	36.7%	20%	26.7%	16.7%	100%	0%	0%	0%
Rut	7	42.9%	28.6%	28.6%	0%	71.4%	0%	0%	28.6%	100%	0%	0%	0%
Rlu	28	82.1%	3.6%	14.3%	0%	78.6%	14.3%	7.1%	0%	92.9%	3.6%	3.6%	0%
Rmo	28	75.0%	21.4%	3.6%	0%	57.1%	25.0%	10.7%	7.1%	100%	0%	0%	0%
Rma	21	0%	14.3%	76.2%	9.5%	23.8%	14.3%	28.6%	33.3%	90.5%	0%	0%	9.5%
Rp	2	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Rka	3	100%	0%	0%	0%	66.7%	33.3%	0%	0%	0%	0%	0%	0%
Rk	3	33.3%	33.3%	33.3%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Rho	1034	30.4%	41.3%	25.4%	2.9%	47.7%	26.7%	20.6%	5.0%	97.2%	1.7%	0.5%	0.6%
Zbm	1												
Zgo	297	35.0%	39.4%	22.9%	2.7%	55.2%	15.5%	18.2%	11.1%	99.0%	0.7%	0.3%	0%
Zbg	9	44.4%	11.1%	33.3%	11.1%	88.9%	0%	0%	11.1%	100%	0%	0%	0%
Zba	125	19.2%	16.0%	23.2%	41.6%	46.4%	13.6%	20%	20%	72.8%	11.2%	8.8%	7.2%
Zbo	12	58.3%	16.7%	25.0%	0%	33.3%	33.3%	25.0%	8.3%	91.7%	8.3%	0%	0%
Zp	24	75.0%	16.7%	8.3%	0%	62.5%	25.0%	12.5%	0%	100%	0%	0%	0%
Zz	128	34.4%	20.3%	33.6%	11.7%	55.5%	11.7%	14.8%	18.0%	86.7%	7.0%	3.1%	3.1%

Table 8: Summarized Calcium, Potassium, Magnesium and Sodium concentration ranges within aquifer units

Aquifer Unit	Number of samples	Calcium Ca (mg/l)				Potassium K (mg/l)				Magnesium Mg (mg/l)				Sodium Na (mg/l)			
		Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able
Limit Ranges		80	150	300	>300	25	50	100	>100	30	70	100	>100	100	200	400	>400
Category A: Intergranular aquifers																	
Q	159	78.6%	12.6%	5.0%	3.8%	99.3%	0%	0%	0.7%	29.6%	41.5%	10.1%	18.9%	56.0%	27.0%	13.2%	3.8%
Category B: Fractured aquifers																	
Trb	1																
Pe	28	60.7%	21.4%	0%	17.9%	100%	0%	0%	0%	50%	35.7%	0%	14.3%	25.0%	39.3%	17.9%	17.9%
C-Pd	11	81.8%	18.2%	0%	0%	90.9%	0%	0%	9.1%	81.8%	9.1%	0%	9.1%	0%	9.1%	81.8%	9.1%
Mge	2	100%	0%	0%	0%	100%	0%	0%	0%	0%	50%	0%	50%	50%	50%	0%	0%
Ms	13	92.3%	7.7%	0%	0%	100%	0%	0%	0%	23.1%	46.2%	30.8%	0%	69.2%	30.8%	0%	0%
Mw	747	60%	21.0%	12.6%	6.4%	94.6%	4.4%	0.5%	0.4%	34.0%	28.1%	15.5%	22.4%	39.5%	24.6%	21.8%	14.1%
Mpa	6	33.3%	16.7%	50%	0%	100%	0%	0%	0%	0%	33.3%	50%	16.7%	0%	50%	33.3%	16.7%
Mz	3	66.7%	33.3%	0%	0%	100%	0%	0%	0%	33.3%	33.3%	33.3%	0%	0%	66.7%	33.3%	0%
Vb	24	91.7%	8.3%	0%	0%	95.2%	4.8%	0%	0%	87.5%	8.3%	4.2%	0%	79.2%	8.3%	8.3%	4.2%
Vrg	2	50%	50%	0%	0%	100%	0%	0%	0%	50%	50%	0%	0%	100%	0%	0%	0%
Vp	1																
Vh	3	66.7%	33.3%	0%	0%	100%	0%	0%	0%	33.3%	33.3%	0%	33.3%	66.7%	0%	0%	33.3%
Vbl	12	91.7%	8.3%	0%	0%	100%	0%	0%	0%	83.3%	8.3%	0%	8.3%	100%	0%	0%	0%
Rp	14	78.6%	21.4%	0%	0%	100%	0%	0%	0%	7.1%	71.4%	14.3%	7.1%	57.1%	35.7%	7.1%	0%
Vw	2	100%	0%	0%	0%	100%	0%	0%	0%	50%	50%	0%	0%	100%	0%	0%	0%
Category C: Karst aquifers																	
Vh	34	73.5%	23.5%	2.9%	0%	96.9%	3.1%	0%	0%	23.5%	44.1%	23.5%	8.8%	88.2%	2.9%	2.9%	5.9%

Table 8: Summarized Calcium, Potassium, Magnesium and Sodium concentration ranges within aquifer units

Aquifer Unit	Number of samples	Calcium Ca (mg/l)				Potassium K (mg/l)				Magnesium Mg (mg/l)				Sodium Na (mg/l)			
		Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able	Class 0 (Ideal)	Class I (Accept-able)	Class II (Max Allowed)	Un-accept-able
Limit Ranges		80	150	300	>300	25	50	100	>100	30	70	100	>100	100	200	400	>400
Category D: Intergranular and fractured aquifers																	
Jl	352	47.7%	24.4%	18.8%	9.1%	98.6%	1.4%	0%	0%	28.7%	26.1%	12.8%	32.4%	58.2%	33.8%	6.3%	1.7%
Trc	226	66.8%	20.4%	8.0%	4.9%	94.6%	3.6%	1.2%	0.6%	51.8%	27.0%	8.0%	13.3%	50.4%	31.4%	11.9%	6.2%
P-Tri	71	52.1%	22.5%	19.7%	5.6%	96.0%	2.0%	2.0%	0%	31.0%	32.4%	15.5%	21.1%	8.5%	38.0%	42.3%	11.3%
Pe	70	65.7%	21.4%	11.4%	1.4%	73.8%	24.6%	1.5%	0%	42.9%	15.7%	10%	31.4%	7.1%	7.1%	47.1%	38.6%
N-Zd	81	63.0%	24.7%	11.1%	1.2%	98.7%	1.3%	0%	0%	33.3%	38.3%	14.8%	13.6%	32.1%	42.0%	22.2%	3.7%
Msp	7	85.7%	14.3%	0%	0%	100%	0%	0%	0%	71.4%	0%	28.6%	0%	71.4%	28.6%	0%	0%
Ms	38	78.9%	18.4%	2.6%	0%	97.3%	2.7%	0%	0%	44.7%	36.8%	13.2%	5.3%	83.8%	13.5%	2.7%	0%
Mle	347	77.8%	15.6%	6.3%	0.3%	97.1%	2.3%	0.6%	0%	71.8%	15.9%	4.9%	7.5%	59.7%	23.3%	10.4%	6.6%
Vr	411	58.6%	29.9%	9.5%	1.9%	98.0%	2.0%	0%	0%	14.1%	28.2%	22.1%	35.5%	45.0%	29.0%	21.9%	4.1%
Vp	129	61.2%	23.3%	9.3%	6.2%	92.2%	6.3%	1.6%	0%	31.0%	34.9%	14.0%	20.2%	65.1%	7.8%	10.9%	16.3%
Vco	9	33.3%	44.4%	22.2%	0%	100%	0%	0%	0%	0%	33.3%	22.2%	44.4%	33.3%	33.3%	33.3%	0%
Vnh	2	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Vtu	120	91.7%	6.7%	1.7%	0%	99.2%	0.8%	0%	0%	59.2%	36.7%	4.2%	0%	62.5%	22.5%	14.2%	0.8%
Rat	30	73.3%	6.7%	16.7%	3.3%	100%	0%	0%	0%	40%	30%	13.3%	16.7%	13.3%	26.7%	33.3%	26.7%
Rut	7	85.7%	14.3%	0%	0%	100%	0%	0%	0%	42.9%	57.1%	0%	0%	28.6%	28.6%	42.9%	0%
Rlu	28	89.3%	10.7%	0%	0%	100%	0%	0%	0%	89.3%	7.1%	0%	3.6%	75.0%	14.3%	7.1%	3.6%
Rmo	28	100%	0%	0%	0%	92.9%	3.6%	3.6%	0%	96.4%	0%	0%	3.6%	53.6%	46.4%	0%	0%
Rma	21	57.1%	33.3%	0%	9.5%	90.5%	9.5%	0%	0%	9.5%	57.1%	23.8%	9.5%	0%	28.6%	57.1%	14.3%
Rp	2	100%	0%	0%	0%	100%	0%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%
Rka	3	100%	0%	0%	0%	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%
Rk	3	66.7%	33.3%	0%	0%	100%	0%	0%	0%	66.7%	0%	33.3%	0%	33.3%	33.3%	33.3%	0%
Rho	1034	88.3%	9.7%	1.8%	0.2%	95.3%	3.4%	0.9%	0.4%	22.6%	43.5%	25.4%	8.4%	34.2%	52.7%	11.8%	1.3%
Zbm	1																
Zgo	297	89.6%	7.7%	2.7%	0%	99.3%	0.7%	0%	0%	24.9%	33.0%	27.9%	14.1%	39.2%	51.0%	9.1%	0.7%
Zbg	9	88.9%	0%	11.1%	0%	88.9%	11.1%	0%	0%	55.6%	33.3%	0%	11.1%	44.4%	55.6%	0%	0%
Zba	125	40%	21.6%	20.8%	17.6%	98.4%	1.6%	0%	0%	16.8%	27.2%	12.8%	43.2%	23.2%	25.6%	28.8%	22.4%
Zbo	12	75.0%	25.0%	0%	0%	100%	0%	0%	0%	8.3%	83.3%	8.3%	0%	66.7%	25.0%	8.3%	0%
Zp	24	95.8%	4.2%	0%	0%	100%	0%	0%	0%	29.2%	70.8%	0%	0%	75.0%	16.7%	8.3%	0%
Zz	128	67.2%	23.4%	5.5%	3.9%	99.2%	0.8%	0%	0%	10.2%	35.2%	23.4%	31.3%	43.8%	28.1%	20.3%	7.8%

Table 9: Summarized Electrical Conductivity, pH and Fluoride concentration ranges within aquifer units

Aquifer Unit	Number of samples	Conductivity (mS/m)				pH (pH units)				Fluoride F (mg/l)			
		Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Acceptable to max Acidity	Ideal	Acceptable to max Alkalinity	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable
Limit Ranges		70	150	370	>370	4.0 -5.9	6.0-9.0	9.1 - 10.0	>10 & <4	0.07	1	1.5	>1.5
Category A: Intergranular aquifers													
Q	159	22.6%	44.7%	27.0%	5.7%	0.00%	98.11%	0.63%	1.26%	46.5%	27.7%	11.9%	13.8%
Category B: Fractured aquifers													
Trb	1					0%	100%	0%	0%				
P-Trs	0												
Pe	28	3.6%	50%	28.6%	17.9%	10.7%	89.3%	0%	0%	53.6%	0%	17.9%	28.6%
C-Pd	11	0%	45.5%	45.5%	9.1%	0%	100%	0%	0%	18.2%	0%	0%	81.8%
Mge	2	0%	50%	50%	0%	0%	100%	0%	0%	0%	0%	50%	50%
Ms	13	23.1%	69.2%	7.7%	0%	0%	100%	0%	0%	84.6%	7.7%	7.7%	0%
Mw	747	26.6%	24.8%	33.5%	15.1%	0.8%	98.9%	0.3%	0%	68.4%	12.3%	9.0%	10.3%
Mko	0												
Mpa	6	0%	33.3%	50%	16.7%	0%	100%	0%	0%	33.3%	0%	0%	66.7%
Mz	3	0%	0%	100%	0%	0%	100%	0%	0%	33.3%	33.3%	0%	33.3%
Vb	24	83.3%	4.2%	12.5%	0%	4.2%	95.8%	0%	0%	33.3%	0%	8.3%	58.3%
Vrg	2	50%	0%	50%	0%	0%	100%	0%	0%	100%	0%	0%	0%
Vp	1					0%	100%	0%	0%				
Vh	3	66.7%	0%	0%	33.3%	0%	100%	0%	0%	100%	0%	0%	0%
Vbl	12	91.7%	0%	8.3%	0%	0%	91.7%	8.3%	0%	100%	0%	0%	0%
Rp	14	0%	85.7%	14.3%	0%	0%	100%	0%	0%	85.7%	14.3%	0%	0%
Vw	2	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%
R-Vbo	?												
Category C: Karst aquifers													
Vh	34	44.1%	41.2%	11.8%	2.9%	0%	100%	0%	0%	90.6%	0%	6.3%	3.1%

Table 9: Summarized Electrical Conductivity, pH and Fluoride concentration ranges within aquifer units

Aquifer Unit	Number of samples	Conductivity (mS/m)				pH (pH units)				Fluoride F (mg/l)			
		Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable	Acceptable to max Acidity	Ideal	Acceptable to max Alkalinity	Unacceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Maximum Allowable)	Unacceptable
Limits Ranges		70	150	370	>370	4.0 -5.9	6.0-9.0	9.1 - 10.0	>10 & <4	0.07	1	1.5	>1.5
Category D: Intergranular and fractured aquifers													
Jl	352	22.2%	31.0%	36.6%	10.2%	0%	98.0%	2.0%	0%	86.6%	3.8%	5.2%	4.4%
Trc	226	35.8%	33.6%	21.7%	8.8%	0.9%	98.7%	0.4%	0%	76.1%	5.8%	2.2%	15.9%
P-Tri	71	1.4%	39.4%	42.3%	16.9%	0%	98.6%	1.4%	0%	38.0%	14.1%	18.3%	29.6%
Pe	70	4.3%	7.1%	61.4%	27.1%	0%	100%	0%	0%	7.1%	7.1%	8.6%	77.1%
N-Zd	81	16.0%	46.9%	30.9%	6.2%	0%	100%	0%	0%	40.7%	18.5%	8.6%	32.1%
Msp	7	28.6%	71.4%	0%	0%	0%	100%	0%	0%	85.7%	0%	0%	14.3%
Ms	38	57.9%	26.3%	13.2%	2.6%	0%	94.7%	5.3%	0%	97.4%	2.6%	0%	0%
Mle	347	49.9%	25.6%	19.6%	4.9%	0.3%	99.4%	0.3%	0%	25.4%	8.6%	13.5%	52.4%
Vr	411	11.4%	35.8%	46.0%	6.8%	0%	100%	0%	0%	71.2%	9.5%	10.2%	9.0%
Vp	129	33.3%	32.6%	17.1%	17.1%	0%	100%	0%	0%	58.9%	11.6%	7.8%	21.7%
Vco	9	0%	33.3%	66.7%	0%	0%	100%	0%	0%	55.6%	22.2%	11.1%	11.1%
Vnh	2	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%
Vtu	120	41.7%	45.8%	11.7%	0.8%	0%	99.2%	0.8%	0%	52.5%	10%	16.7%	20.8%
Rat	30	13.3%	30%	43.3%	13.3%	0%	100%	0%	0%	30%	10%	10%	50%
Rut	7	14.3%	57.1%	28.6%	0%	0%	100%	0%	0%	57.1%	14.3%	14.3%	14.3%
Rlu	28	71.4%	17.9%	10.7%	0%	0%	100%	0%	0%	21.4%	3.6%	10.7%	64.3%
Rmo	28	35.7%	60.7%	3.6%	0%	0%	100%	0%	0%	21.4%	17.9%	21.4%	39.3%
Rma	21	0%	19.0%	71.4%	9.5%	0%	100%	0%	0%	9.5%	9.5%	19.0%	61.9%
Rp	2	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%
Rka	3	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Rk	3	33.3%	33.3%	33.3%	0%	0%	100%	0%	0%	66.7%	0%	0%	33.3%
Rho	1034	11.5%	63.0%	24.7%	0.9%	0%	98.9%	1.1%	0%	85.6%	6.5%	4.5%	3.4%
Zbm	1					0%	100%	0%	0%				
Zgo	297	20.5%	48.8%	29.3%	1.3%	0%	100%	0%	0%	85.9%	6.1%	5.4%	2.7%
Zbg	9	22.2%	55.6%	22.2%	0%	0%	100%	0%	0%	44.4%	55.6%	0%	0%
Zba	125	4.0%	30.4%	36.0%	29.6%	2.4%	97.6%	0%	0%	72.8%	11.2%	8.8%	7.2%
Zbo	12	0%	75.0%	25.0%	0%	0%	100%	0%	0%	25.0%	25.0%	41.7%	8.3%
Zp	24	50%	41.7%	8.3%	0%	0%	100%	0%	0%	66.7%	12.5%	4.2%	16.7%
Zz	128	6.3%	49.2%	38.3%	6.3%	0.8%	97.7%	1.6%	0%	44.5%	18.8%	19.5%	17.2%

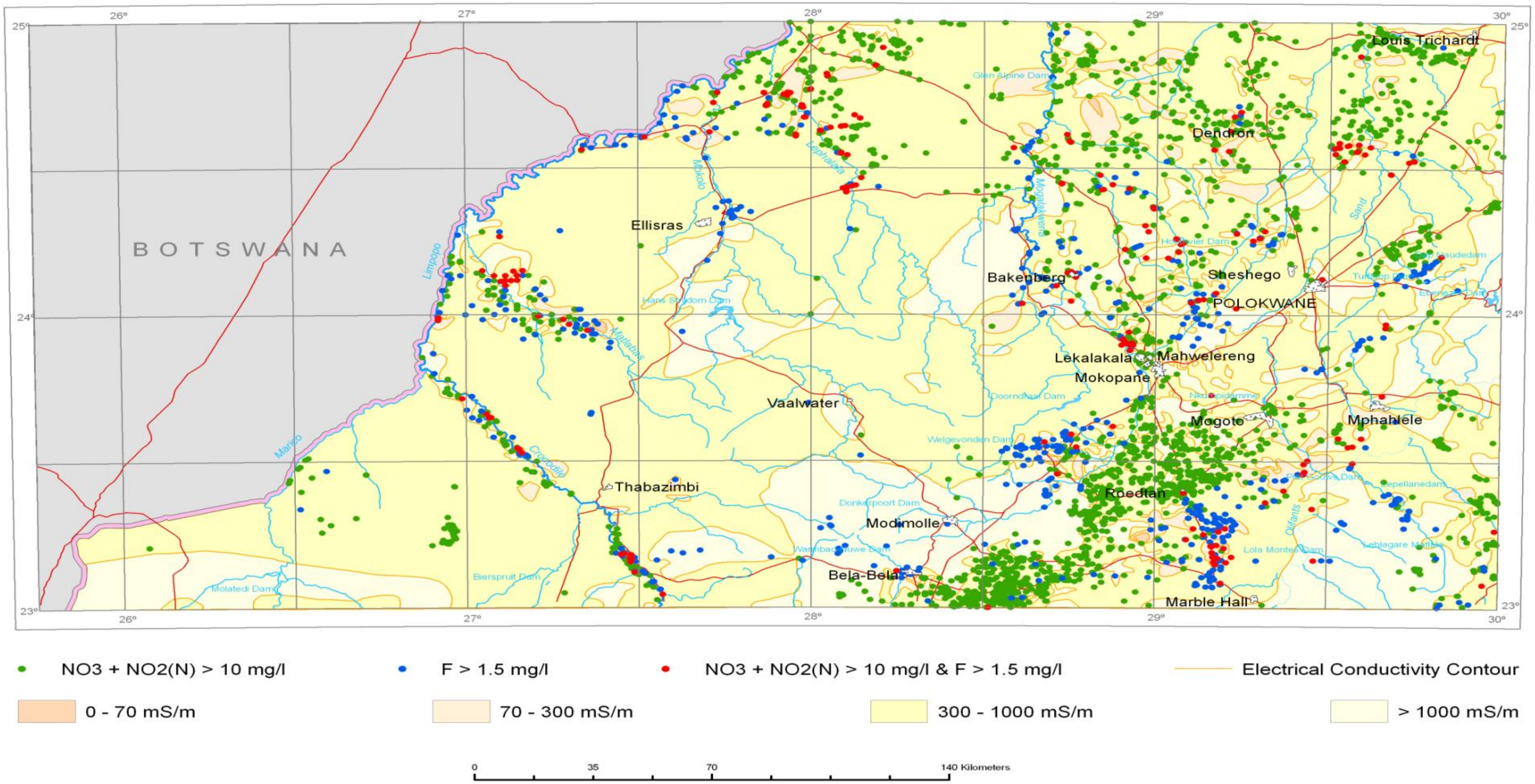

Figure 7: Distribution of electric conductivity (EC) and boreholes with nitrate and fluoride values exceeding the acceptable levels for human consumption.

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. The hydrogeology is supported by a statistical analysis of the borehole data available for each group or formation. For yield data, the results are portrait as borehole yield frequency diagrams and for the hydrochemistry as stiff diagrams. Table 10 shows the percentage boreholes in each yield range as obtained from the yield frequency diagrams.

Table 10: Summary of borehole yield distributions.

Aquifer Unit	Total dry boreholes	Total wet boreholes	% dry boreholes	0-0.01 (ℓ/s)	0.1-0.5 (ℓ/s)	0.5-2 (ℓ/s)	2-5 (ℓ/s)	>5 (ℓ/s)
Category A: Intergranular aquifers								
Q	14	240	6	4	10	23	21	43
Category B: Fractured aquifers								
Trb	9	23	39	35	30	30	0	4
P-Trs								
Pe	42	285	15	18	26	37	15	5
C-Pd	10	81	12	19	19	40	17	6
Mge	0	6	0	17	0	67	17	0
Ms	9	19	47	16	26	37	5	16
Mw	814	4198	19	17	27	35	15	6
Mko	1	1	100	0	0	100	0	0
Mpa	4	19	21	16	21	26	26	11
Mz	8	8	100	0	38	50	0	13
Vb	34	300	11	13	26	39	17	5
Vrg	16	34	47	12	21	44	24	0
Vp	4	8	50	0	25	50	25	0
Vh	17	23	74	13	26	35	9	17
Vbl	0	9	0	0	0	44	44	11
Rp	4	18	22	0	25	50	25	0
Vw	13	51	25	10	10	33	31	16
R-Vbo								
Rp	4	18	22	0	25	50	25	0
Category C: Karst aquifers								
Vh	61	207	29	28	15	28	16	13
Category D: Intergranular and Fractured aquifers								
Jl	126	2114	6	3	8	21	25	44
Trc	128	917	14	9	26	32	17	16
P-Tri	23	161	14	15	35	29	13	8
Pe	28	301	9	11	17	36	16	20
N-Zd	101	345	29	14	26	37	16	7
Msp	7	14	50	0	0	29	21	50
Ms	26	106	25	9	12	30	25	23
Mle	288	638	45	23	26	32	11	8
Vr	224	464	48	13	18	31	19	19
Vp	129	487	26	17	21	30	16	15
Vco	17	30	57	23	20	40	17	0
Vnh	4	25	16	32	32	24	12	0
Vtu	21	156	13	12	24	40	15	10

Table 10: Summary of borehole yield distributions.

Aquifer Unit	Total dry boreholes	Total wet boreholes	% dry boreholes	0-0.01 (ℓ/s)	0.1-0.5 (ℓ/s)	0.5-2 (ℓ/s)	2-5 (ℓ/s)	>5 (ℓ/s)
Category D: Intergranular and Fractured aquifers								
Vz	1	3	33	33	33	33	0	0
Rat	4	19	21	6	6	50	11	26
Rmo	4	48	8	4	15	23	44	15
Rhu	No data							
Rma	13	34	38	35	21	15	26	3
Rlu	7	41	17	46	27	22	5	0
Rut	7	8	88	25	50	13	13	0
Rui	0	5	0	60	40	0	0	0
Rge	4	18	22	17	33	33	11	6
Rga	94	155	61	36	30	23	10	2
Rp	1	9	11	22	0	33	22	22
Rka	4	30	13	50	13	17	17	3
Rk	36	54	67	37	30	19	9	6
Rho	140	2266	6	4	5	17	20	54
Zmo	No data							
Zbm								
Zgo	295	1242	24	9	17	33	25	15
Z								
Zbo	30	35	86	31	23	40	3	3
Zba	210	674	31	19	20	31	19	10
Zbg	21	33	64	19	48	24	5	5
Zga								
Zp	13	134	10	4	5	28	21	42
Zz	556	938	59	28	20	36	12	4
Total:	3626	**17052**	**21%**					

7.1 PRIMARY AQUIFERS

7.1.1 CATEGORY A: INTERGRANULAR AQUIFERS

7.1.1.1 Tertiary-quaternary alluvial deposits (Q)

Groundwater occurs in tertiary-quaternary alluvial deposits of limited lateral extent and thickness along most river terraces in the map area. Accumulatively it only covers approximately 1.7% of the total map area (Figure 8). In general the alluvium consists of a clay/silt layer overlying poorly to well-sorted sand and gravel layers. Thicknesses of up to 30m have been found along the Sand River at the Mara Research Station but in general it seldom exceeds 20m.

With the exception of cases such as along the Limpopo, Mokolo, Lephalale, Sand (mostly from boreholes), and Diep Rivers where sand points have been installed in places, the alluvial aquifers in the map area are mostly utilized in conjunction with the underlying weathered and fractured bedrock aquifers. Water levels respond quickly during recharge events i.e. when the rivers flow. Due to its limited extent laterally and vertically the aquifers are vulnerable to over-abstraction especially during periods of drought when rivers are dry or with limited flow that influence the recharge to the aquifers. The well field at the Mara Research Station is an example where the alluvial aquifer is being depleted due to lack of recharge. Borehole yields are generally high.

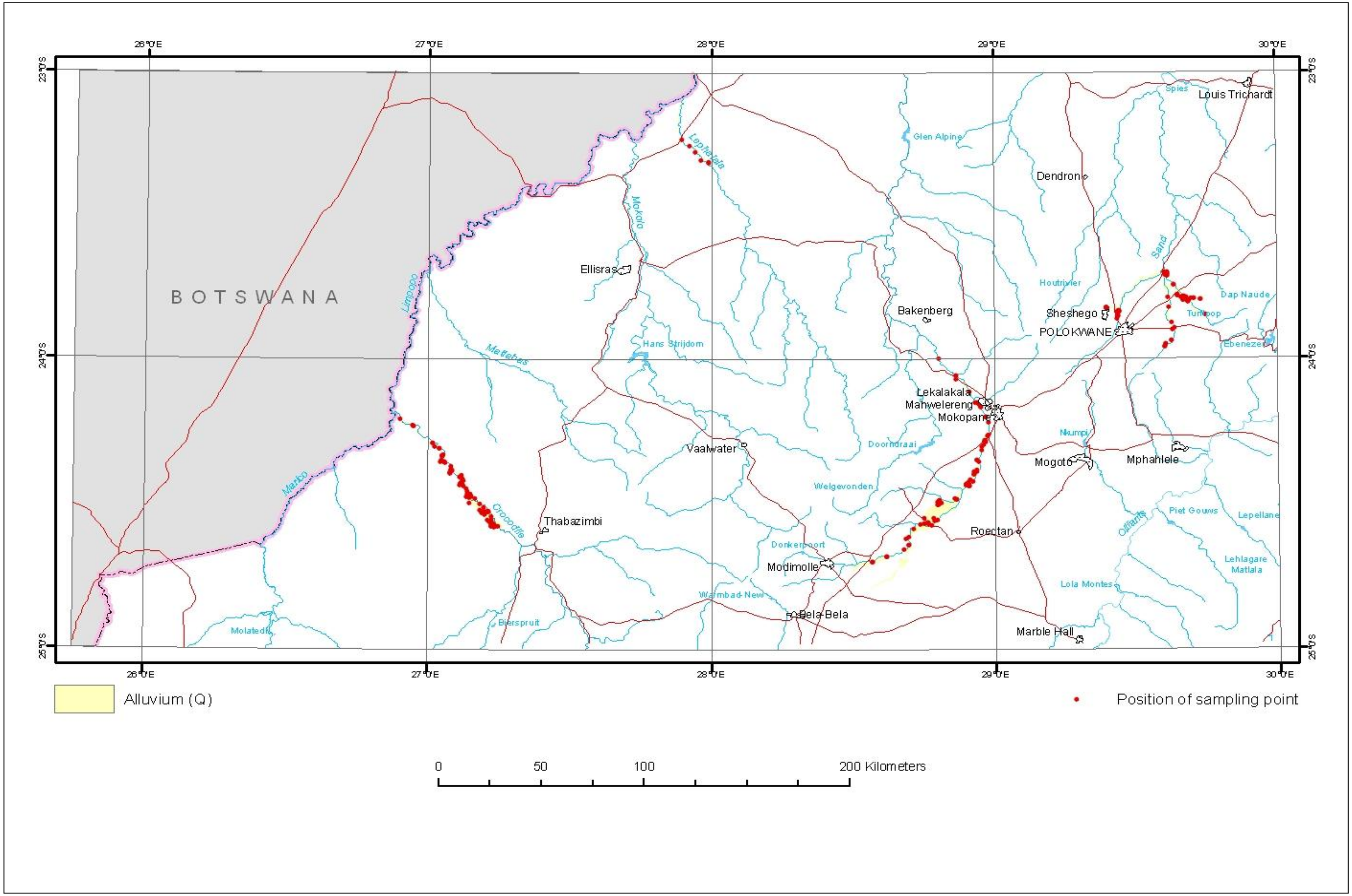

Figure 8: Geographical distribution of the intergranular aquifers (Q) and the associated groundwater sampling points

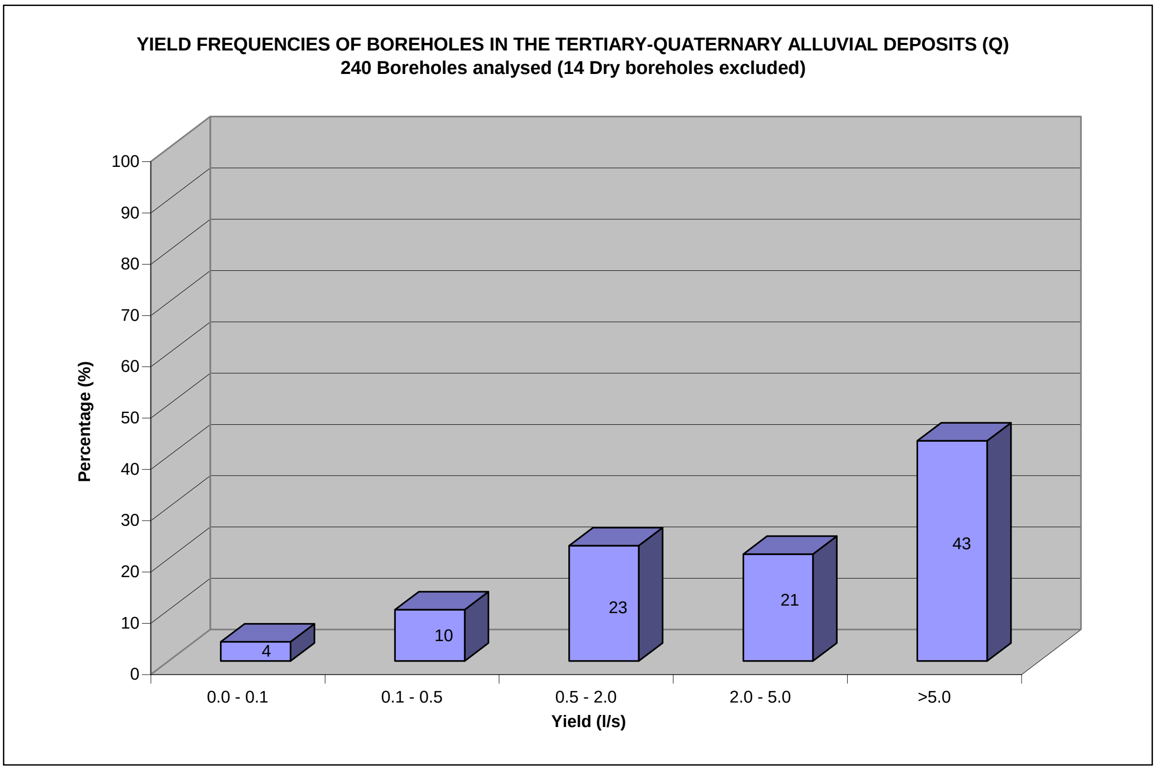

Figure 9: Yield frequency for Tertiary-Quaternary alluvial (Q) aquifers.

Figure 9 is a representative yield frequency diagram of yields within the alluvial aquifers. The diagram shows that existing borehole yields are generally high with 43% of the successful boreholes in excess of 5 ℓ/s.

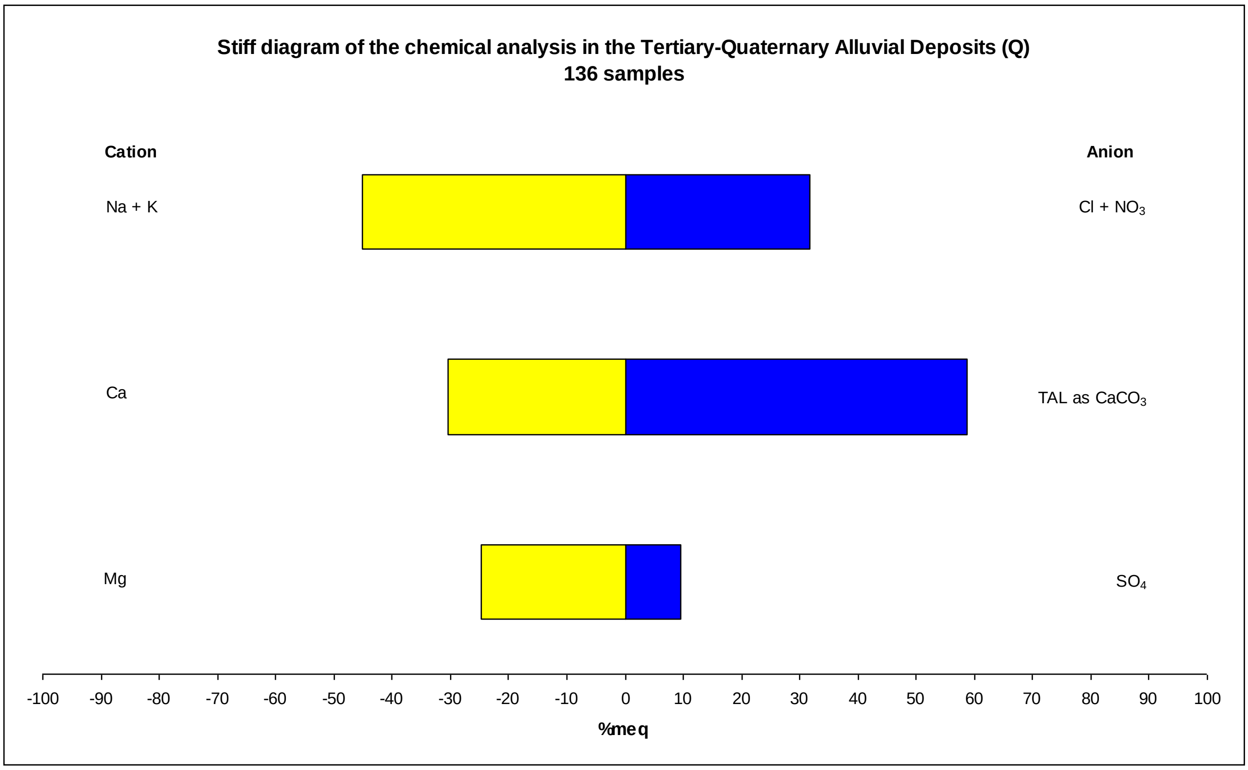

Figure 10: Stiff diagram representing chemical analysis of the alluvial deposits (Q)

Groundwater abstracted from these aquifers is mainly utilized for domestic and irrigation purposes. Water quality is good with electric conductivity (EC) values varying between 7.9 and 338mS/m in

95.6% of the analysis with 75mS/m calculated as the Harmonic mean. Elevated concentrations of nitrate (N >6mg/l) in 18% and fluoride (F >1mg/l) in 26% of the analysis occurs. Figure 10 is a plot of the dominant anions/cations present. Depending on the location, the water is either a Calcium-Magnesium-Bicarbonate or Sodium-Bicarbonate or Chloride water. (See also section 6).

7.2 SECONDARY AQUIFERS

Consolidated hard rocks cover virtually all (± 98.3%) of the map area. The rock mass was formed over a period of 3800 million years which 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 vary between Karst, fractured and intergranular & fractured.

7.2.1 CATEGORY B: FRACTURED AQUIFERS

- Bosbokpoort Formation (Trb)
- Solitude Formation (P-Trs)
- Ecca Group (Pe), (Clastic sediments)
- Dwyka Group (C-Pd)
- Glenover Complex (Mge)
- Soutpansberg Group (Ms), (Quartzite & sandstone)
- Waterberg Group (Mw)
- Koedoesrand Formation (Mko)
- Palala Granite (Mpa)
- Unnamed Mokolian Rocks (Mz)
- Rooiberg Group (Vb)
- Rashoop Suite (Vrg)
- Pretoria Group (Vp), (Conglomerate, sandstone and quartzite)
- Chuniespoort Group (Vp), (Banded ironstone)
- Black Reef Formation (Vbl)
- Wolkberg Group (Vw)
- Bothaville Formation (R-Vbo)
- Platberg Group (Rp), (Quartzite)

The geographical distribution of the fractured rock aquifers is shown as Figure 11.

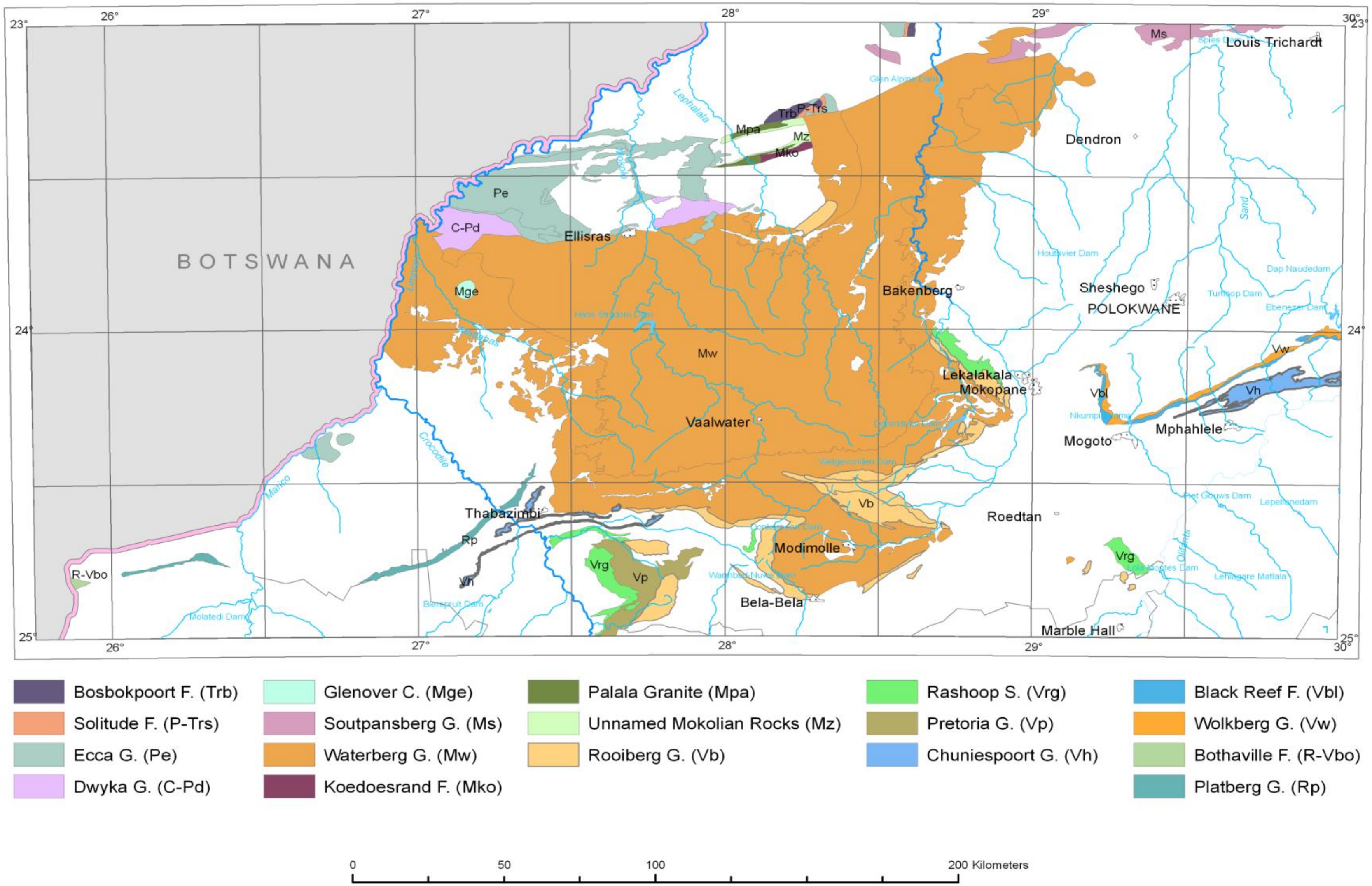

Figure 11: Geographical distribution of the fractured rock aquifers

7.2.1.1 BOSBOKPOORT FORMATION (Trb)

The Bosbokpoort Formation comprises a red massive mudstone to very fine grained sandstone which has a thickness of at least 45m. The unit occurs in two cluster areas, the biggest approximately 15km east of Baltimore and bounded on the south by the Melinda fault. The second smaller cluster is 5km southeast of Zwartwater.

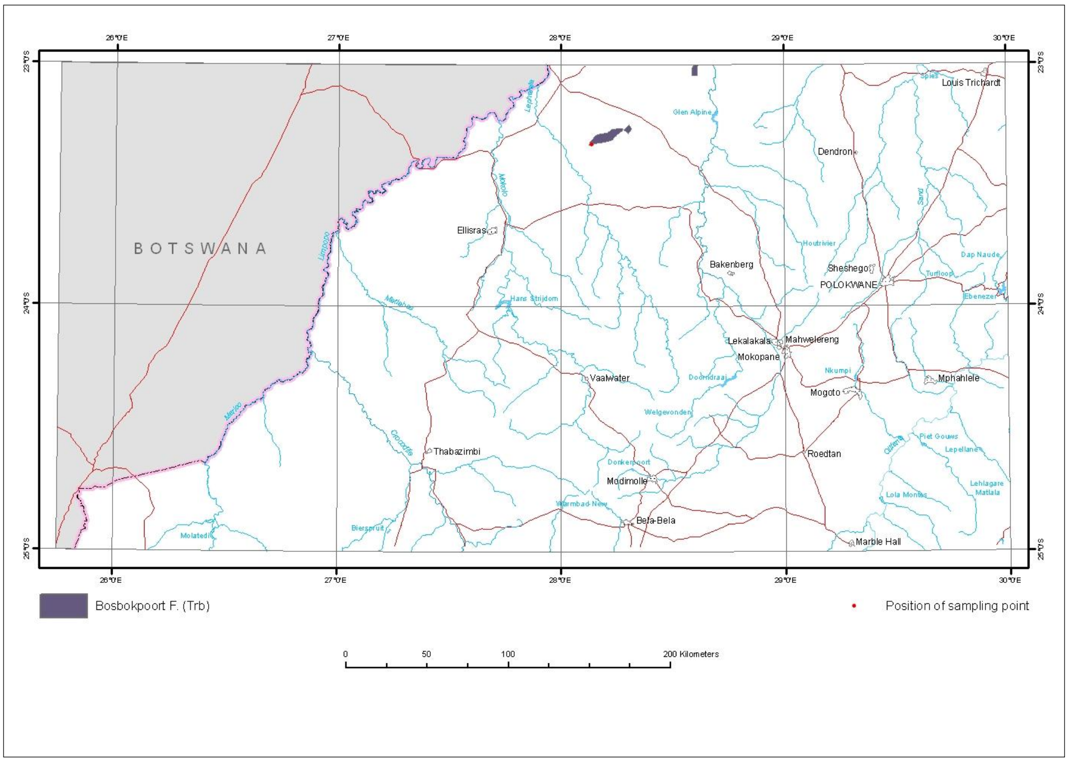

Figure 12: Geographical distribution of the Bosbokpoort Formation (Trb) and the associated groundwater sampling points

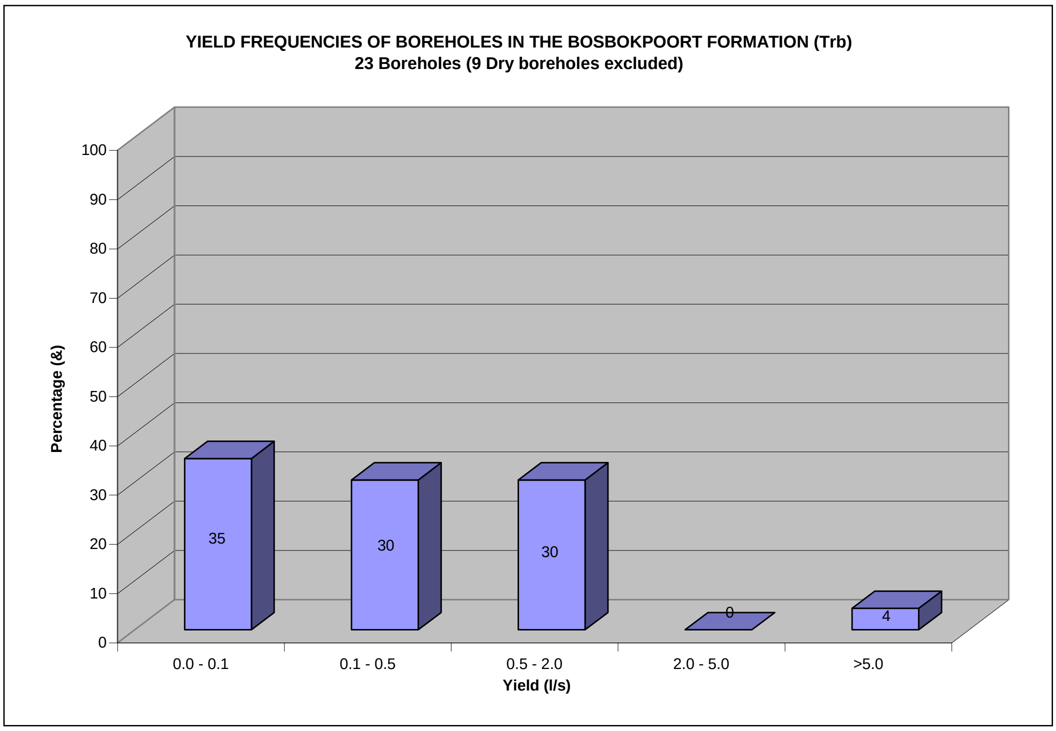

Figure 13: Yield frequency for fractured aquifers of the Bosbokpoort Formation (Trb).

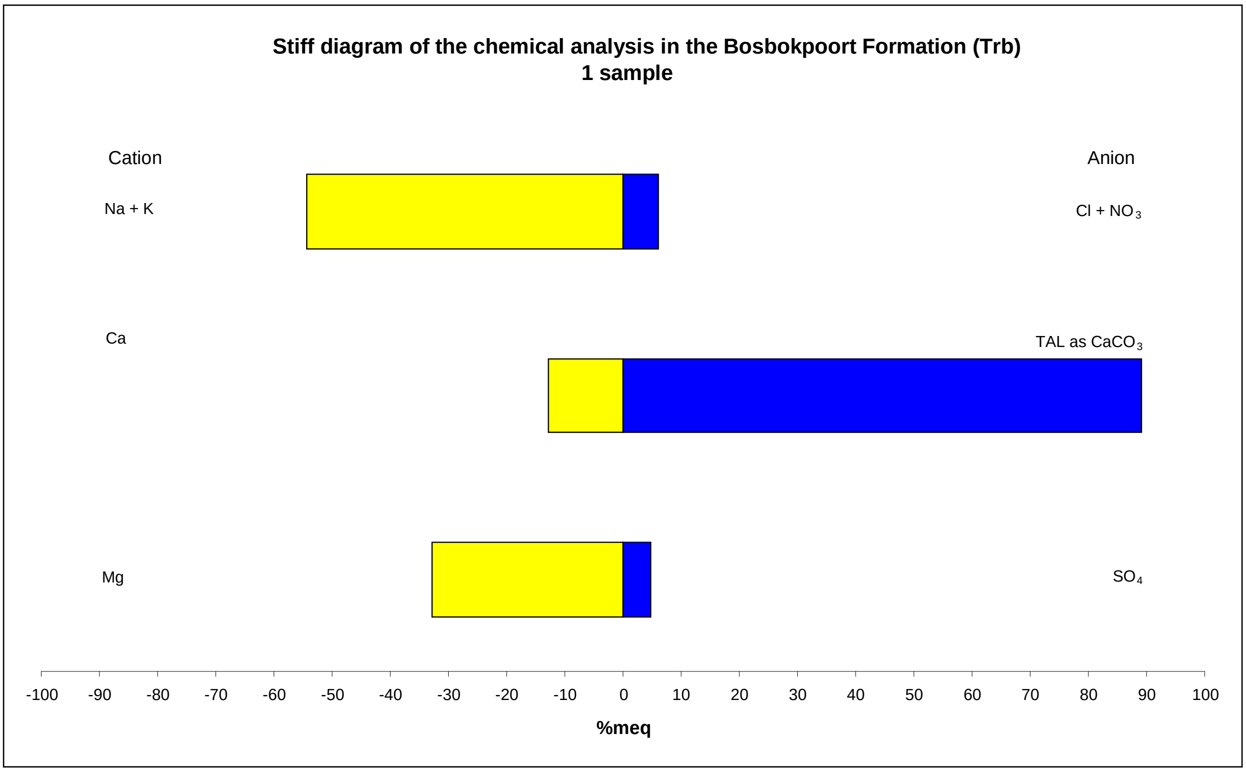

Figure 14: Stiff diagram representing chemical analysis of the Bosbokpoort Formation (Trb)

The unit is a poor aquifer as available information indicates 39% of the existing boreholes to be dry and 65% of the successful boreholes yielding less than 0.5 ℓ/s. Rocks from this formation have a low to very low primary permeability with low storage potential. Water is generally obtained in fractures and joints locally developed bedding plains, contact zones between sediments, faults and associated shear zones. Contact zones with intrusive dolerite sills and dykes where present can also be targeted in the search for groundwater. From the stiff diagram representing the chemical analysis of one sample, (Figure 14), the water is of a sodium-magnesium-bicarbonate water type. Groundwater in this formation is usually abstracted for domestic and farming purposes.

7.2.1.2 SOLITUDE FORMATION (P-Trs)

Rocks of the Solitude Formation occur in the same areas on the map sheet as the Bosbokpoort formation (Figure 15). It consists of massive dark-grey, red and purple mudstone with scattered silty and sandy beds. In the Tolwe area it has a thickness of about 50m and in the Marnitz area it is approximately 20m thick.

Neither yield nor chemical data is available for boreholes in this formation. Water is generally obtained in fractures and joints locally developed along bedding planes, contact zones between sediments, faults and associated shear zones. Dolerite intrusions in the form of dykes and sills also created secondary fractures and joints at the contact with the host rock which can be targeted for successful groundwater development.

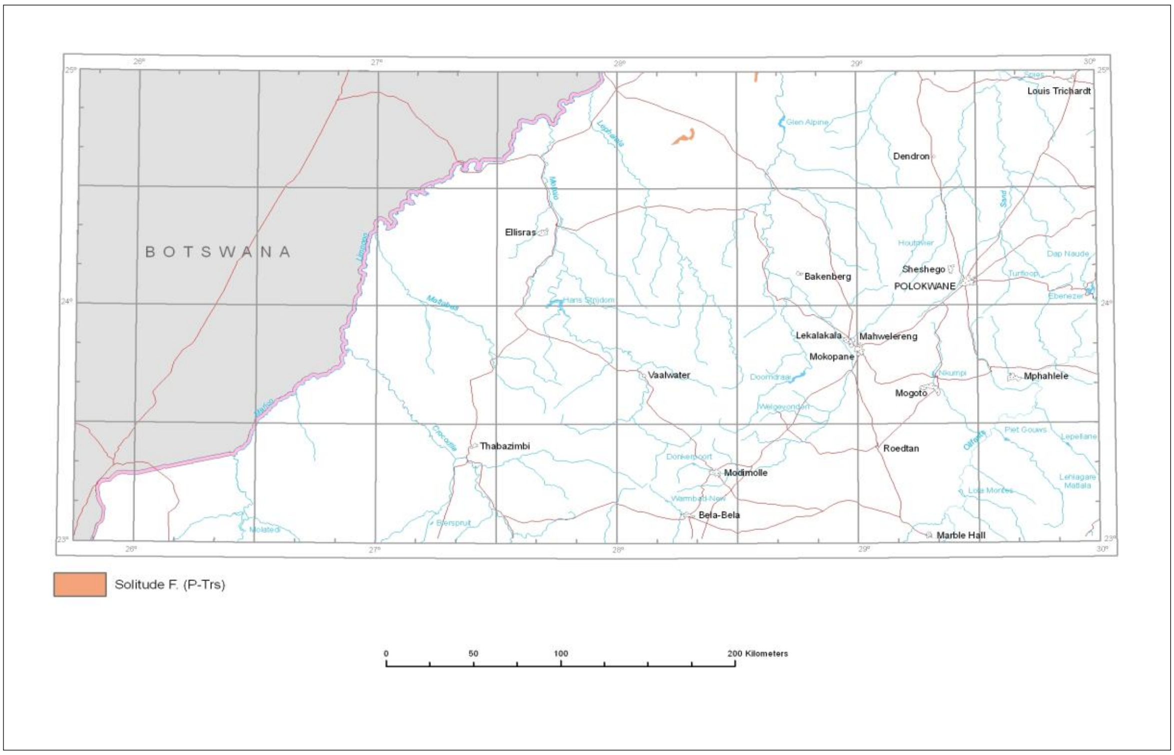

Figure 15: Geographical distribution of the Solitude Formation (P-Trs)

7.2.1.3 ECCA GROUP (Pe) (Clastic sediments)

The Ecca Group (Pe) appears on the map as fractured and as intergranular and fractured aquifers respectively. The latter is described in section 7.2.3.4. The **fractured unit** occurs as scattered clusters in the Lephalale (Ellisras) area (Figure 16). It consists predominantly of fine grained clastic sediments of the Lisbon, Eendragtpan, Grootegeluk, Goedgedacht and Swartrant Formations.

Exploration for groundwater in this unit includes targets such as the various northeast and northwest trending fault zones, bedding plane contacts and the contact with the underlying Waterberg Group delineated by the east-west trending Eenzaamheid fault zone. Future and current mining of coal will be the main activity influencing groundwater in this unit.

The analysis of 285 borehole records indicates that 37% of the yields are between 0.5 and 2ℓ/s. 44% are less than 0.5ℓ/s and 20% are more than 2ℓ/s, (Figure 17). The quality of the water is moderate to poor with EC values ranging between 52-625mS/m with a harmonic mean of 121mS/m. The general water quality also tends to vary over short distances. The water displays a sodium-calcium-chloride nature. In section 6 the unit is referred to as a chloride type with reverse ion exchange (replacement of Na^+ with Ca^{2+} and Mg^{2+}). Elevated concentrations of sulphate, chloride, fluoride and calcium occur especially in the Grootegeluk Formation.

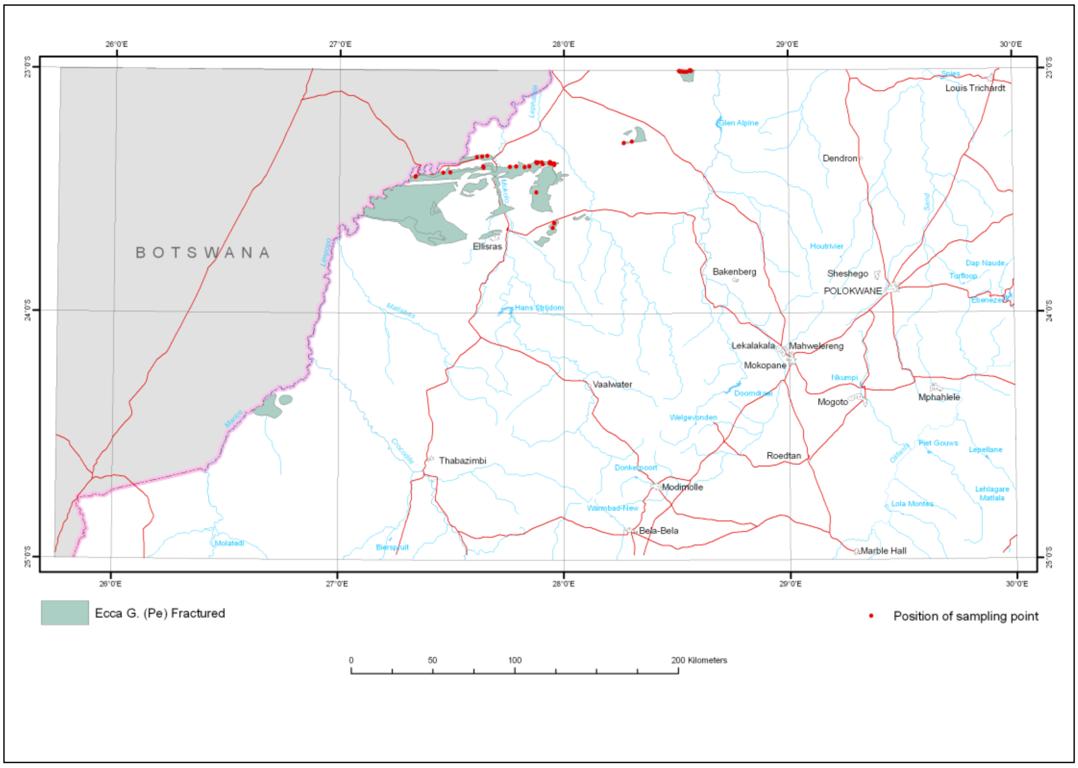

Figure 16: Geographical distribution of the Ecca Group (Pe) (clastic sediments) and the associated groundwater sampling points.

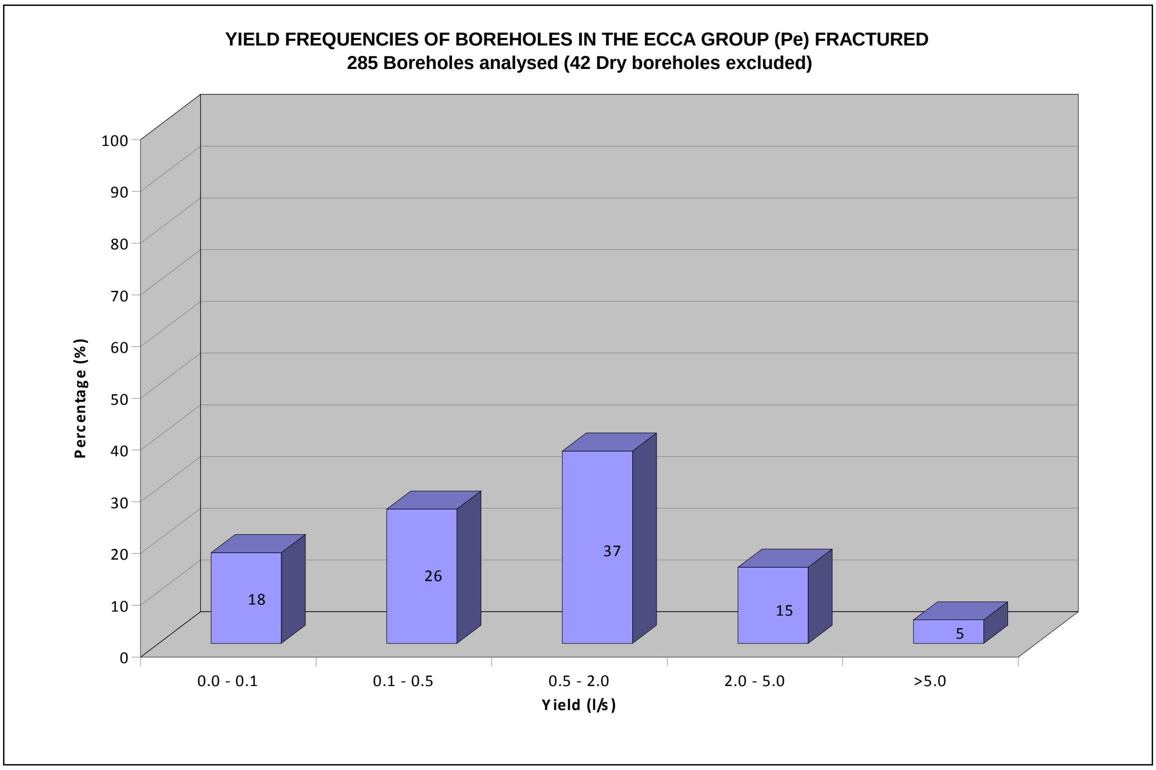

Figure 17: Yield frequency for fractured aquifers of the Ecca Group (Pe) (clastic sediments).

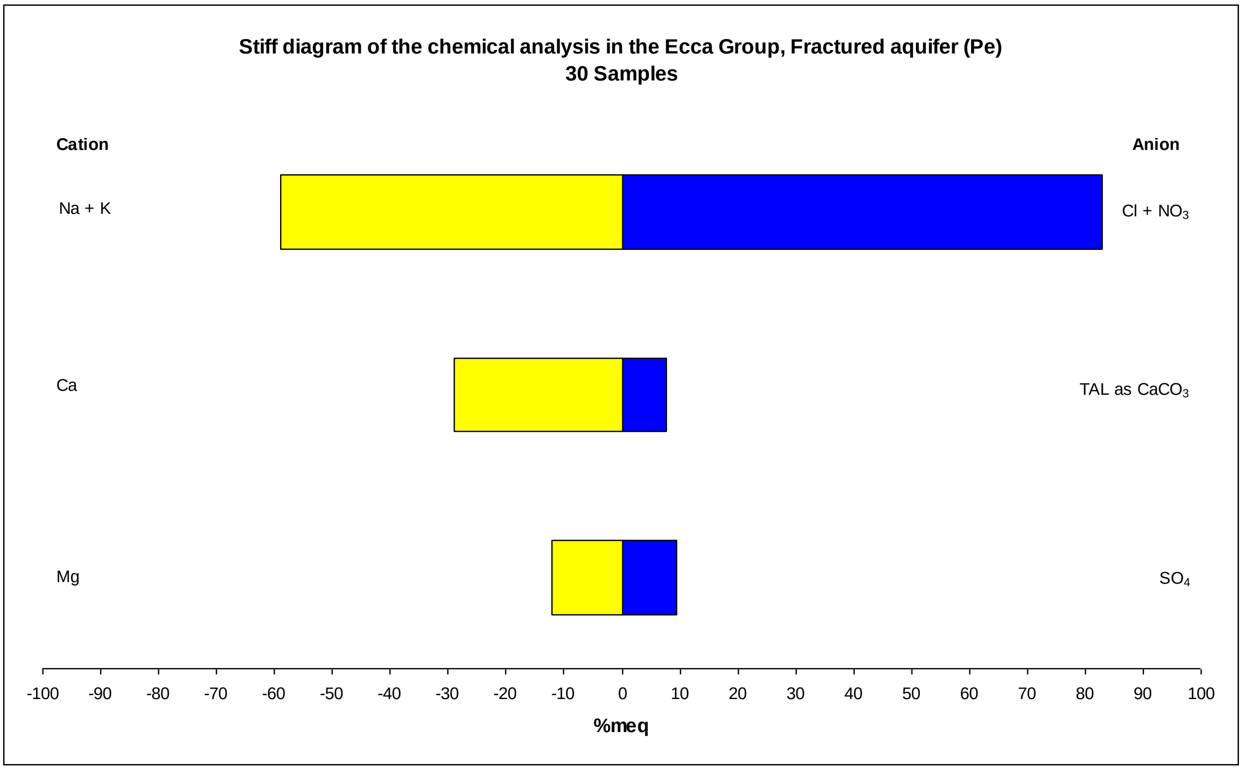

Figure 18: Stiff diagram representing chemical analysis for the Ecca Group (Pe) (clastic sediments)

7.2.1.4 DWYKA GROUP (C-Pd)

The principal rock type of this group is diamictite, mudstone, siltstone and minor grit and sandstone. Two clusters occur east and west of Lephalale (Ellisras) respectively (Figure 19).

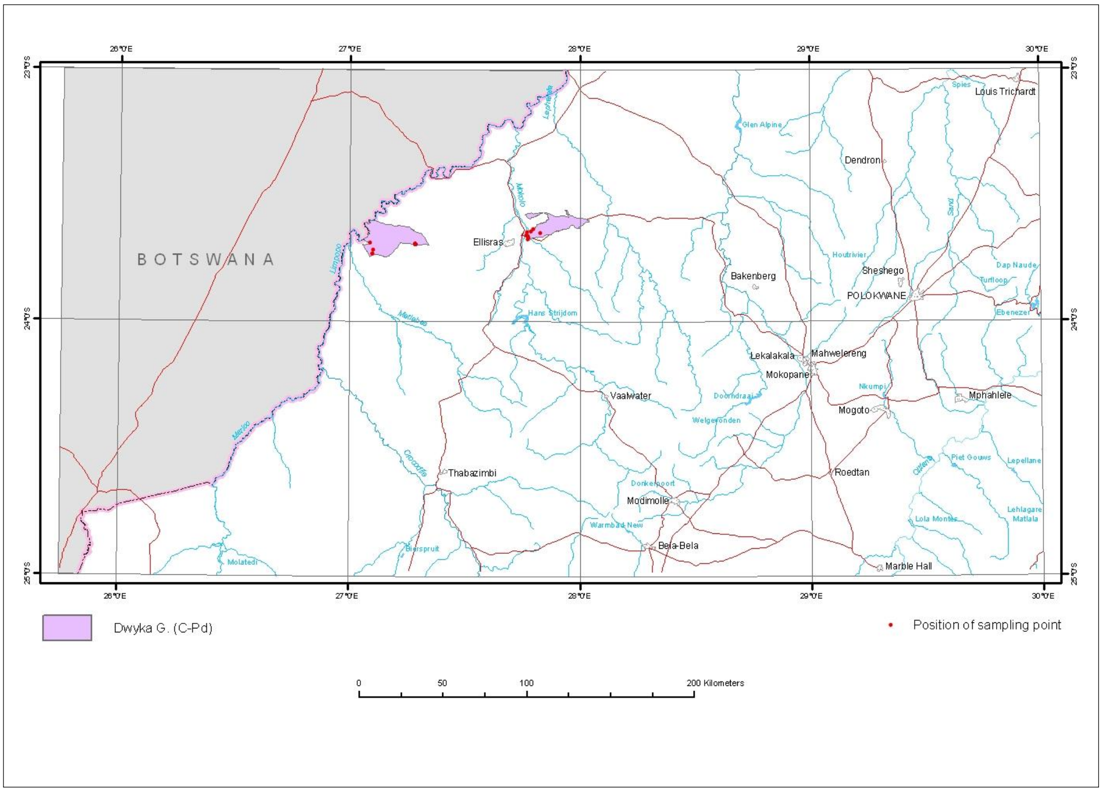

Figure 19: Geographical distribution of the Dwyka Group (C-Pd) and the associated groundwater sampling points

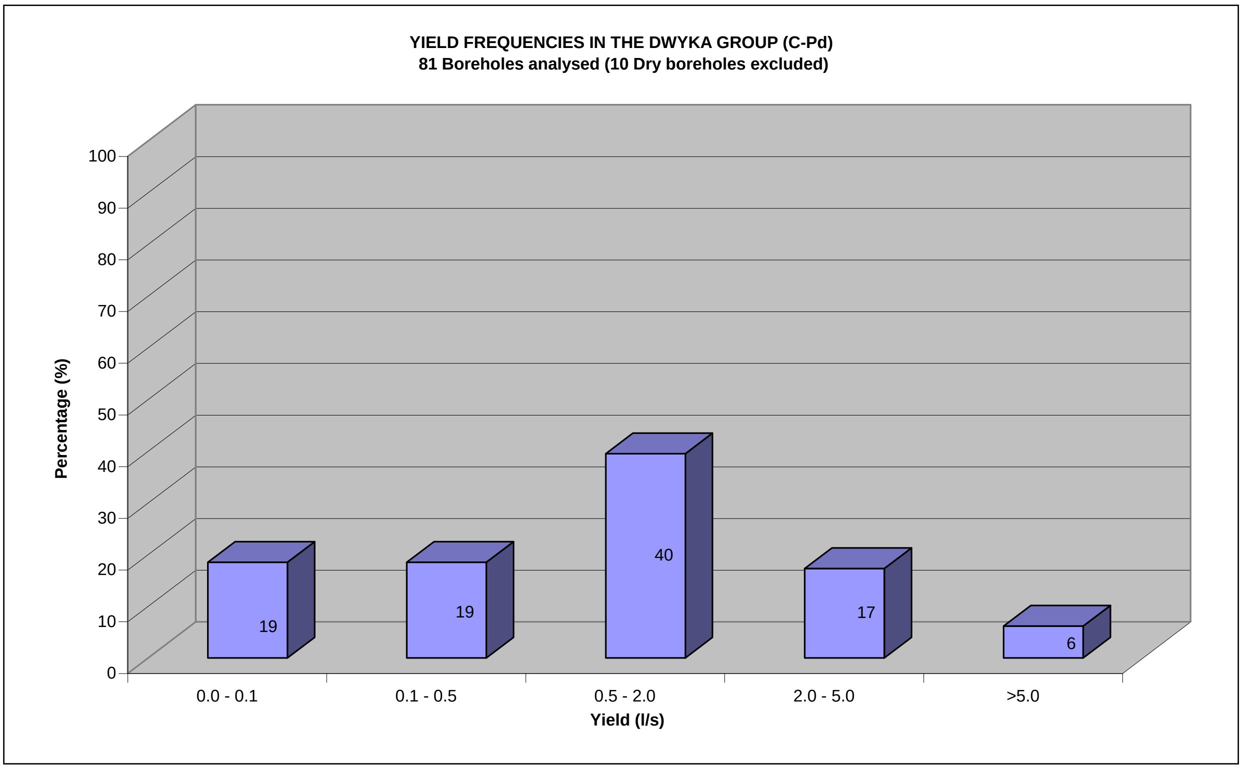

Figure 20: Yield frequency for fractured aquifers of the Dwyka Group (C-Pd)

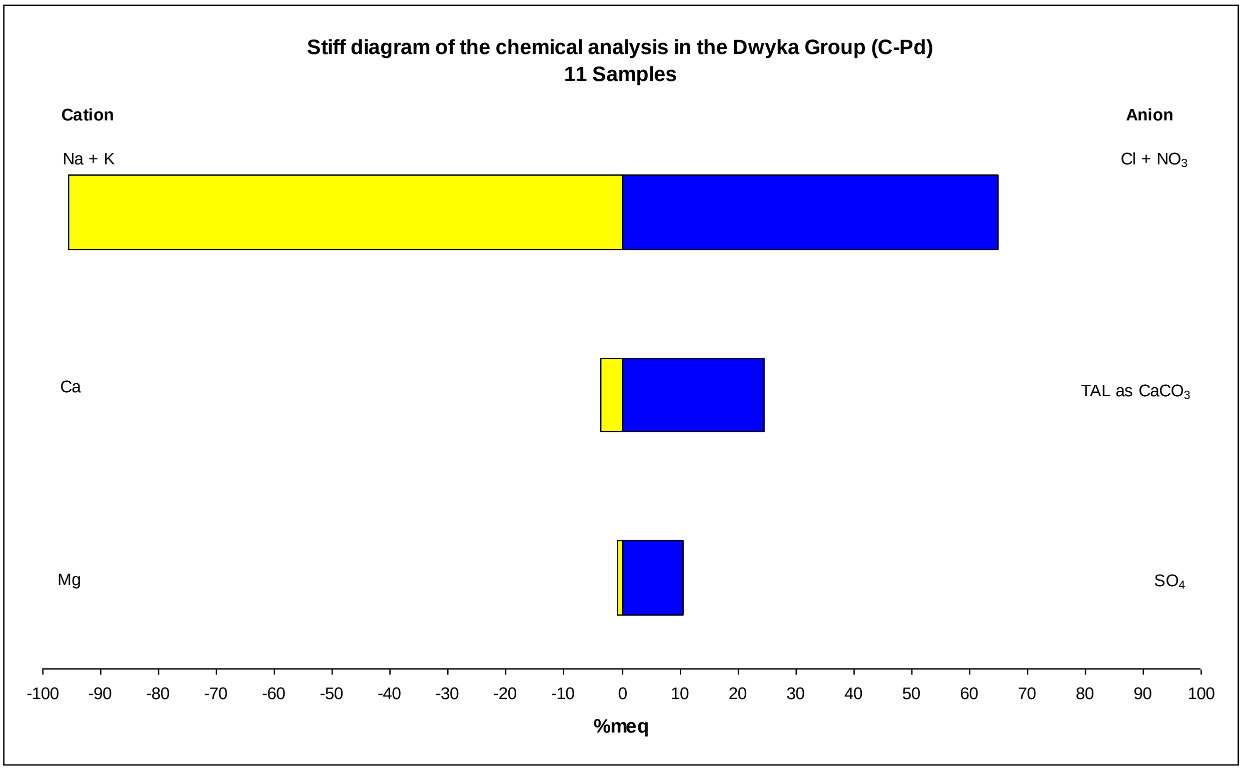

Figure 21: Stiff diagram representing chemical analysis of the Dwyka Group (C-Pd)

The yield frequency distribution (Figure 20) indicates that 40% of the successful boreholes yield between 0.5 and 2ℓ/s and 38% less than 0.5ℓ/s. Similar to the Bosbokpoort and Solitude Formations, groundwater occurs in fractures and joints developed along bedding planes, contact zones between sediments, faults and associated shear zones. During intrusion and subsequent cooling of intrusive rocks (predominantly dolerite), secondary fractures might developed at the contact with the host rock that can be targeted in the development of groundwater sources. The water is of a sodium-chloride-bicarbonate type (Figure 21). EC values vary between 143-665mS/m with a Harmonic mean of 167mS/m. High Fluoride concentrations are reported in the cluster occurring east of Ellisras (Lephalale) and elevated concentrations of nitrate and nitrite expressed as N are reported in the western cluster. The water is abstracted for domestic purposes, stock watering, and where the quality allows it, for small scale irrigation.

7.2.1.5 GLENOVER COMPLEX (Mge)

The Glenover Complex forms a circular ring structure approximately 90km northeast of Thabazimbi (Figure 22) and comprises a central breccia body consisting of biotite, pyroxenite and carbonatite surrounded by red and white fenite and fenitised sandstone. Excluding the latter, the intrusive body has a diameter of about 3500m. With the exception of the breccia body, which forms a small prominent ‘breccia hill”, the other lithologies of the Glenover Complex underlie flat country with only rare exposures. The name originates from one of the five farms underlain by the unit.

Although there is not sufficient yield data for a proper conclusion, the indication is that the Glenover Complex has a reasonable groundwater potential as 17% of the successful boreholes yield more than 2ℓ/s and 67% between 0.5 and 2ℓ/s (Figure 23).

Nine chemical samples are available but only two are acceptable if the plausibility of electro neutrality is used. Comparison of the harmonic mean (9 samples) and the plot of the stiff diagram (2 samples) resulted in more or less the same major cation and anion distribution. The EC value varies little in the 9 samples with a calculated arithmetic mean of 128mS/m and a harmonic mean of 115mS/m. The water displays a magnesium-sodium-bicarbonate-chloride character (Figure 24).

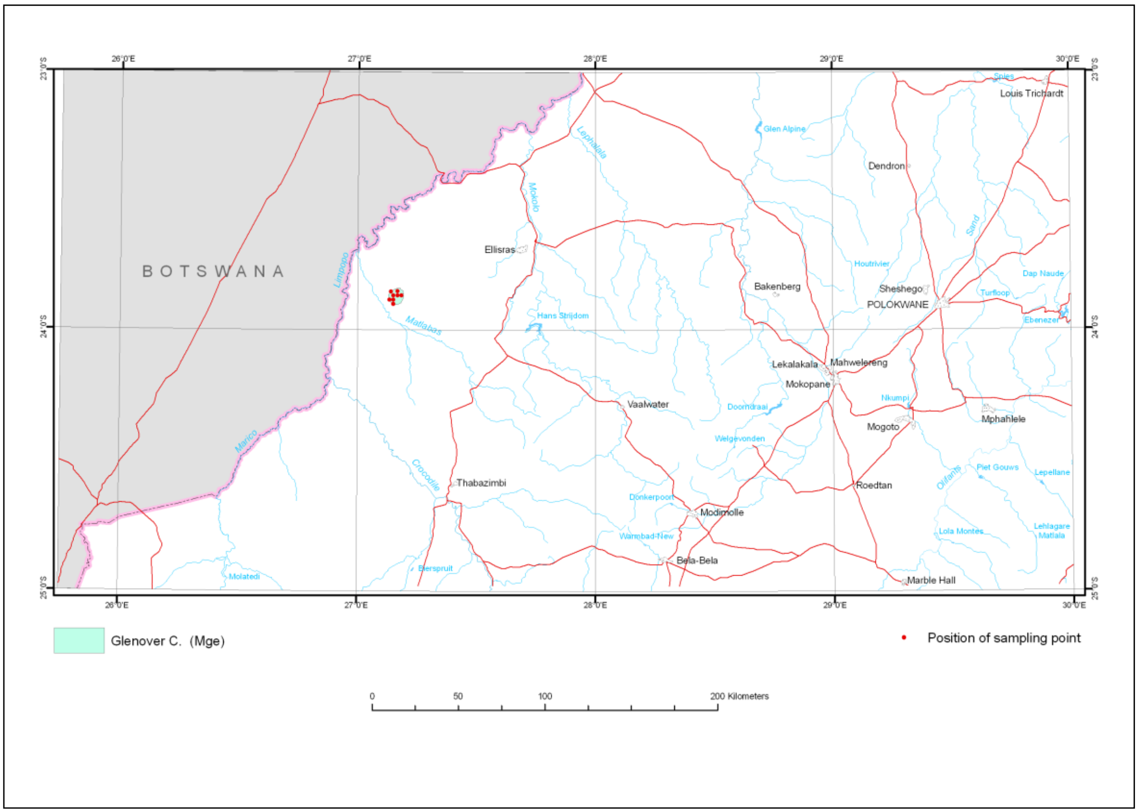

Figure 22: Geographical distribution of the Glenover Complex (Mge) and the associated groundwater sampling points.

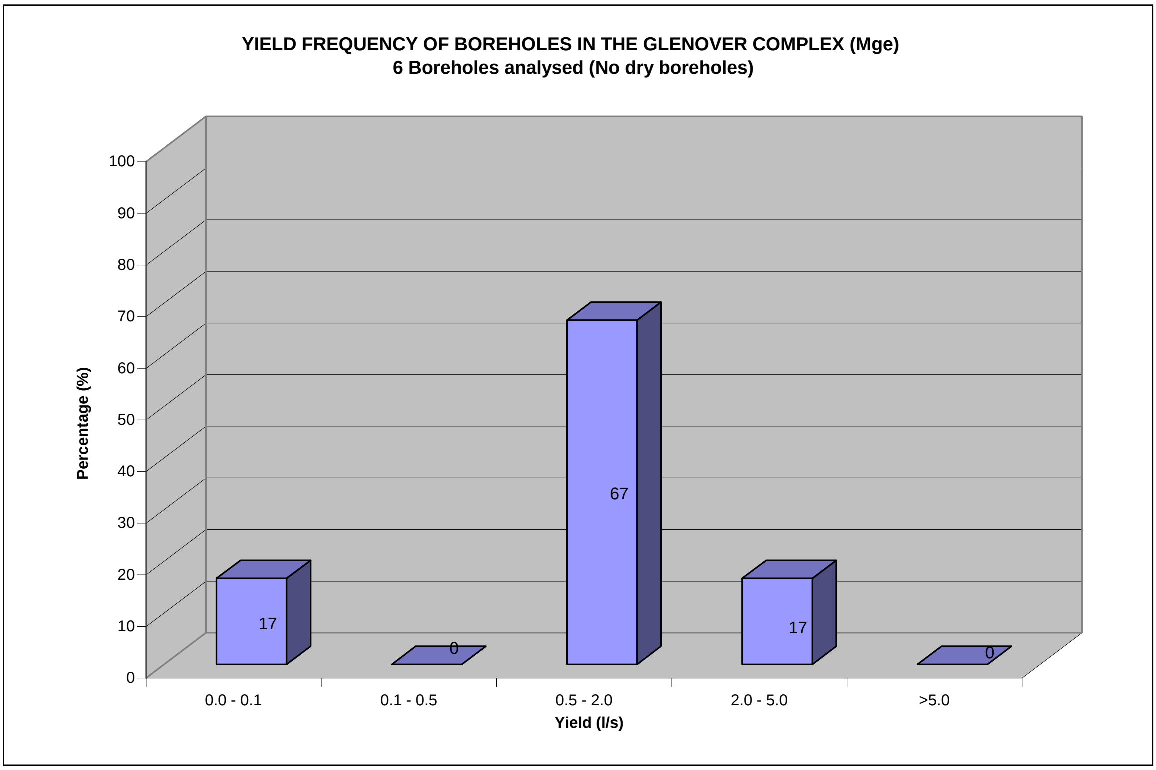

Figure 23: Yield frequency for fractured aquifers of the Glenover Complex (Mge).

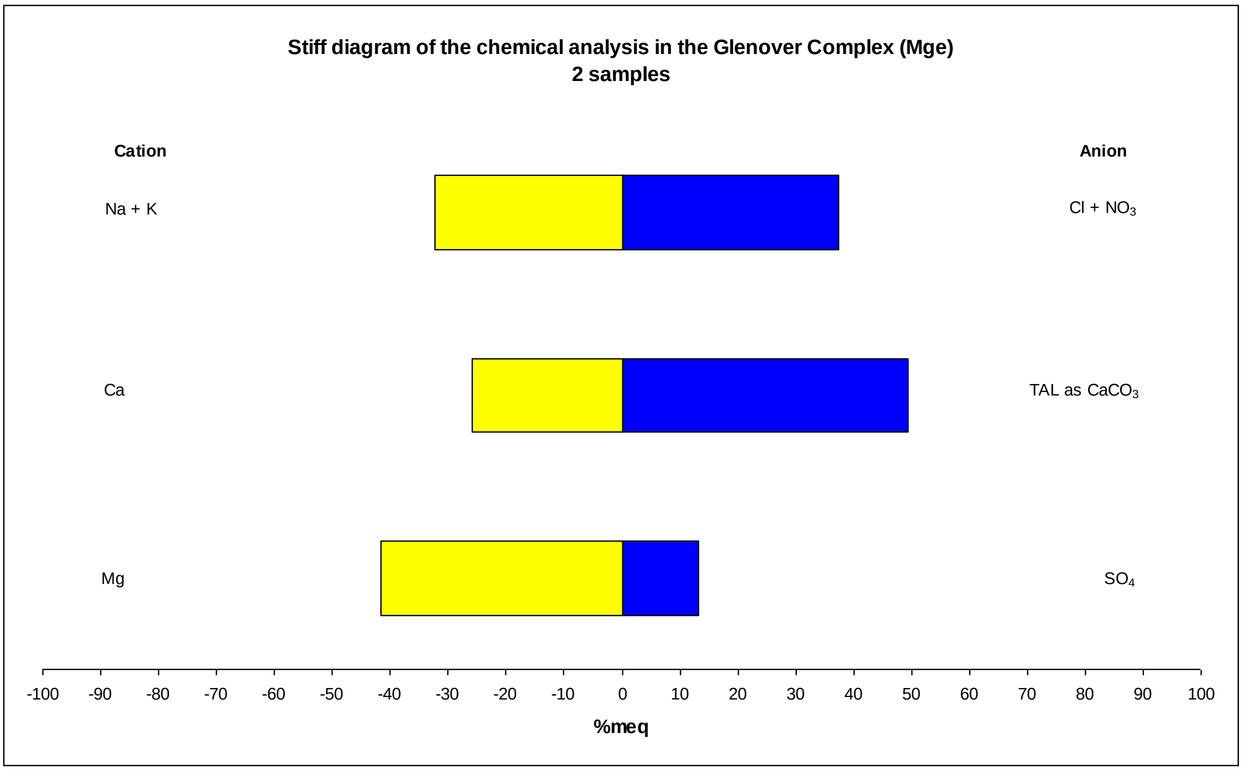

Figure 24: Stiff diagram representing chemical analysis of the Glenover Complex (Mge).

7.2.1.6 SOUTPANSBERG GROUP (Ms) (Quartzite and sandstone)

The Soutpansberg Group appears on the maps as fractured and as intergranular and fractured aquifers. The fractured aquifer (quartzite & sandstone) unit occurs north of Blouberg and Louis Trichardt respectively (Figure 25). It covers approximately 0.3% of the total map area and comprises mostly quartzite and sandstone with interbedded grit, conglomerate, shale, mudstone, siltstone and lava of the Wyllies Poort Formation.

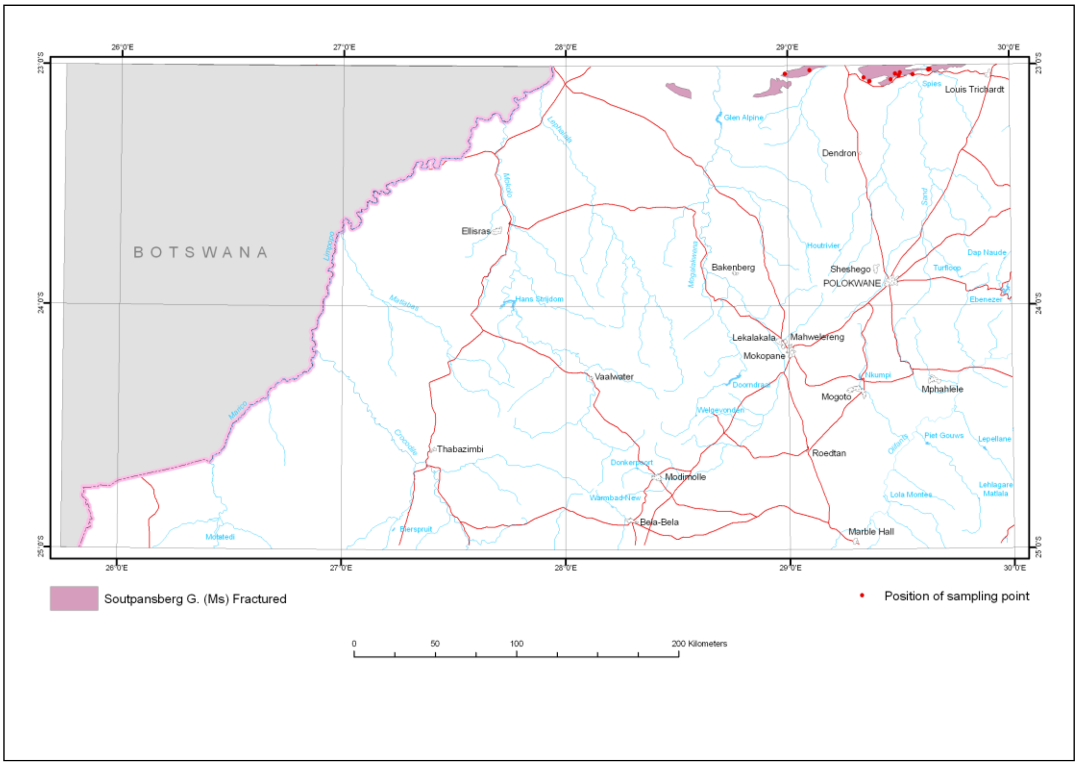

Figure 25: Geographical distribution of the Soutpansberg Group (Ms) (quartzite and sandstone) and the associated groundwater sampling points.

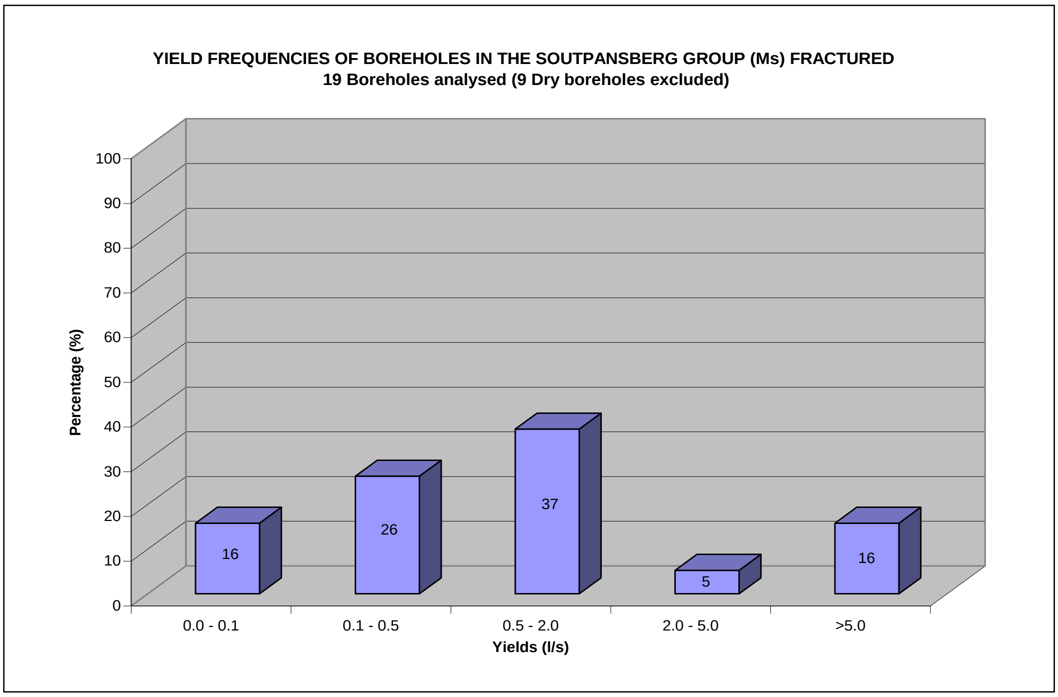

Figure 26: Yield frequency for fractured aquifers of the Soutpansberg Group (Ms) (quartzite and

sandstone).

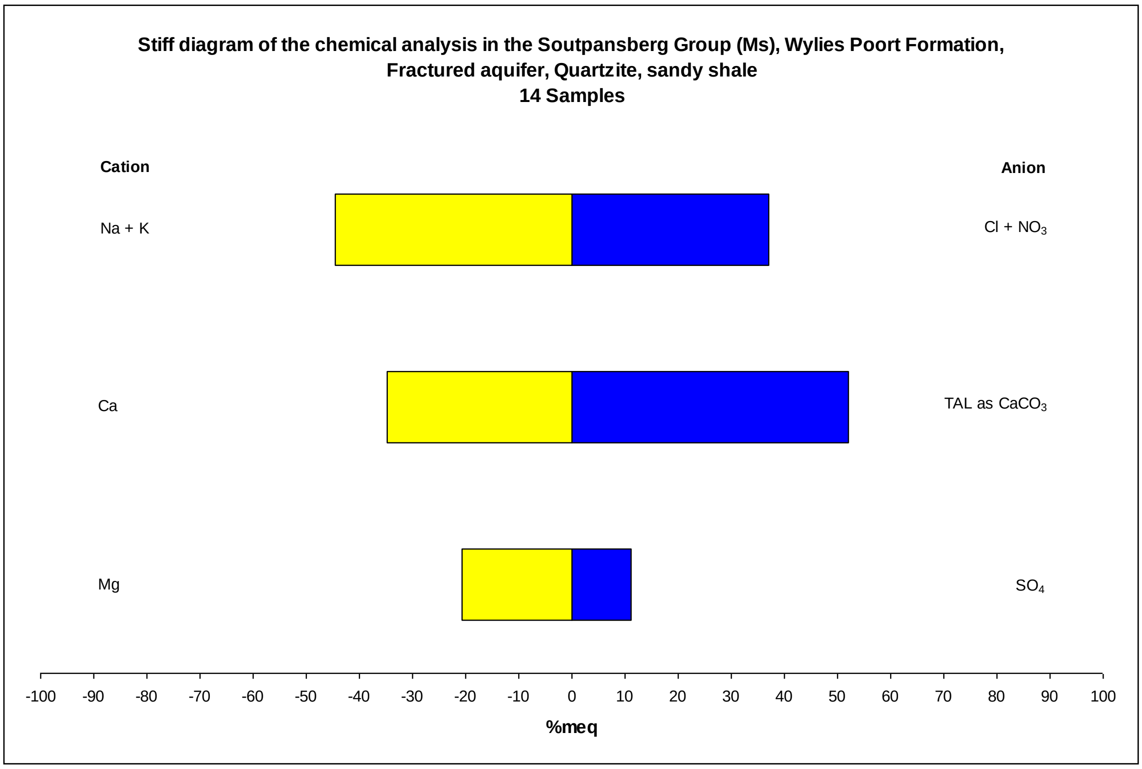

Figure 27: Stiff diagram representing chemical analysis of the Soutpansberg Group (Ms) (quartzite and sandstone)

Figure 26 indicates that the quartzite and sandstone of the Soutpansberg Group has a reasonable potential as 37% of the boreholes yield between 0.5 and 2ℓ/s and 21% more than 2ℓ/s. Numerous faults cut through the unit, which are also the main targets for good groundwater supplies. The water-bearing properties of this unit are in many respects similar to those of the Waterberg Group (Section 7.2.1.7).

The EC value varies between 53-177mS/m with the calculated arithmetic mean as 107mS/m and the harmonic mean as 62mS/m. 35% of the samples used in the analysis have nitrate and nitrite (presented as N) concentrations >10mg/l with the highest reported as 45.8mg/l. Poor sanitation practices in the rural areas combined with shallow sandy overburden and open fractures are contributing to the high values. Figure 27 shows the broad classification according to anions and cations. Groundwater in this unit is a sodium-calcium-bicarbonate-chloride water type.

7.2.1.7 WATERBERG GROUP (Mw)

The Waterberg Group occurs in two sedimentary basins of which only the Waterberg basin occurs on the map. It covers approximately 29.1% of the total map area. The basin is bounded on the southern side by the Waterberg and Sandriviersberg mountains and by Karoo rocks on the northern side, the contact being a fault (Figure 28).

Plate 1: Intensely fractured Mogalakwena Formation on the farm Klipfontein 797 LR, which consists of purplish brown, coarse grained sandstone with interbedded conglomerate and boulder conglomerate (Photograph: WH du Toit).

The basin has been sub-divided into three sub-groups viz. Nylstroom, Matlabas and Kransberg. The Koedoesrand Formation (Mko) which occupies a narrow strip to the north of Villa Nora is also part of the Waterberg Group, but is described as a separate unit in chapter 7.2.1.8. The Waterberg Group consists essentially of sandstone, conglomerate, shale, grit and siltstone. It has been intruded extensively by sills and dykes of predominantly diabasic composition. These diabase intrusions (N-Zd) play a major role in the occurrence of groundwater in the Waterberg Group. If dykes and sills are ignored, the groundwater potential of the Waterberg Group is generally low with 79% of yields <2ℓ/s (Figure 29).

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 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. 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 denser vegetation growth along the dykes. These can sometimes be traced for many kilometres. Where sills are weathered and fractured to extended depths below the water level, good supplies can be obtained from them (See also chapter 7.2.3.5). The permeability and storage capacity of the Waterberg Group are generally low. Yields tend to diminish quickly during periods of drought. The static water level varies between 30m up to 60m in places.

The yield frequency diagram (Figure 29) indicates that 35% of the successful boreholes yield between 0.5 and 2ℓ/s. 44% is yielding less than 0.5ℓ/s and 21% are yielding more than 2ℓ/s.

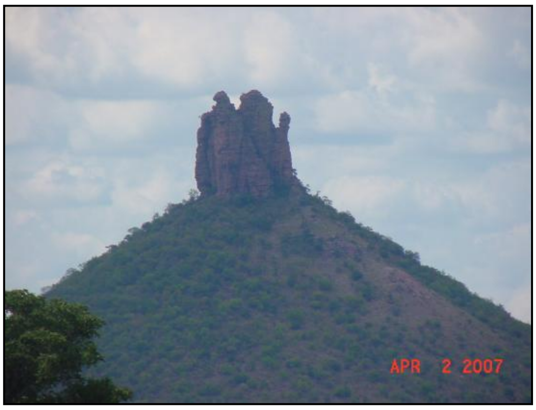

Plate 2 & Plate 3: Weathering of the sandstone of the Mogalakwena Formation produces extraordinary and beautiful scenery and rock shapes as illustrated in the photographs (Photograph: WH du Toit).

Plate 4: Bushman paintings engraved in sandstone of the Mogalakwena Formation on the farm Waterval 601 LQ south of Lephalale (Ellisras) (Photograph: WH du Toit).

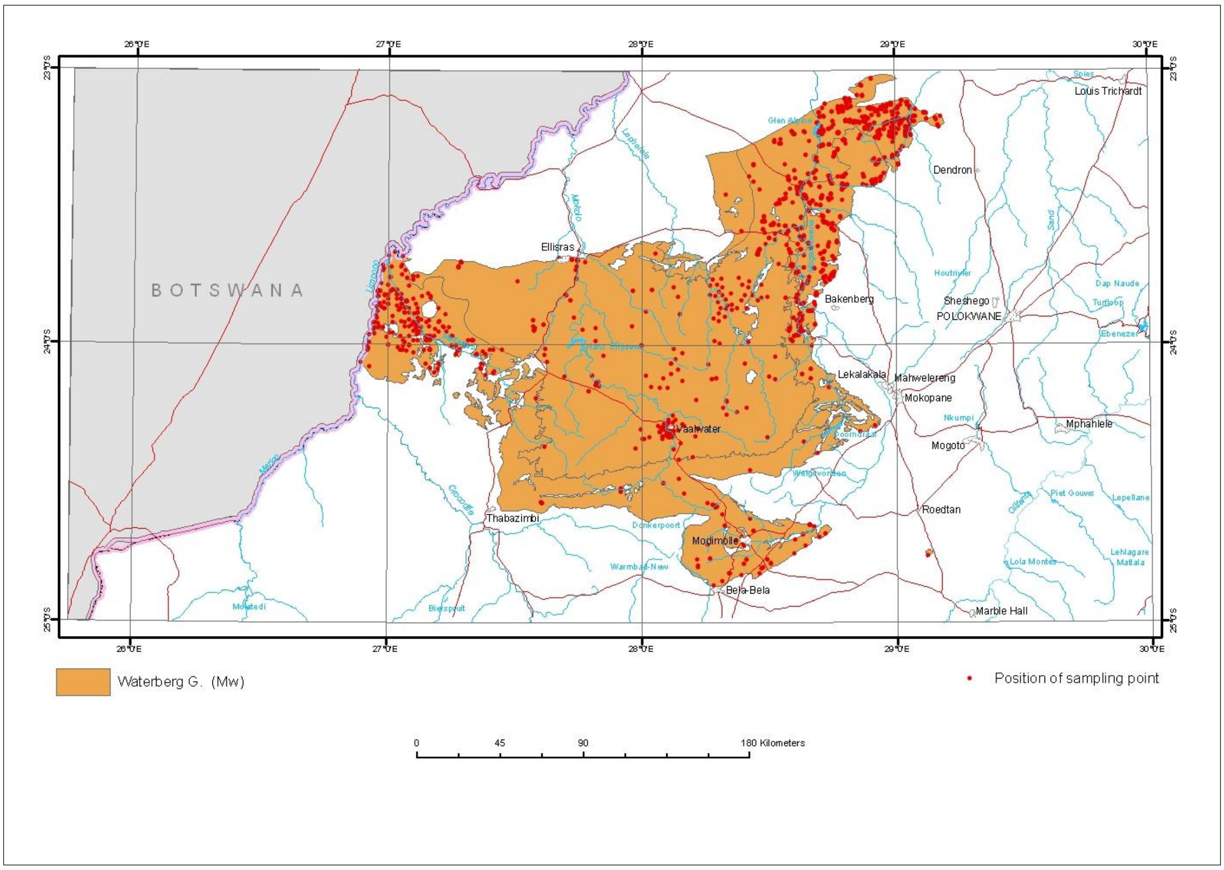

Figure 28: Geographical distribution of the Waterberg Group (Mw) and the associated groundwater sampling points

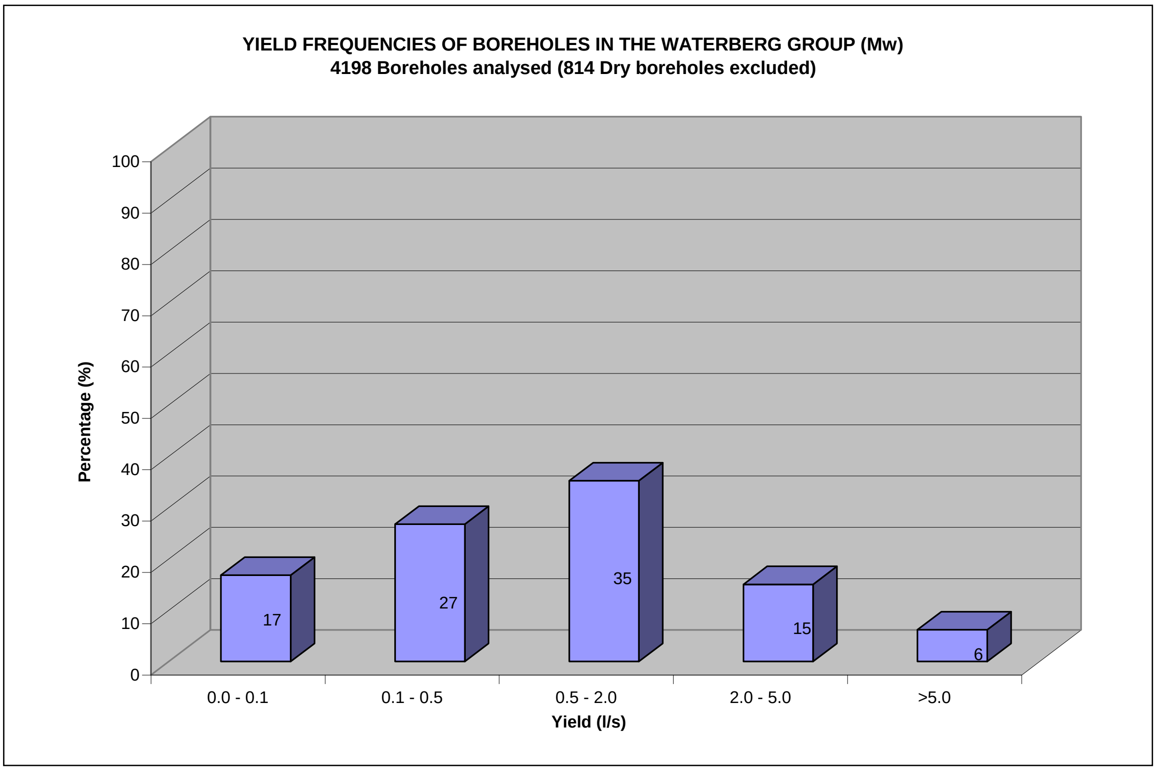

Figure 29: Yield frequency for fractured aquifers of the Waterberg Group (Mw).

Groundwater is abstracted for livestock watering, domestic purposes and to a lesser extent for irrigation. It is also the only water source available for small towns like Vaalwater and Alma whereas in larger towns such as Modimole (Nylstroom), groundwater supplements the surface water supply to a large extent.

The quality of the water is not the same throughout the unit. EC values in the Claremont Formation in the vicinity of Vaalwater are between 2-50mS/m. In the central area roughly between Vaalwater, Marken and Ellisras (Lephalale) EC values are between 10-400mS/m with average values increasing towards the Botswana border in the west where scattered boreholes indicate values up to 1100mS/m. The highest average values are in the vicinity of the Blouberg area with recorded values of up to 3000mS/m. According to Bond (1947) the water is suitable for most purposes although some very high fluoride levels (up to 15mg/l) have been found in boreholes in the Ellisras area. The source of these fluorides has not yet been established. Depending on geology and location the water is classified as a sodium-bicarbonate-chloride type with elevated concentrations of calcium and magnesium related to reverse ion exchange (replacing Na^{+} with Ca^{2+} and Mg^{2+} (Figure 30).

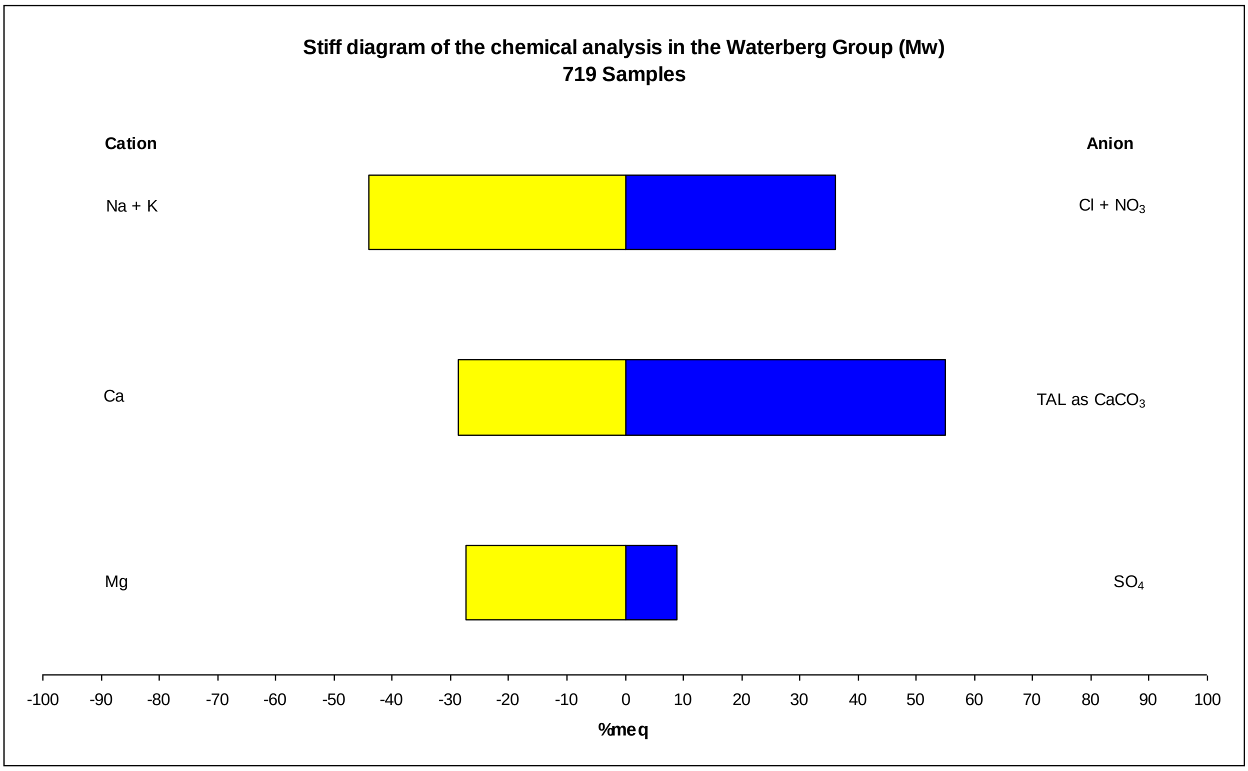

Figure 30: Stiff diagram representing chemical analysis of the Waterberg Group (Mw)

7.2.1.8 KOEDOESRAND FORMATION (Mko)

This formation is confined to a narrow fault-bounded zone, bounded by the Abbottspoort Fault on the south to form pronounced topographic features (Figure 31). According to Visser (1953), it consists in general of a 90m-thick basal unit of light -coloured quartzitic sandstone, shaly rocks and quartz-sericite schist, overlain by 130m of mainly conglomerate. At the top, 300m of sandstone and grit with occasional pebble beds are developed. This Formation is intruded by the Palala Granite.

There is insufficient yield and chemical data available for the unit to make any proper assessment. The aquifer characteristics of this unit need to be determined, but it is expected to be similar to that of the Waterberg Group (chapter 7.2.1.7). Based on the limited information available as displayed in the yield frequency diagram (Figure 32) yields of up to 2ℓ/s can be obtained in the unit.

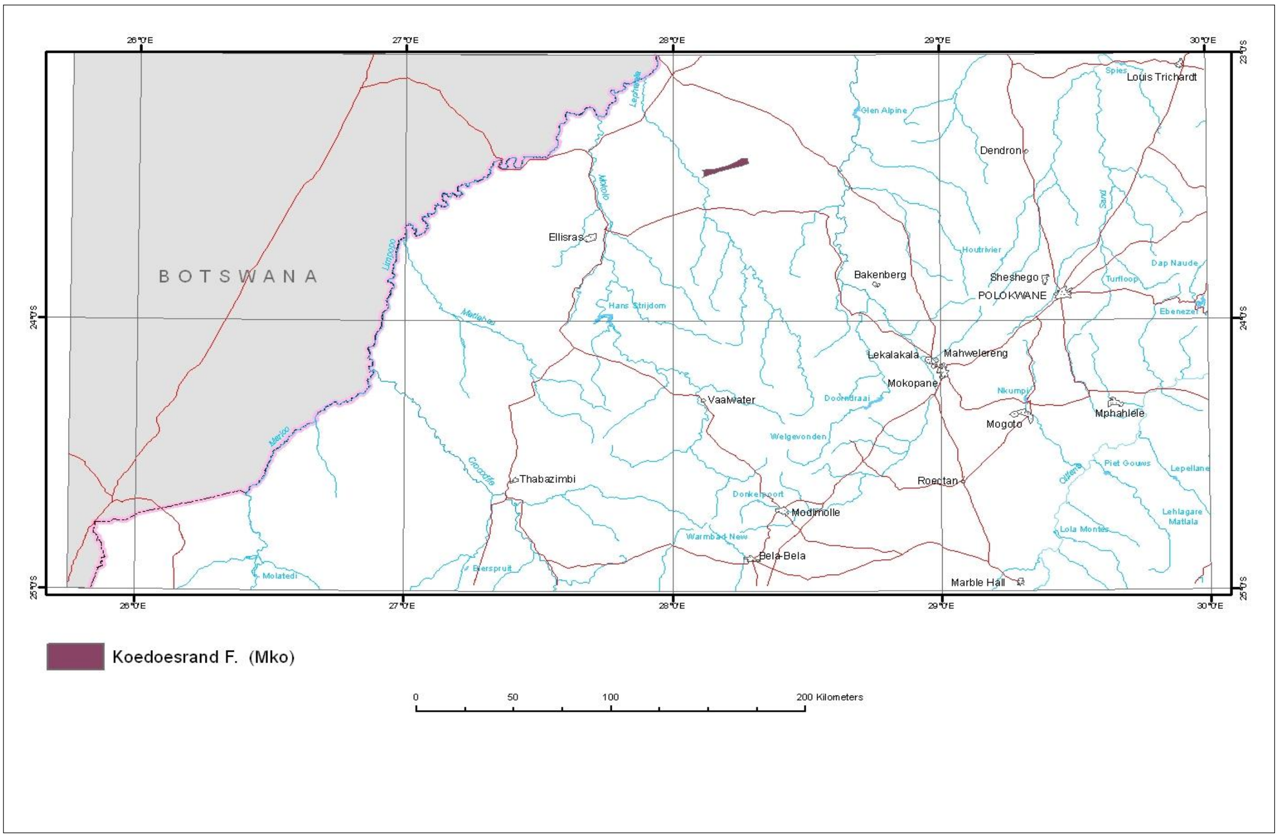

Figure 31: Geographical distribution of the Koedoesrand Formation (Mko)

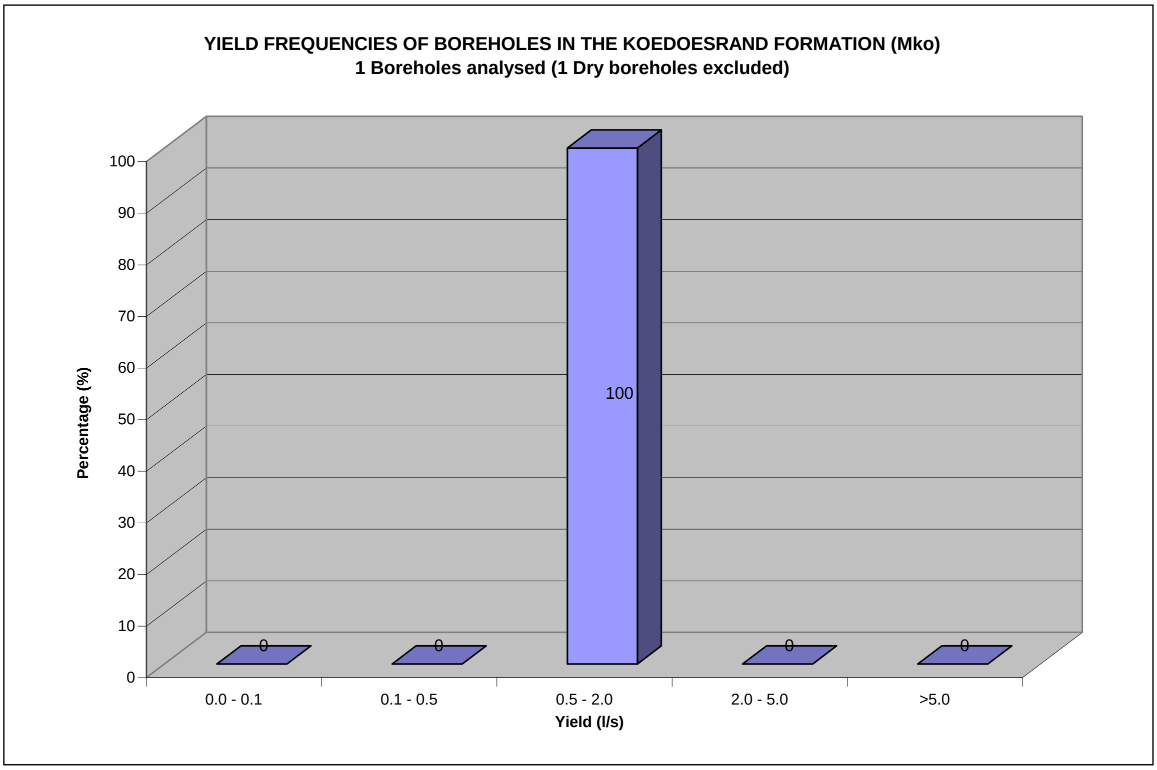

Figure 32: Yield frequency for fractured aquifers of the Koedoesrand Formation (Mko).

7.2.1.9 PALALA GRANITE (Mpa)

The Palala Granite occurs as two narrow strips orientated in an east-west direction to the north of Villa Nora (Figure 33). Both occurrences are bounded by normal faults. This unit covers approximately 0.1% of the total map area. The boundary between the central and marginal zones of the Limpopo Mobile Belt is marked by the 10km-wide Palala shear zone characterized by mylonitic rocks.

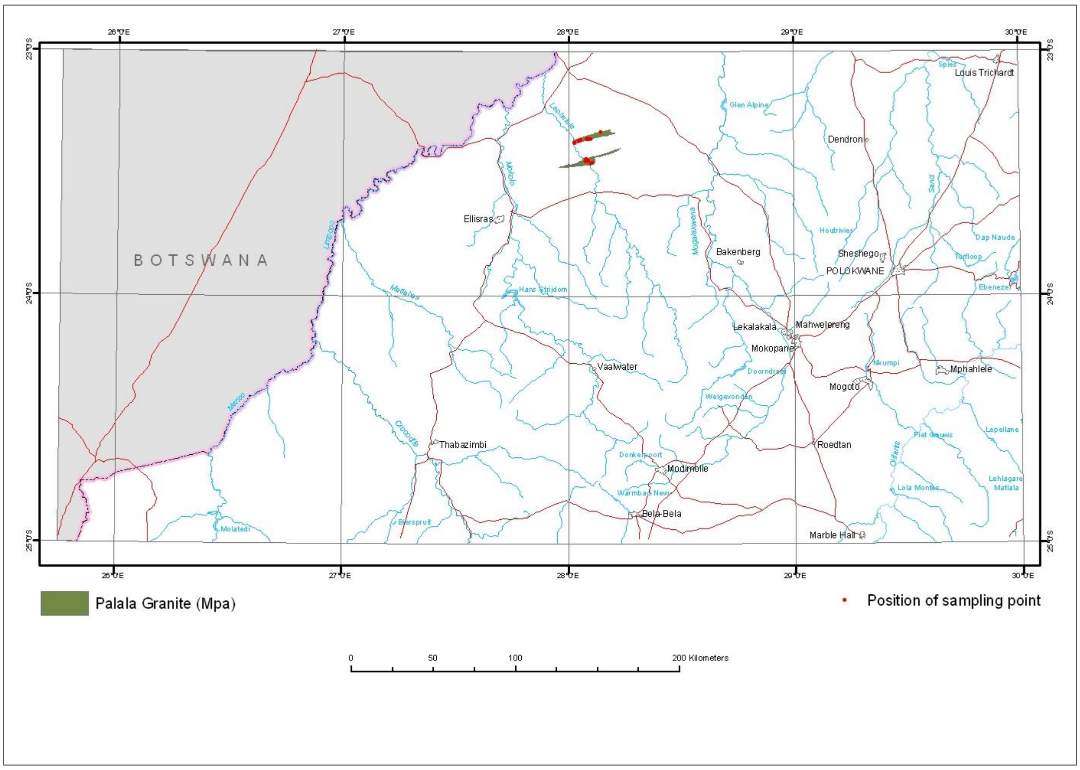

Figure 33: Geographical distribution of the Palala Granite (Mpa) and the associated groundwater sampling points

Groundwater occurs mainly in fault and shear zones. Owing to its very limited occurrence, the groundwater resources of the Palala Granite are regarded as insignificant. Although yield data are limited, the yield frequency diagram indicates that despite the insignificance of this unit as a resource reasonable yields can be obtained from the Palala Granite. 26% of the borehole yield between 0.5 and 2ℓ/s and 37% are more than 2ℓ/s (Figure 34). Groundwater in the area is mostly abstracted for domestic and livestock watering.

A combined plot of the available 7 water samples indicates a sodium-magnesium-chloride-bicarbonate water type. One of the samples exhibits elevated concentrations of sodium (Na=1972mg/l: HARMEAN=152mg/l), sulphate (SO_4=2225.7mg/l:HARMEAN=41mg/l) and chloride (Cl=1972.7mg/l: HARMEAN 169mg/l). The EC value of 821mS/m of this sample is also higher than the harmonic mean of 157mS/m calculated from the remaining analysis of the unit. Although the sample does not change the cation and anion character of the water in this unit, the area can be investigated further to establish if the high concentrations found in the one sample occurs elsewhere in the area.

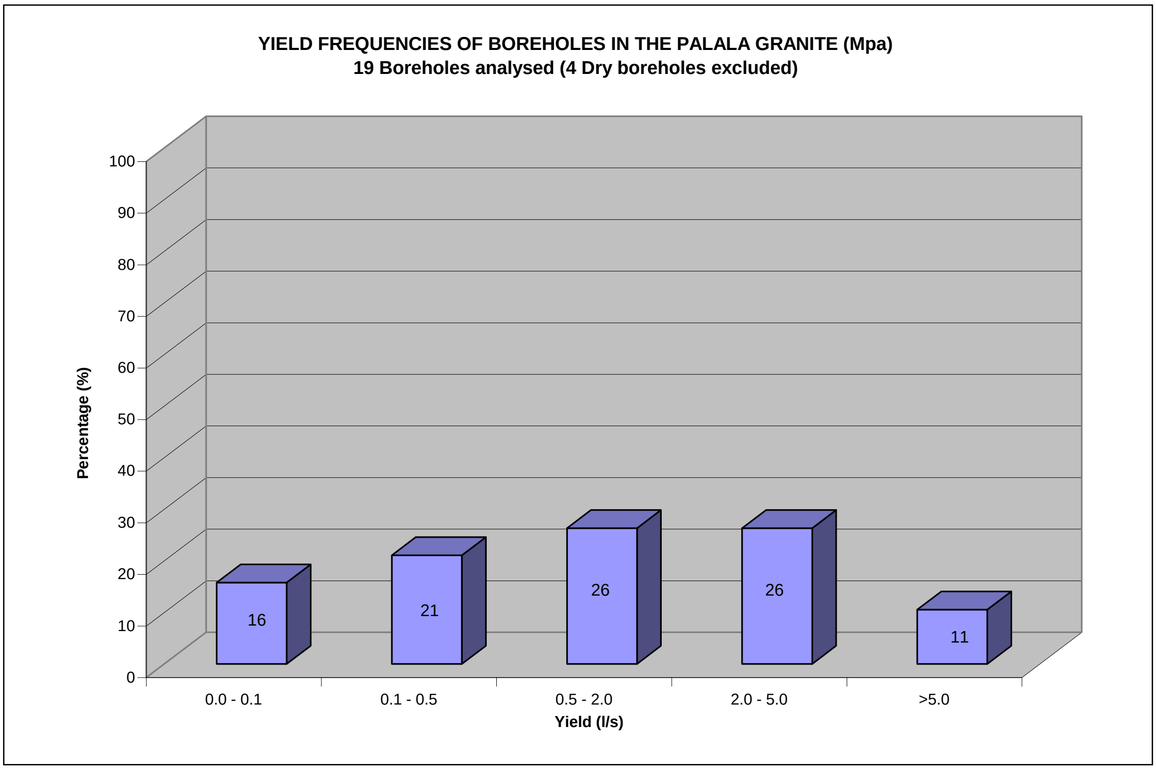

Figure 34: Yield frequency for fractured aquifers of the Palala Granite (Mpa).

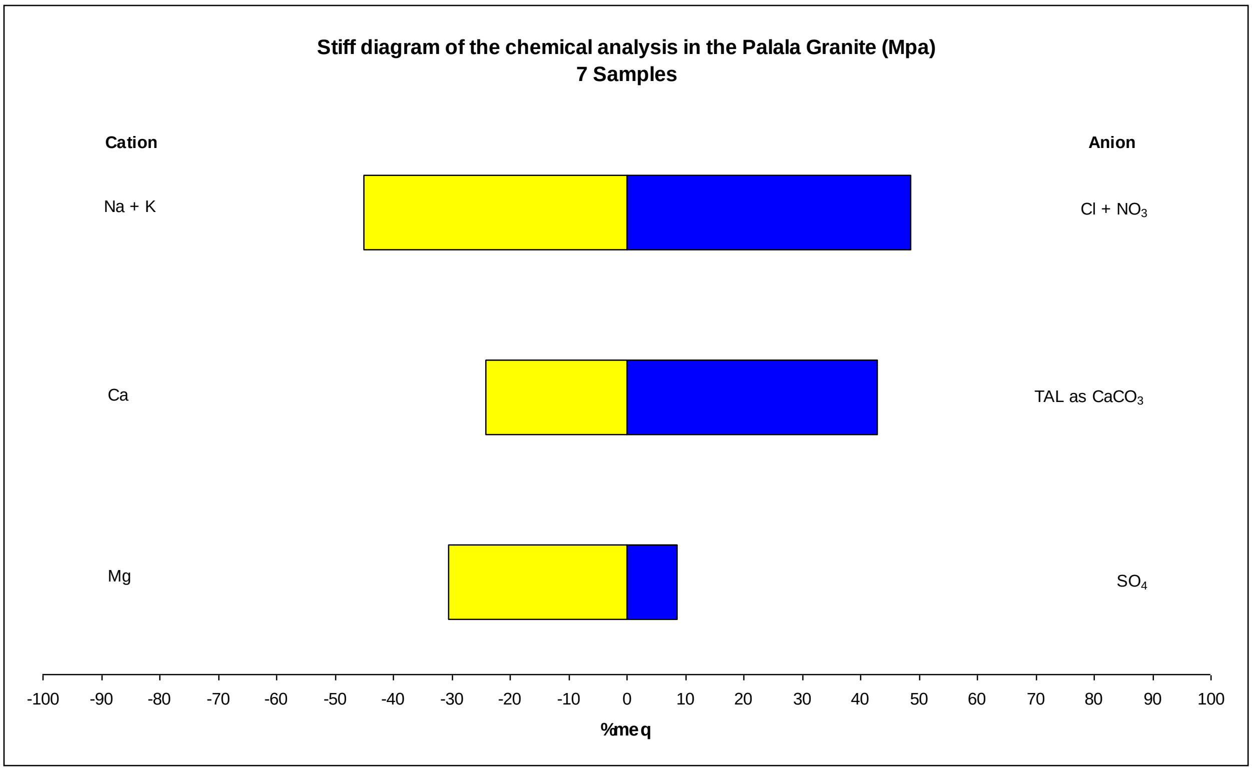

Figure 35: Stiff diagram representing chemical analysis of the Palala Granite (Mpa)

7.2.1.10 UNNAMED MOKOLIAN ROCKS (Mz)

These Unnamed Rocks also occur as east-west striking narrow strips along the Palala shear zone between the Melinda Fault in the south and Abbottspoort Fault in the north (Figure 36). It comprises a variety of metamorphic rocks. Although not many boreholes occur within this unit, the yield frequency diagram provides a reasonable indication of expected conditions. 50% of the successful boreholes yield between 0.5 and 2ℓ/s and 13% more than 2ℓ/s (Figure 37). Groundwater is found in fractures and fissures related to faulting and shearing.

Three chemical analyses were available for the compilation of the stiff diagram for this unit (Figure 38). One of the samples differs completely from the other two as the concentrations of sulphate, fluoride and sodium is 2-5 times higher whereas the nitrate and nitrite (reported as N) concentration is much lower at 1.1mg/l compared to 30 to 38mg/l. If the stiff diagram is plotted using the data from this single borehole, the water has a sodium-chloride character. When using the data from the other two boreholes, the water displays a sodium-magnesium-chloride-bicarbonate character. Further sampling and field investigation is needed.

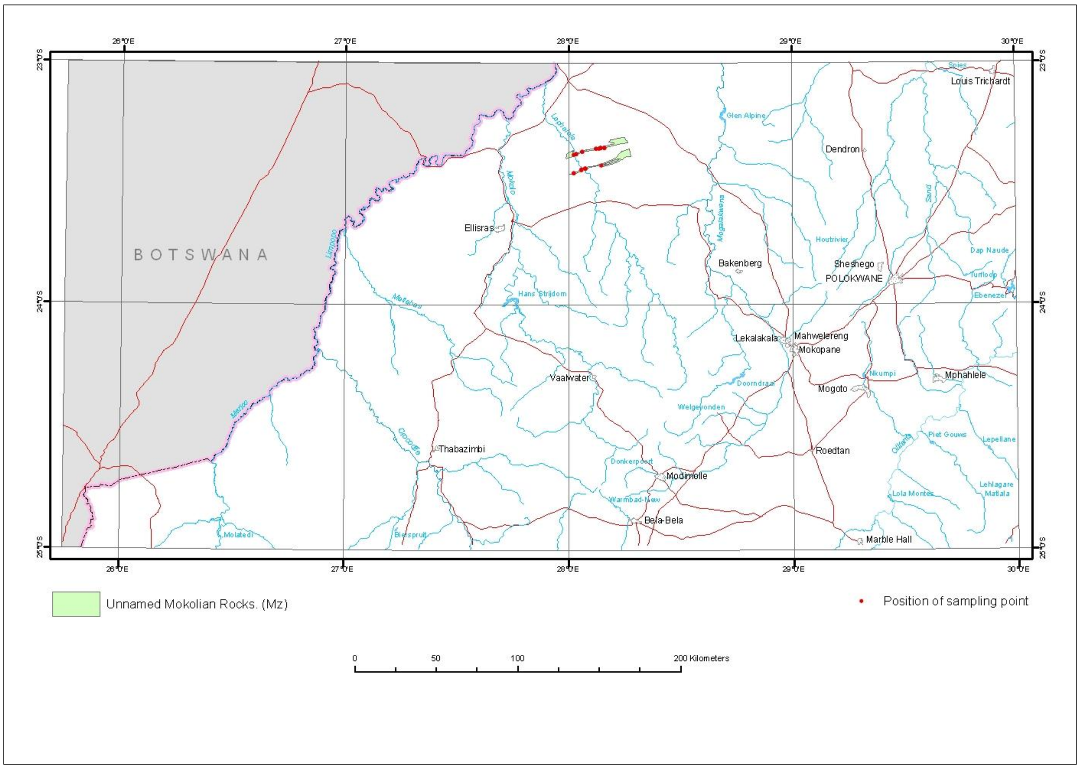

Figure 36: Geographical distribution of the unnamed Mokolian Rocks (Mz) and the associated groundwater sampling points

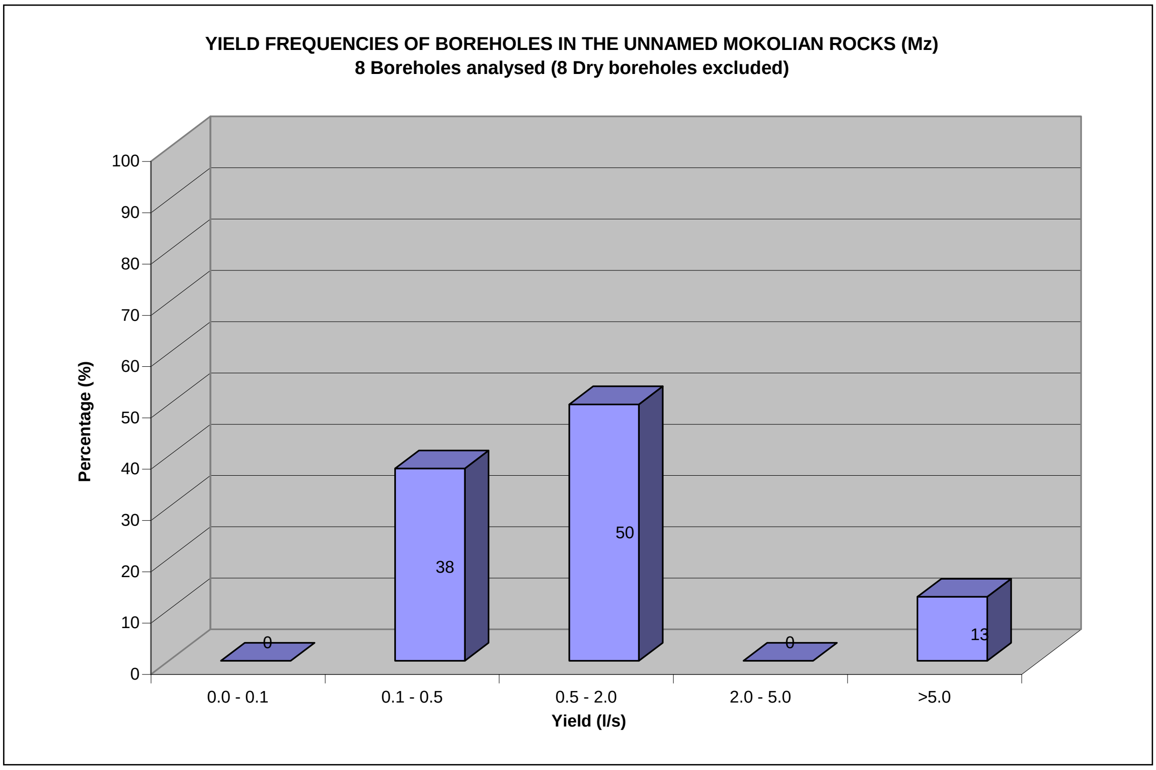

Figure 37: Yield frequency for fractured aquifers of the unnamed Mokolian Rocks (Mz).

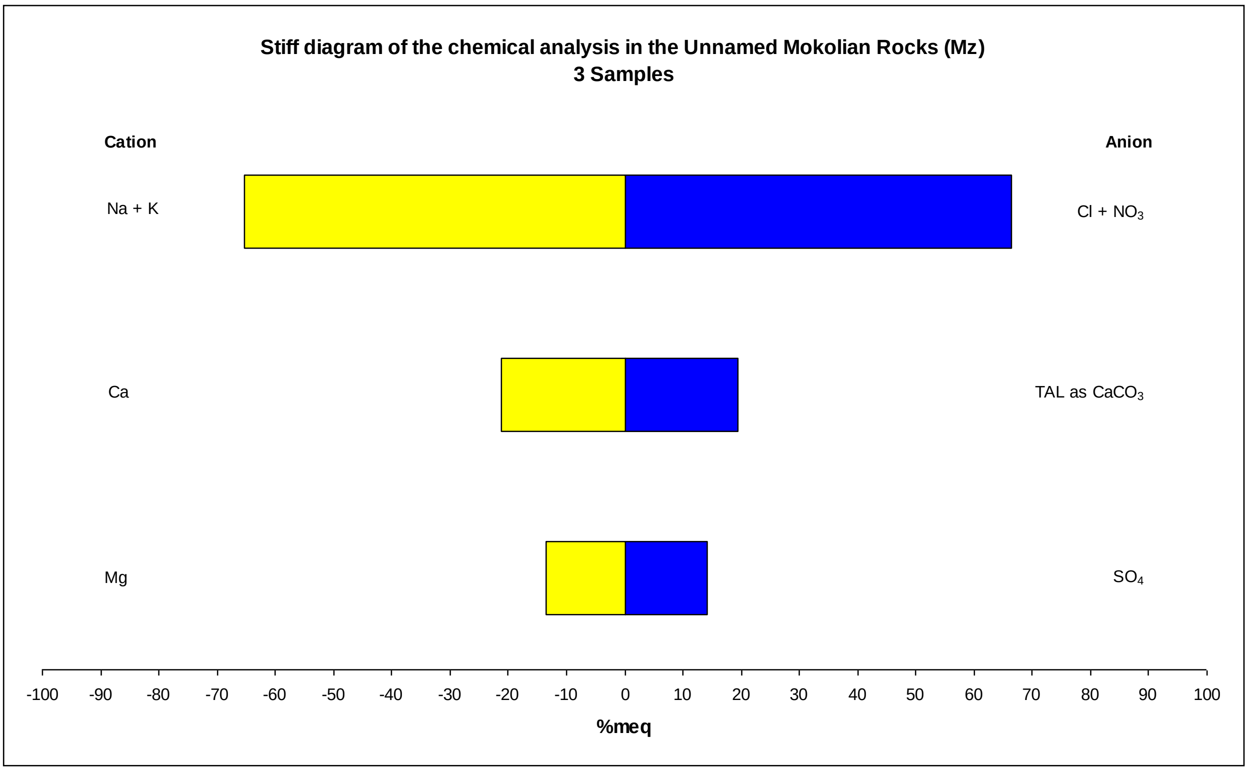

Figure 38: Stiff diagram representing chemical analysis of the unnamed Mokolian Rocks (Mz)

7.2.1.11 ROOIBERG GROUP (Vb)

This Group consists almost entirely of volcanic rocks (fine-grained, porphyritic rhyolite) and is at present regarded as part of the Transvaal Supergroup. It is found exposed in a number of scattered areas on the map (Figure 39), viz. at Rooiberg, west of Bela Bela (Warmbad), northeast of Modimole (Nylstroom), and also a narrow strip west of Mokopane (Potgietersrus). The unit covers approximately 1.4% of the total map area.

Plate 5: Graben structure in rhyolite of the Kwaggasnek Formation in a road cutting along the N1 about 10 km south of Mookgophong (Naboomspruit), photograph: WH du Toit.

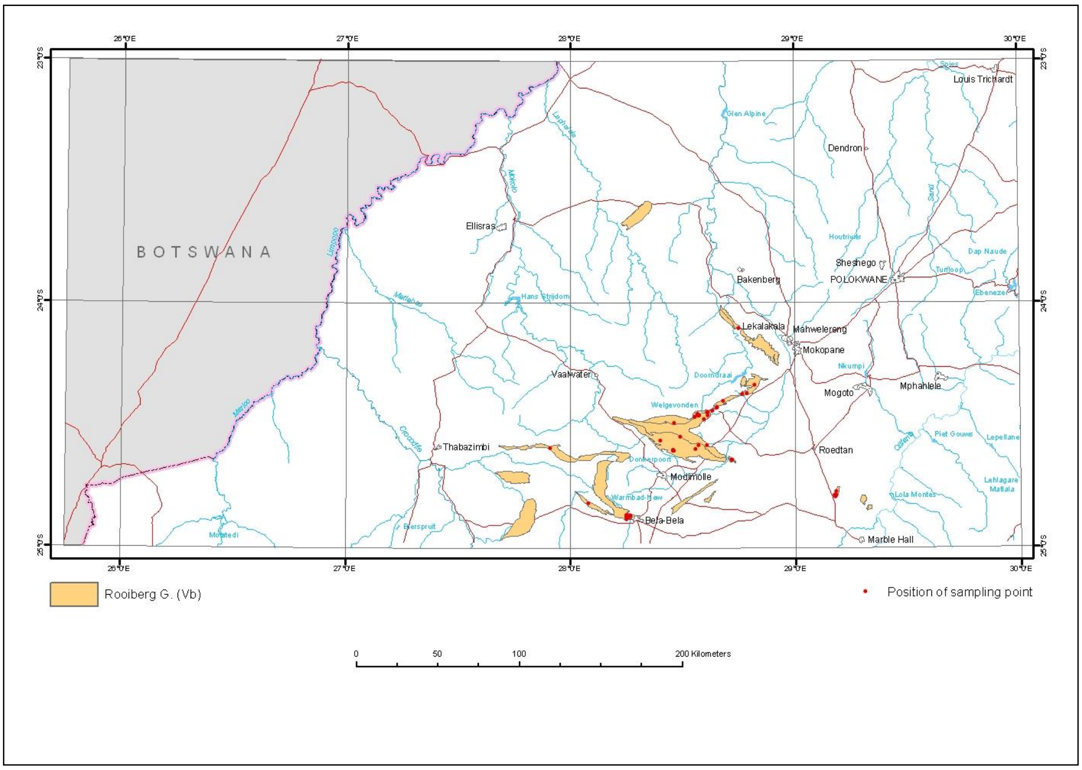

Figure 39: Geographical distribution of the Rooiberg Group (Vb) and the associated groundwater sampling points

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 above and its limited extend restrict the unit to an insignificant aquifer. Groundwater targets includes faults and associated shear zones, fracture zones, dyke contacts, the contact with overlying sandstones (Waterberg Group) and lava flow contacts. The depth to groundwater level is in general <30m.

Approximately 78% of the successful boreholes yield less than 2ℓ/s (Figure 40) while 5% is yielding more than 5ℓ/s. Water is abstracted for domestic purposes and livestock watering.

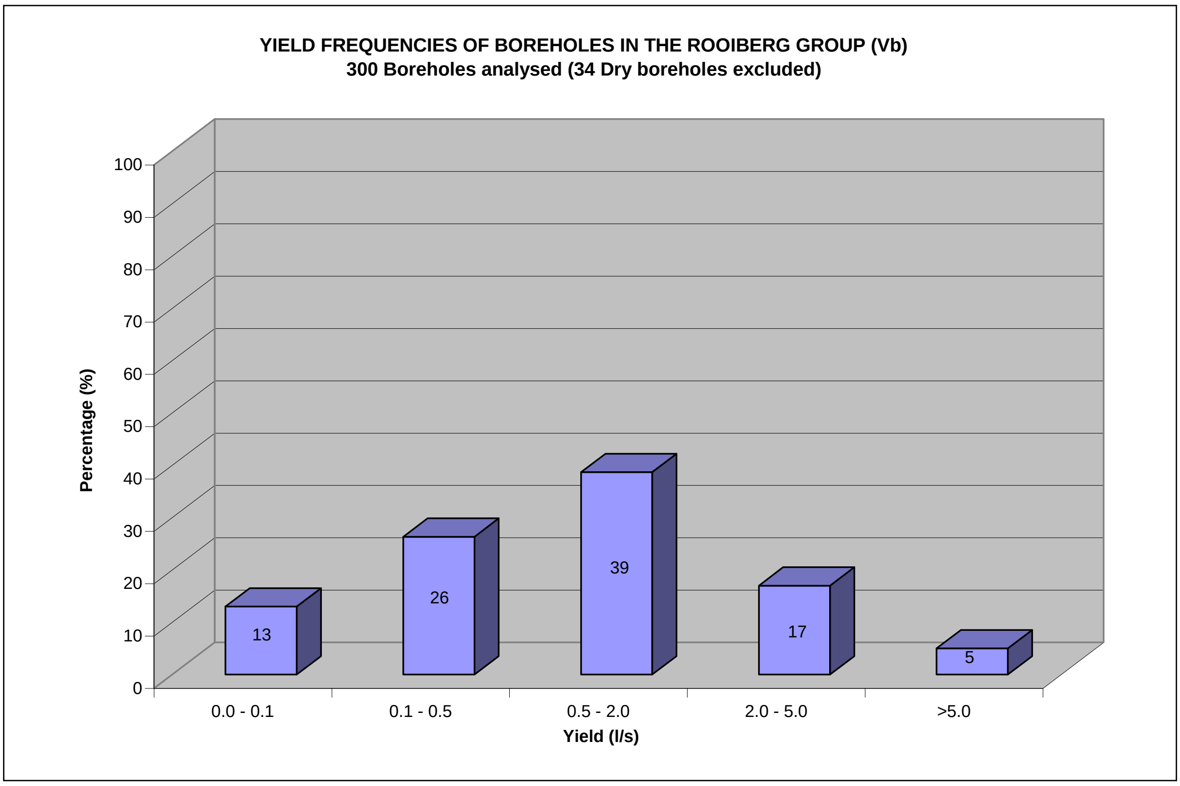

Figure 40: Yield frequency for fractured aquifers of the Rooiberg Group (Vb).

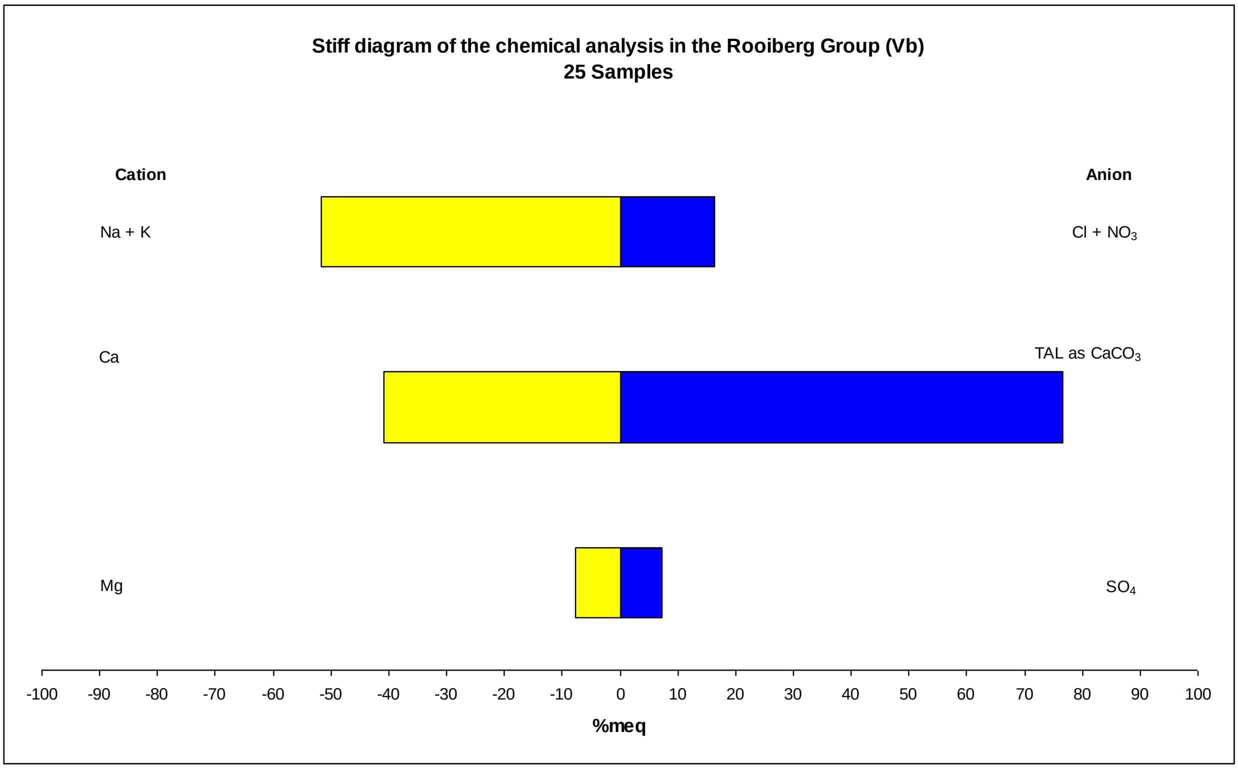

Figure 41: Stiff diagram representing chemical analysis of the Rooiberg Group (Vb)

The quality is in general good to moderate with EC values ranging between 8.6-312mS/m. 84% of the samples have EC values <70mS/m with a calculated harmonic mean of 26.4mS/m for the unit. In 72% of the samples fluoride concentrations exceed the maximum allowed limit (F >1.5mg/l). High nitrate and nitrite (reported as N) concentrations are only reported in one of the samples

(19.4mg/l) while 88% is less than 1mg/l. Figure 41 shows the broad classification according to anions and cations for this Group. The water is classified as a sodium-calcium-bicarbonate water type.

7.2.1.12 RASHOOP SUITE (Vrg)

The Rashoop Granophyre Suite forms part of the Bushveld Igneous Complex and occurs as scattered clusters in the Thabazimbi, Mokopane and Marble Hall areas (Figure 42).

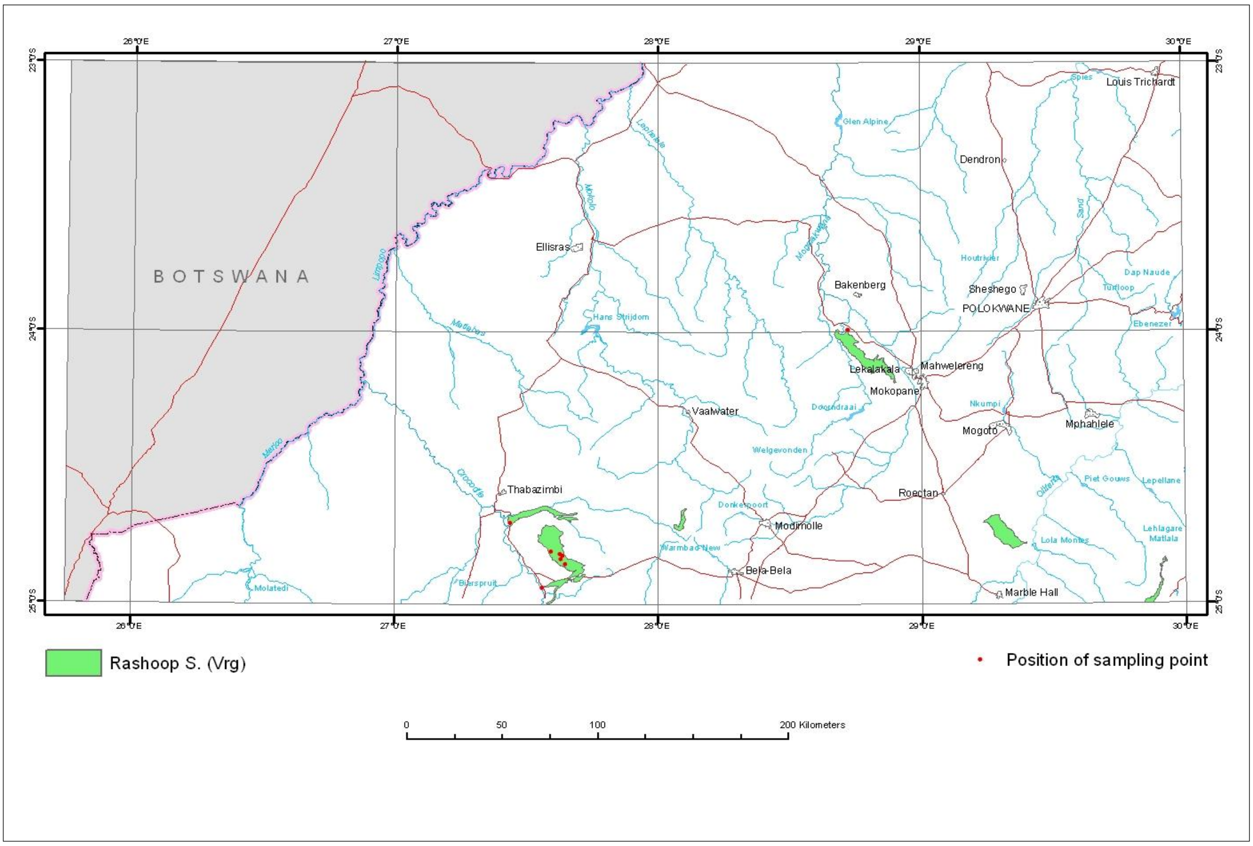

Figure 42: Geographical distribution of the Rashoop Suite (Vrg) and the associated groundwater sampling points.

The groundwater potential of this Suite is generally poor but occasional good supplies (0.5 – 2ℓ/s) do occur (Figure 43). The storage capacity is very low. Water is obtained in faults, fracture zones and dyke contacts.

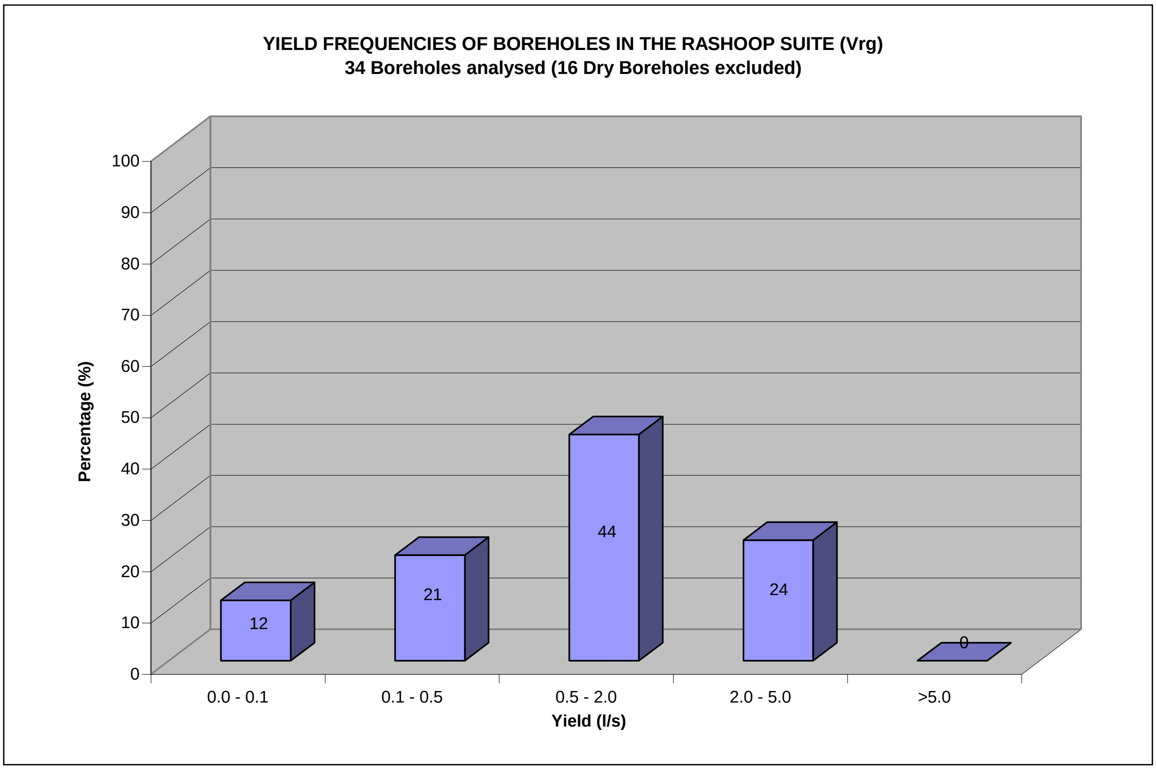

Figure 43: Yield frequency for fractured aquifers of the Rashoop Suite (Vrg).

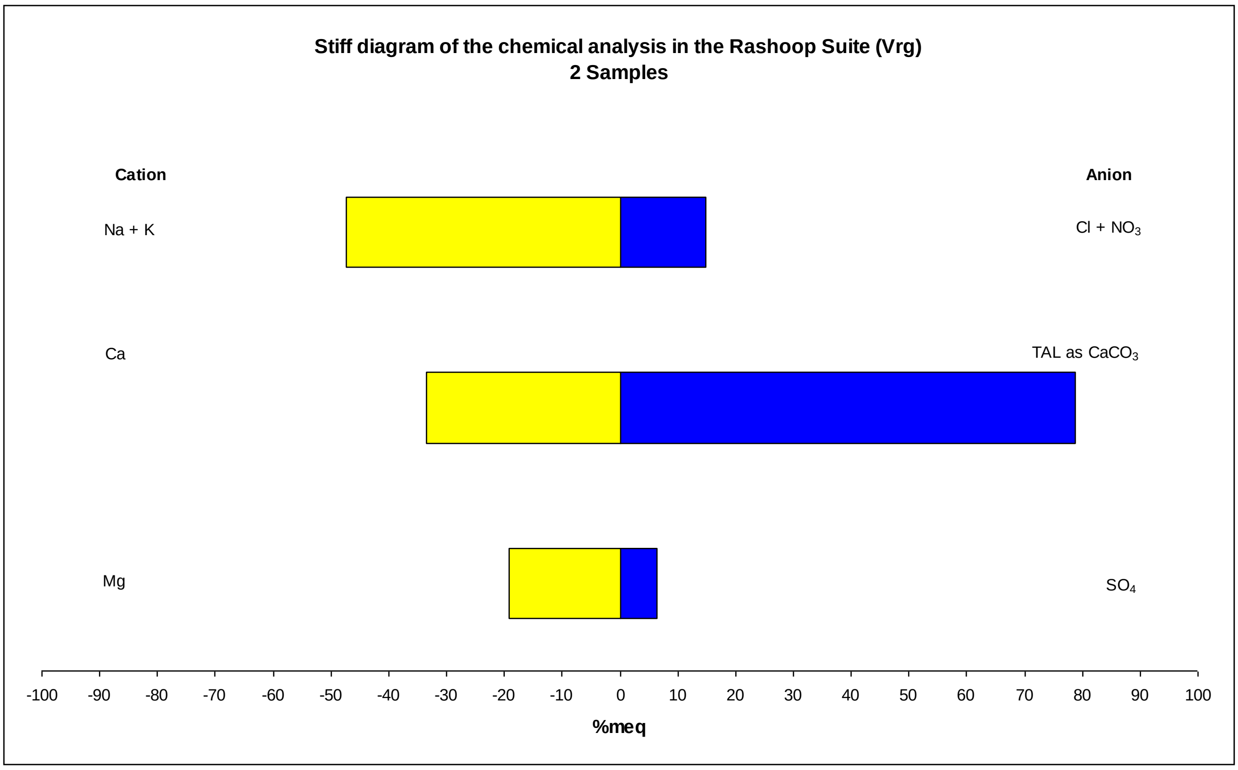

Figure 44: Stiff diagram representing chemical analysis of the Rashoop Suite (Vrg)

Figure 44 represent chemical analysis of two samples within the unit showing the broad classification according to anions and cations. The water is classified as a sodium-calcium-bicarbonate type. If plotted separately, the cations exhibit the same pattern but the anions are either dominated by chloride or bicarbonate.

7.2.1.13 PRETORIA GROUP (Vp) (Conglomerate, sandstone and quartzite)

Due to similar hydrogeological characteristics as well as for cartographic reasons, the different Formations of the Pretoria Group have been lumped together. The unit comprises mostly shale and clastic rocks including quartzite, conglomerate and sandstone. Contrary to the rest of the Pretoria Group, the occurrence of the Pretoria Group located south of Thabazimbi (Figure 45), is classified as a fractured aquifer. It comprises conglomerate, feldspatic sandstone, quartzite and shale. Water occurs mostly in fractures, dyke contacts and faults.

The yield frequency diagram indicates that 50% of the boreholes yield between 0.5 and 2ℓ/s (Figure 46). This might, however, not be a true reflection as only 4 boreholes were used in the assessment.

Very limited information is available on the quality of groundwater found in this occurrence of the Pretoria Group, but indications are that the water can be classified as a sodium-calcium-bicarbonate type (Figure 47).

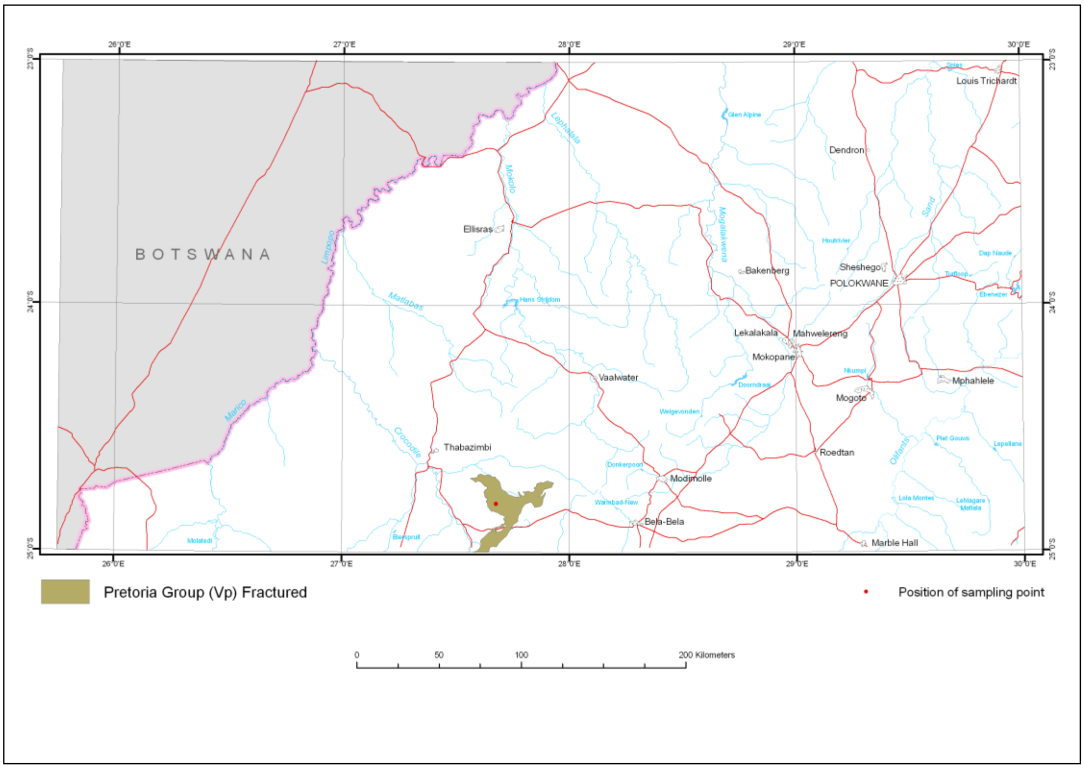

Figure 45: Geographical distribution of the Pretoria Group (Vp) (conglomerate, sandstone & quartzite) and the associated groundwater sampling points

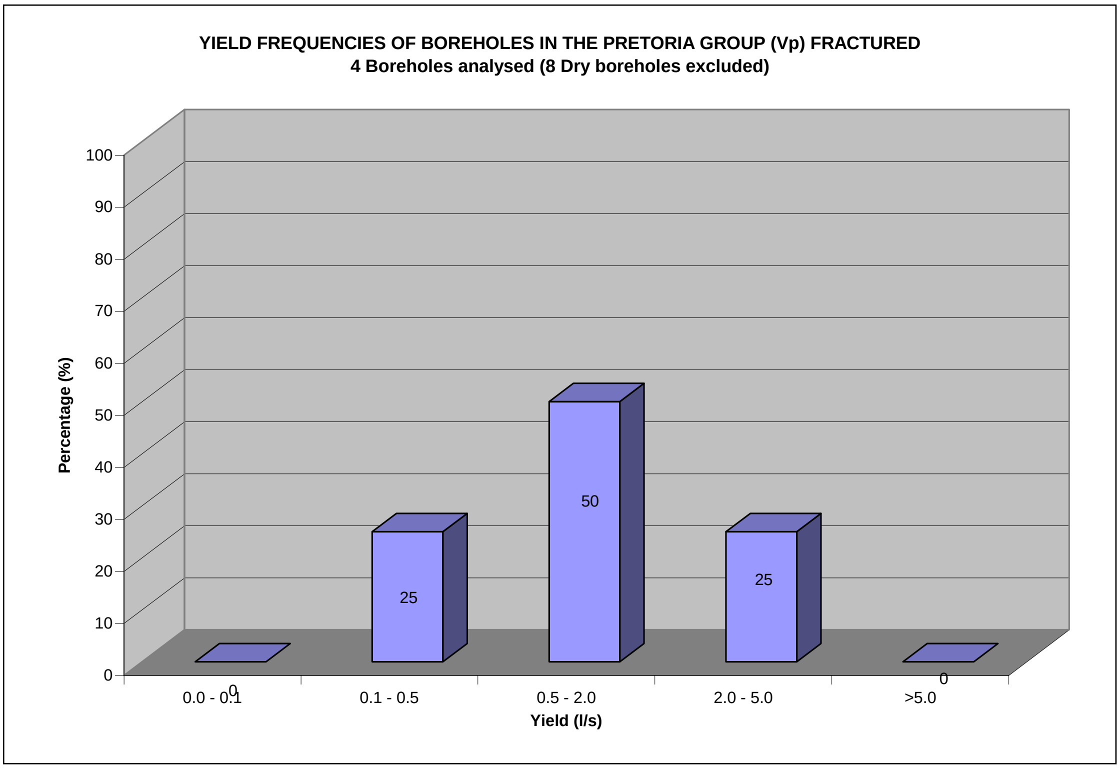

Figure 46: Yield frequency for fractured aquifers of the Pretoria Group (Vp). (conglomerate, sandstone & quartzite)

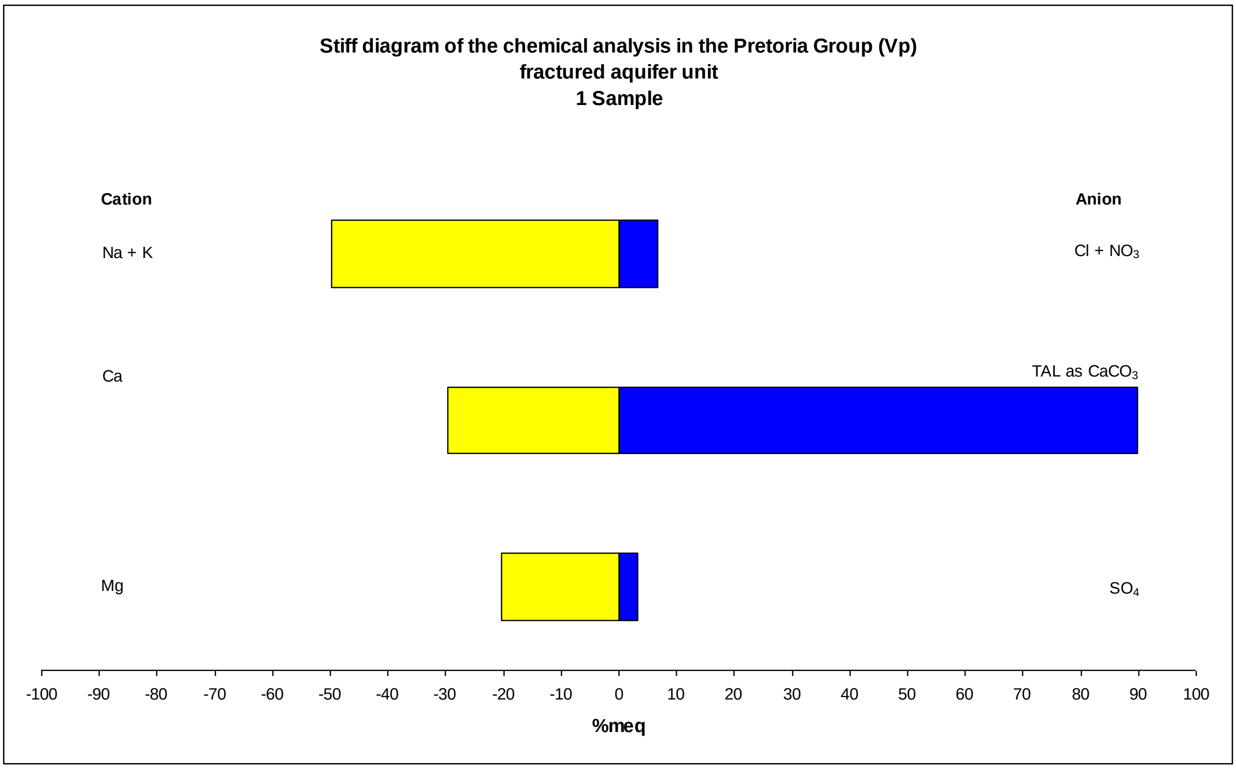

Figure 47: Stiff diagram representing chemical analysis for the fractured aquifers of Pretoria Group (Vp) (conglomerate, sandstone & quartzite)

7.2.1.14 CHUNIESPOORT GROUP (Vh) (Banded Ironstone)

This occurrence of the Chuniespoort Group occurs east of Chuniespoort and comprises banded ironstone, carbonaceous shale, subordinate carbonate rocks and breccia overlying the dolomites of the Chuniespoort Group (Figure 48). Small occurrences appear east of Mokopane (Potgietersrus) but are not shown on the map. It covers approximately 0.4% of the total map area. The Formation occurs in mountainous areas and is generally inaccessible. Due to its inaccessibility and limited occurrence in the area, the groundwater role of the unit is regarded insignificant. Little is known about its groundwater potential but is expected to be moderate to good as it is situated in a high rainfall area and the fractured appearance of the banded ironstone in the field. Geophysical surveys (resistivity, magnetics and electromagnetics) may be hampered due to the iron content in the rock. The yield frequency diagram (Figure 49) indicates that 35% of the boreholes yield between 0.5 and 2ℓ/s and 26% more than 2ℓ/s, confirming the moderate to good potential. The water in this occurrence of the Chuniespoort Group is classified as a calcium-magnesium-bicarbonate type (Figure 50). This type of water is associated with dolomitic aquifers.

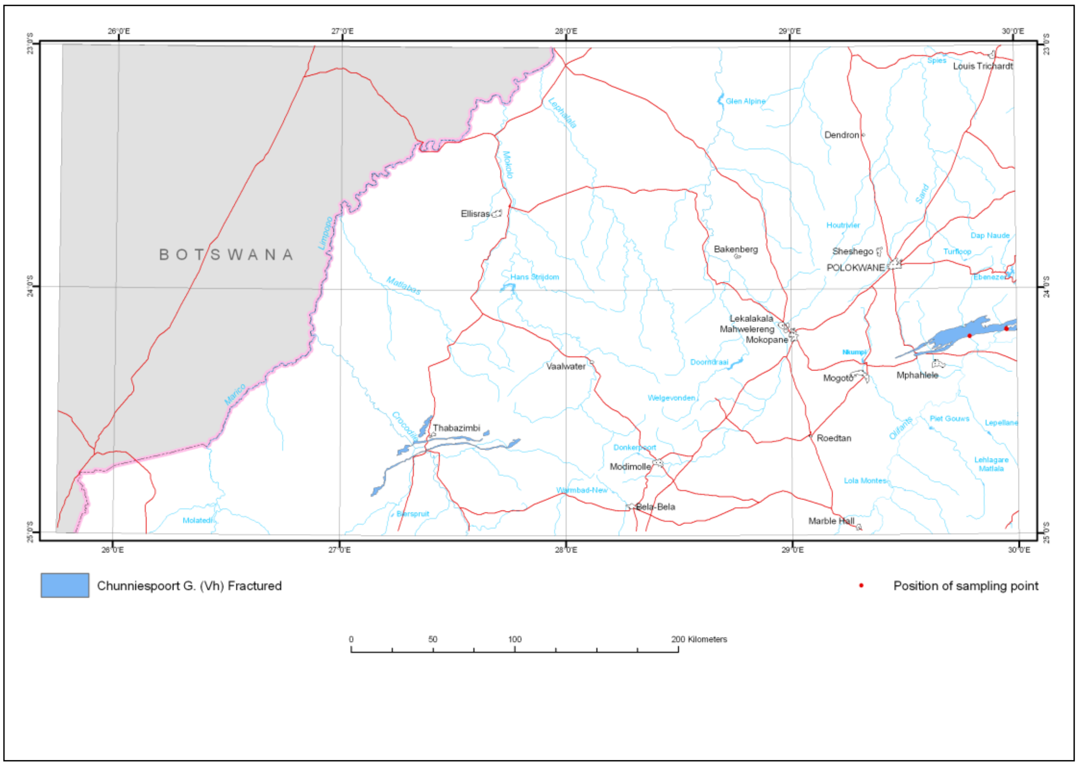

Figure 48: Geographical distribution of the fractured aquifers of the Chuniespoort Group (Vh) (banded ironstone) and the associated groundwater sampling points.

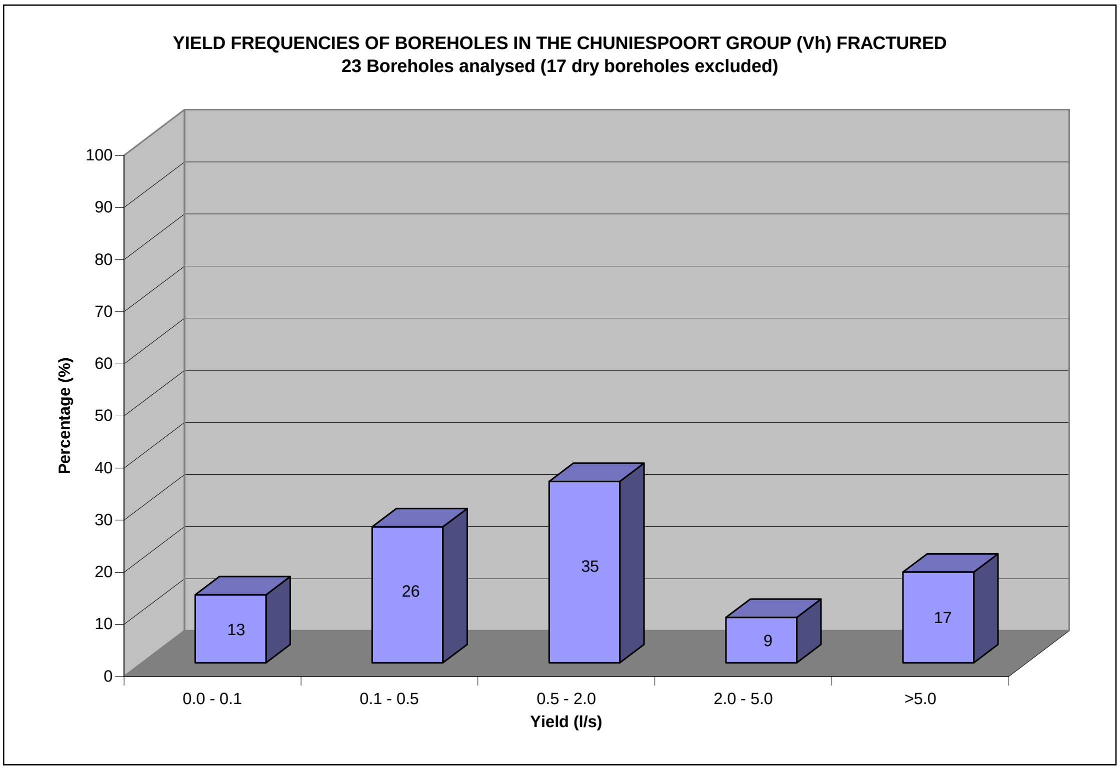

Figure 49: Yield frequency for fractured aquifers of the Chuniespoort Group (Vh) (banded ironstone)

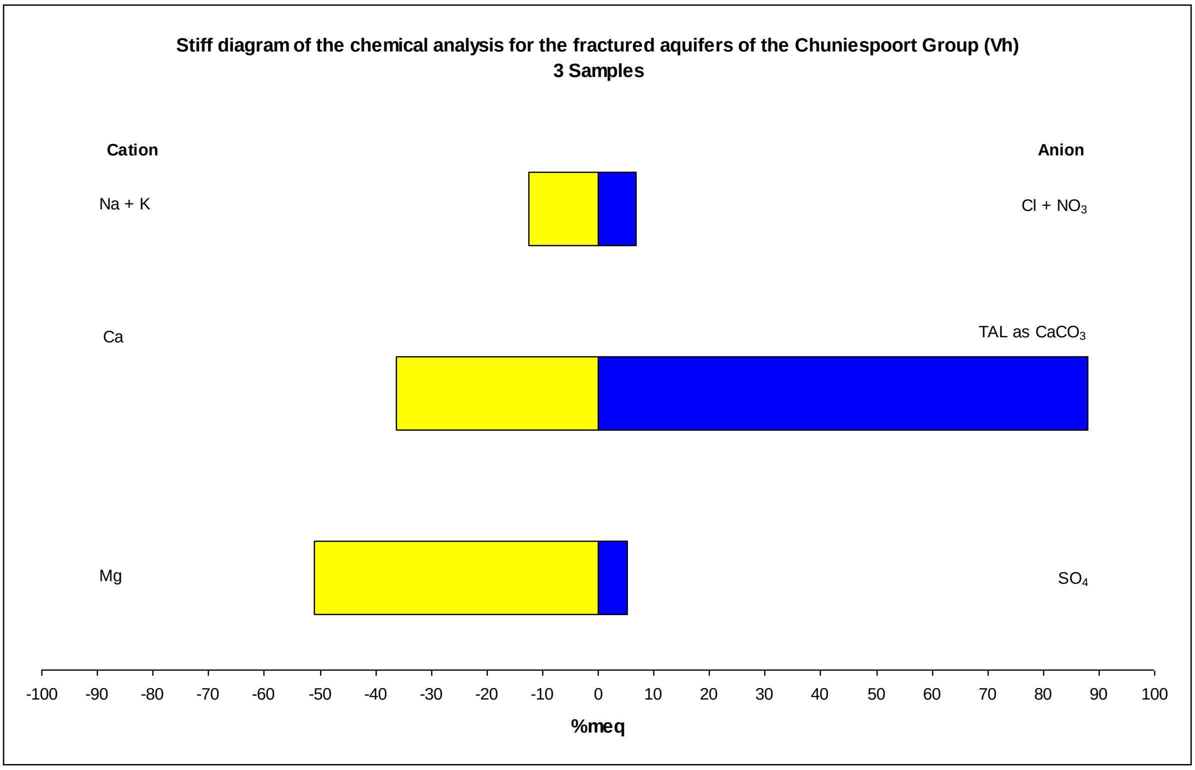

Figure 50: Stiff diagram representing chemical analysis for the fractured aquifers of the Chuniespoort Group (Vh) (banded ironstone).

7.2.1.15 BLACK REEF FORMATION (Vbl)

The formation is composed almost entirely of quartzite, with lenticular beds of grit and conglomerate. Shale is always present, particularly near the top close to the contact with the overlying dolomite. Dips are shallow and everywhere towards the inside of the Transvaal basin. It occurs in the Mokopane (Potgietersrus) and Wolkberg areas (Figure 51) where it rests unconformably on the Archaean granite and paraconformably on the Wolkberg Group respectively. The unit underlay 0.2% of the total map area.

The yield frequency diagram (Figure 52) indicates that 55% of the successful boreholes have yields >2ℓ/s. The unit occurs in mountainous areas and is in many cases inaccessible. Due to this, the groundwater role of the Black Reef Formation is not regarded as significant. Water in the Black Reef Formation is obtained in fractures, dyke contacts and faults.

Groundwater encountered in the Black Reef Formation can be classified as calcium-magnesium-bicarbonate water (Figure 53). This type of water confirm recharge from the overlying dolomites as the water chemistry with HCO_3^- and Ca^{2+}/Mg^{2+} with Mg^{2+} being dominant, is typical of groundwater associated with dolomitic aquifers. Dolomite of the Chuniespoort Group is overlying the quartzitic rocks of the Black Reef Formation. Together, it forms part of the watershed between the two primary drainage regions A and B occurring on the map sheet (Figure 4).

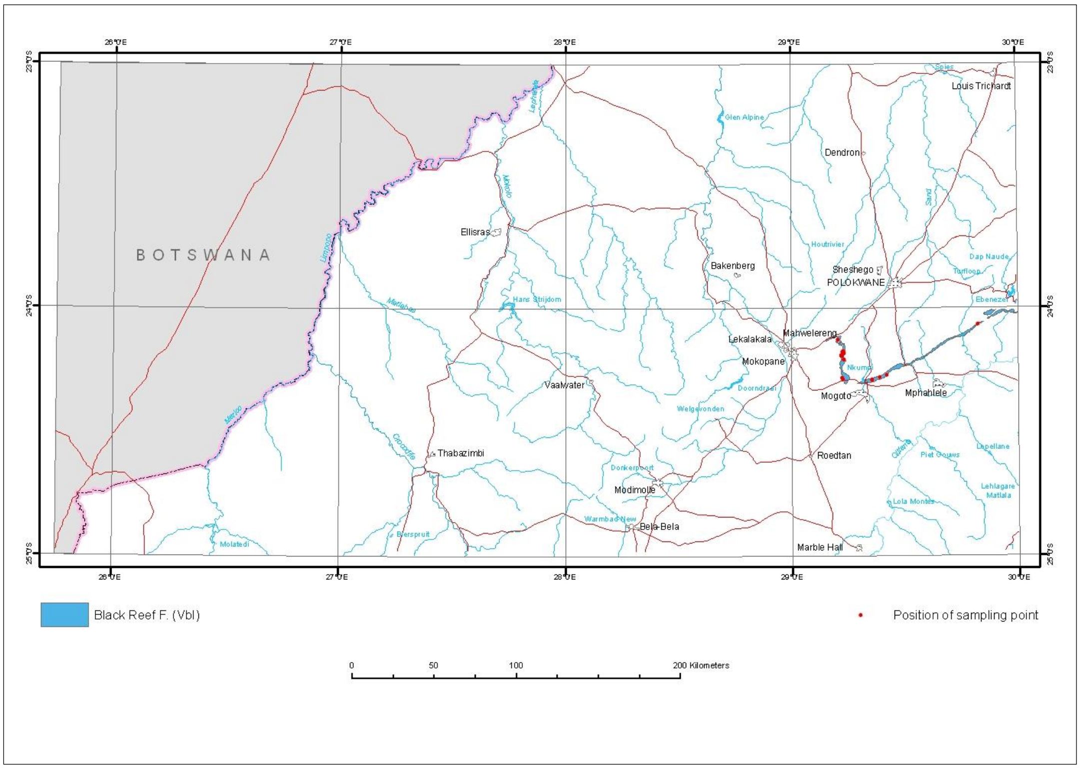

Figure 51: Geographical distribution of the Black Reef Formation (Vbl) and the associated groundwater sampling points.

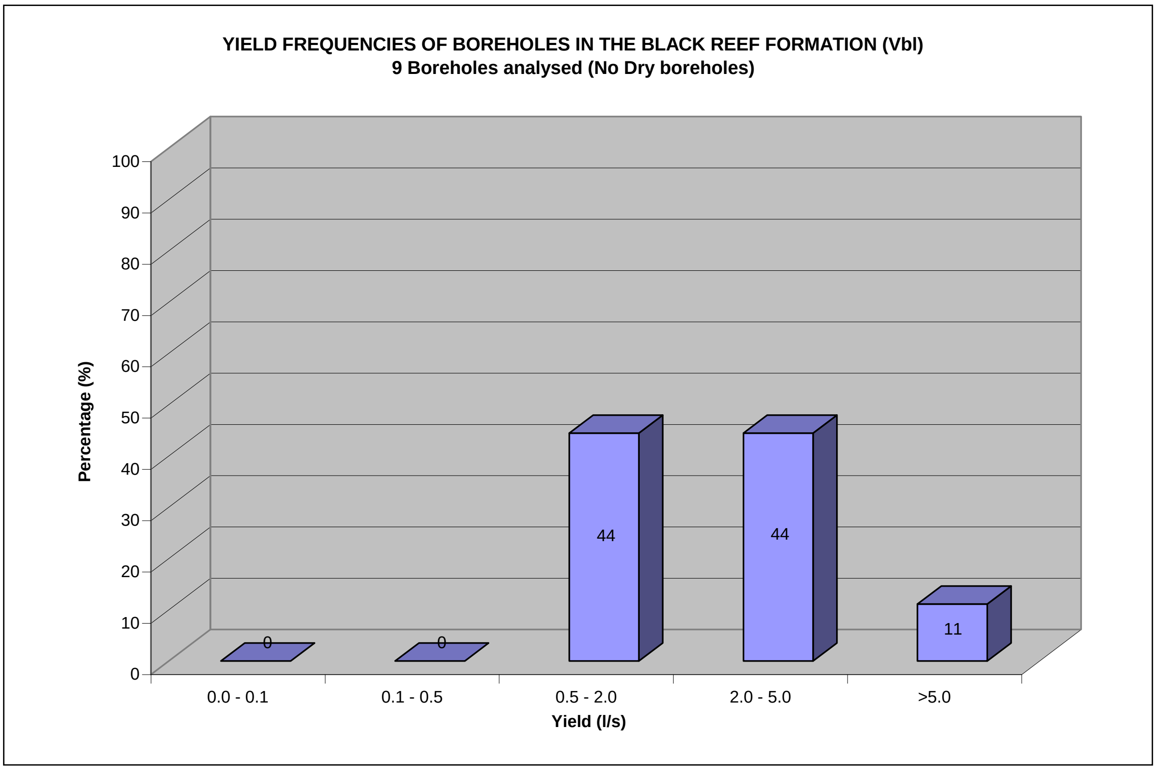

Figure 52: Yield frequency for fractured aquifers of the Black Reef Formation (Vbl).

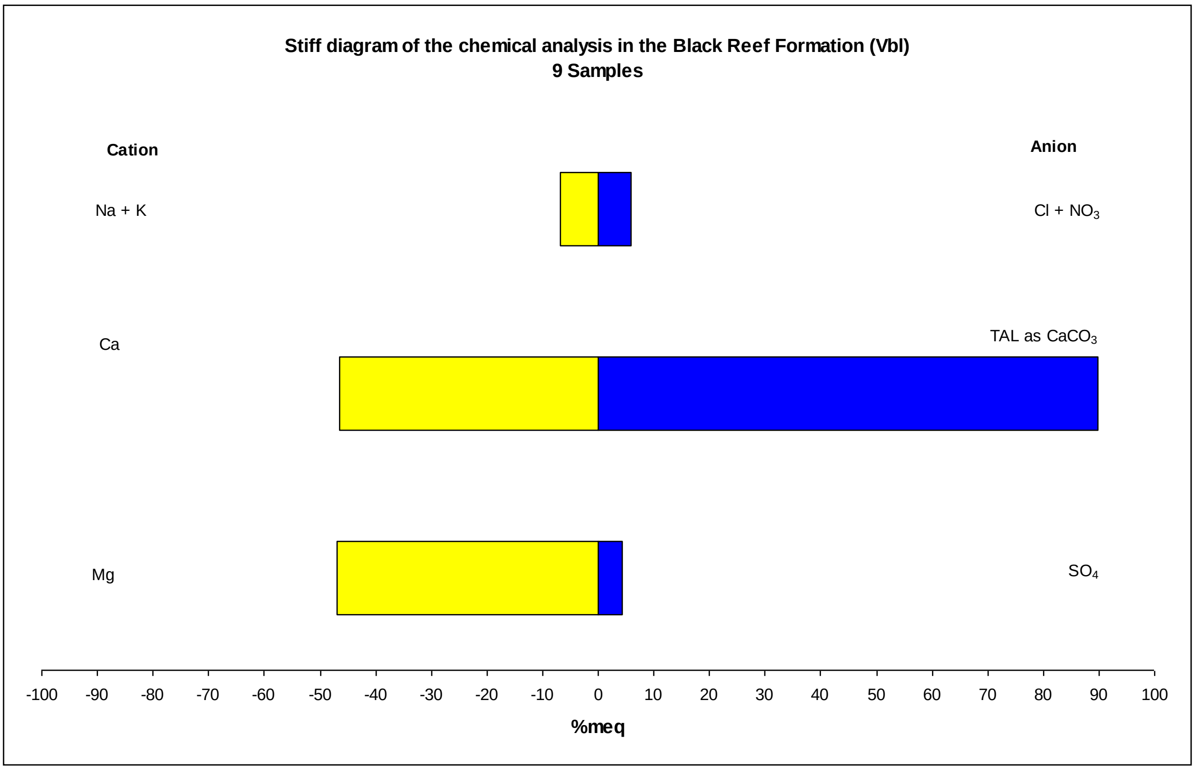

Figure 53: Stiff diagram representing chemical analysis of the Black Reef Formation (Vbl)

7.2.1.16 WOLKBERG GROUP (Vw)

As part of the Transvaal Sequence, the Wolkberg Group attains a maximum thickness of 700m, and wedges out north of Mokopane (Potgietersrus). The Wolkberg Group underlying the Black Reef Formation consist of shale, quartzite and lava (Figure 54).

Plate 6: Chuniespoort is a famous landmark along the Polokwane/Burgersfort road where the Chunies River has carved a path through very resistant shale and quartzite of the Wolkberg Formation (Photograph: WH du Toit).

Statistics indicate that the Wolkberg Group has a moderate to good potential as 47% of the boreholes yield >2ℓ/s (Figure 55). Similar to the Black Reef Formation it occurs in mountainous terrain. Accessibility and extend controls the importance of this unit as an aquifer. Water is obtained in fractures, faults and shear zones, dyke contacts and bedding planes.

Two samples were available and are presented in the plot of the anions and cations (Figure 56). The samples are representative of the anticipated water type for the unit. The water of the unit is characterised by a very high content of HCO_3^- and Ca^{2+}/Mg^{2+} and is classified as a calcium-magnesium-bicarbonate water type.

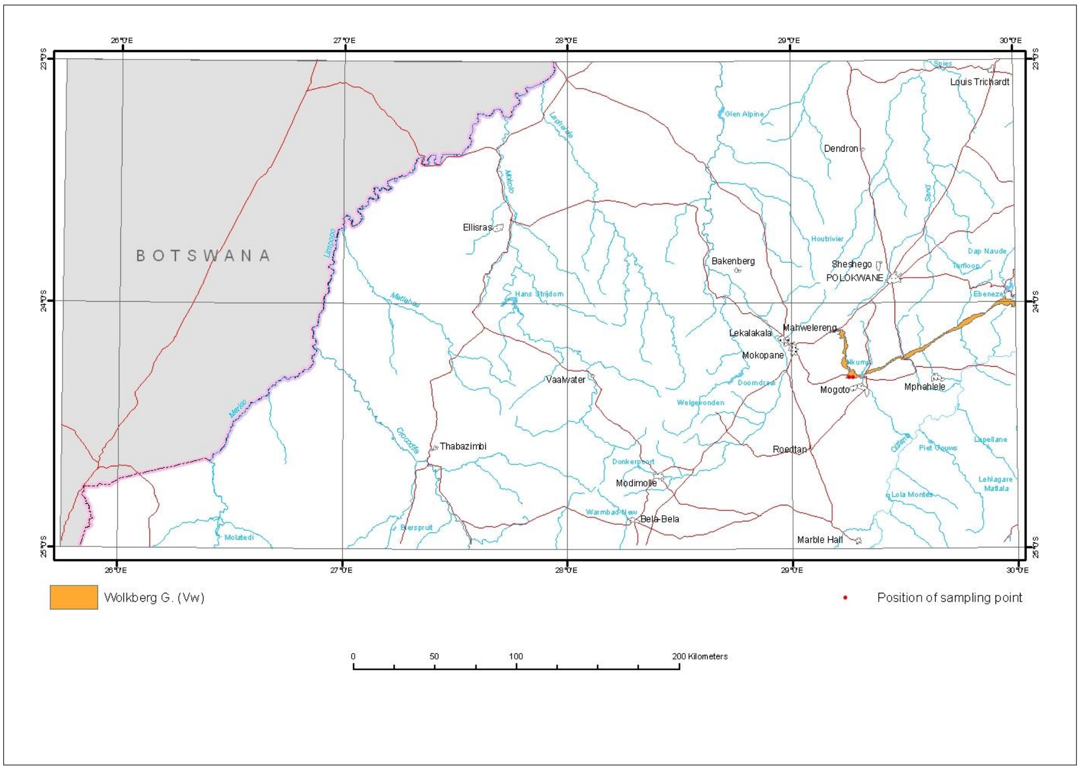

Figure 54: Geographical distribution of the Wolkberg Group (Vw) and the associated groundwater sampling points

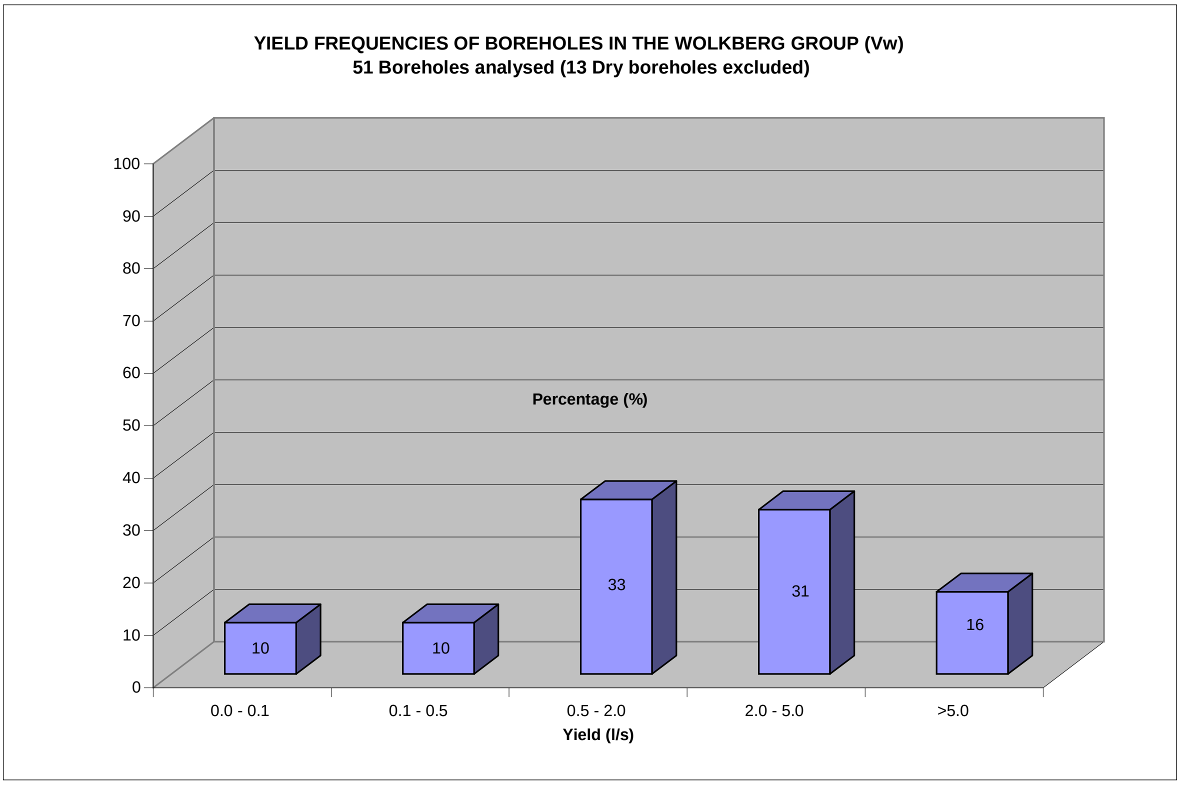

Figure 55: Yield frequency for fractured aquifers of the Wolkberg Group (Vw).

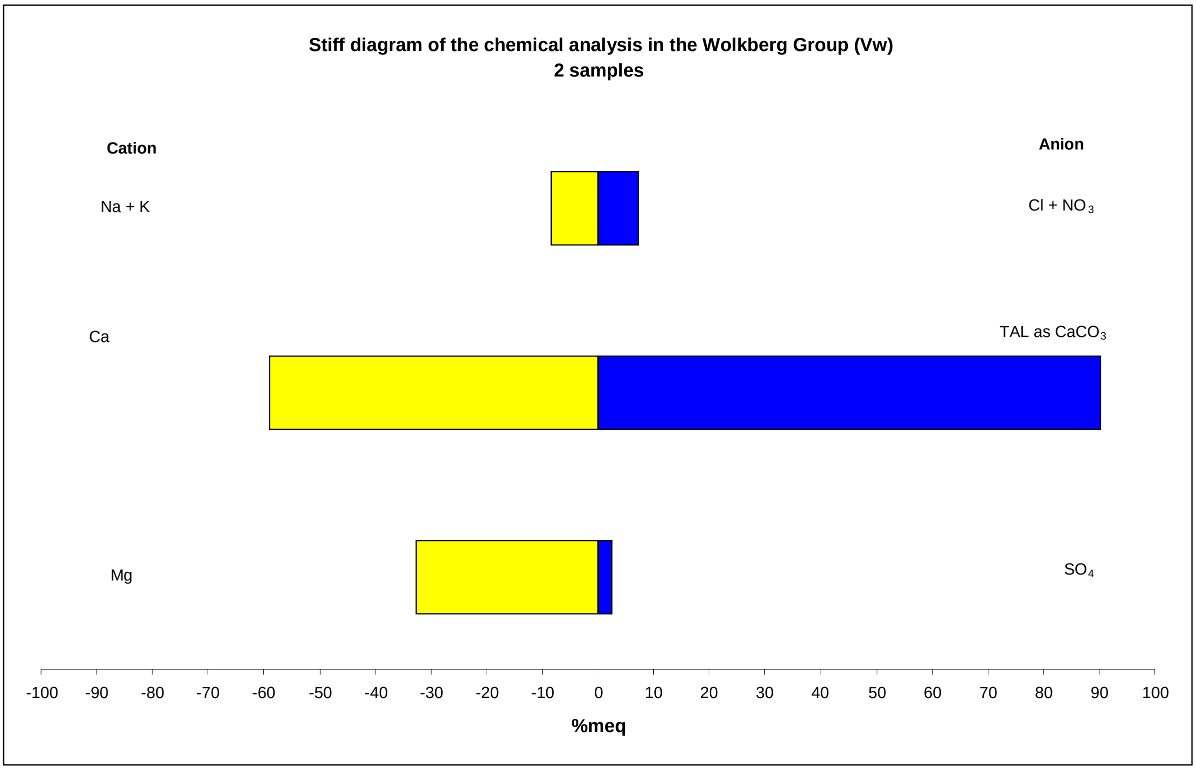

Figure 56: Stiff diagram representing chemical analysis of the Wolkberg Group (Vbl)

7.2.1.17 BOTHAVILLE FORMATION (R-Vbo)

The Formation occurs as a single cluster in the south-western sector of the map sheet approximately 50km southwest of Derdepoort. Regarded as the ''Upper Sedimentary Zone'' of the

Ventersdorp Super Group, the Formation disconformably overlies the graben-fill deposits of the Platberg Group. The sand-grade sediments of the Bothaville Formation are the most mature in the whole Ventersdorp Super Group; they have a subgraywacke to subarkosic composition that differentiates them from the Rietgat Formation which has more immature graywackes (SACS, 1980). The unit as indicated in Figure 57 consist of minor dark shale.

No groundwater information was available to give an indication of the expected yield and quality of the unit. It covers 0.07% of the total map area.

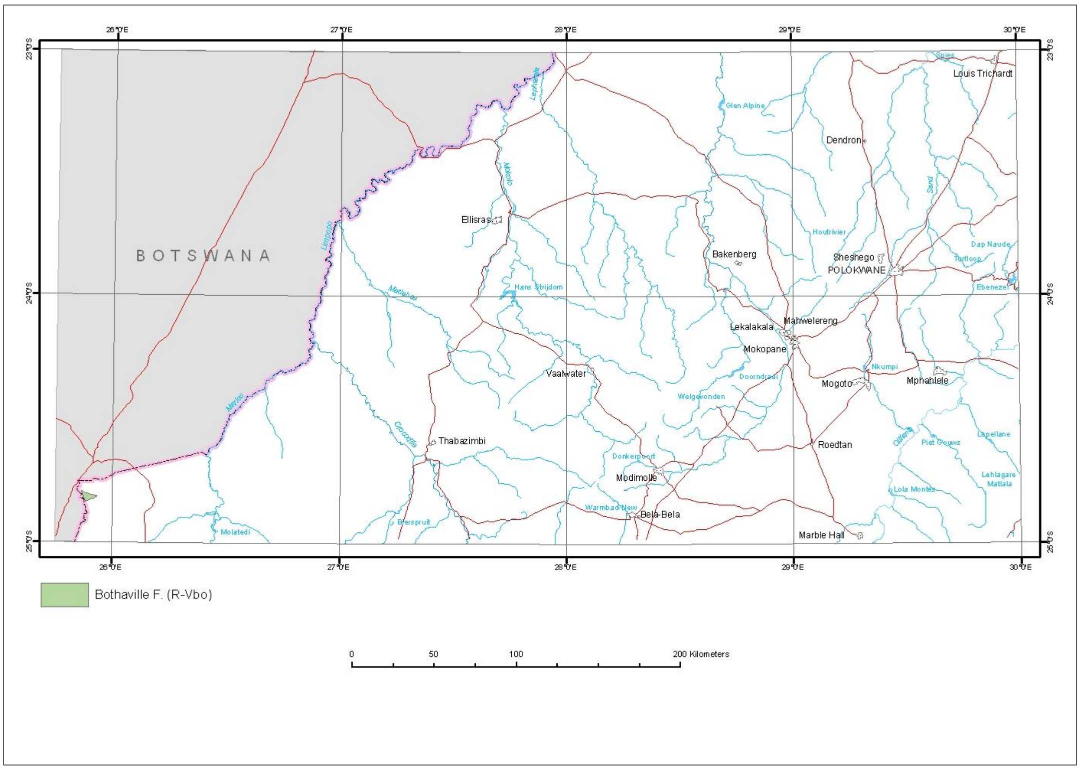

Figure 57: Geographical distribution of the Bothaville Formation (R-Vbo)

7.2.1.18 PLATBERG GROUP (Rp) (Conglomerate and sediments)

The Platberg Group unconformable overlies the Klipriviersberg Group and is divided into two formations i.e. the Kameeldoorns and Makwassie Formations respectively. The Kameeldoorns Formations which represents the fractured aquifer unit of the Platberg Group has accumulated at the base in a block-faulted terrain and is characterized by rapid facies changes and interfingering. At the fault scarp it fines rapidly away from a greywacke boulder conglomerate to coarse immature first-cycle sediments and by marked facies variations due to contemporary tectonism.

The Platberg Group occurs as narrow strips in two areas east of Thabazimbi (Figure 58). The occurrence nearest to Thabazimbi has now been placed under the Transvaal Super Group (1:1000 000 South African geological map sheet and explanatory booklet, fourth edition, 1984) and renamed as the Buffelsfontein Group.

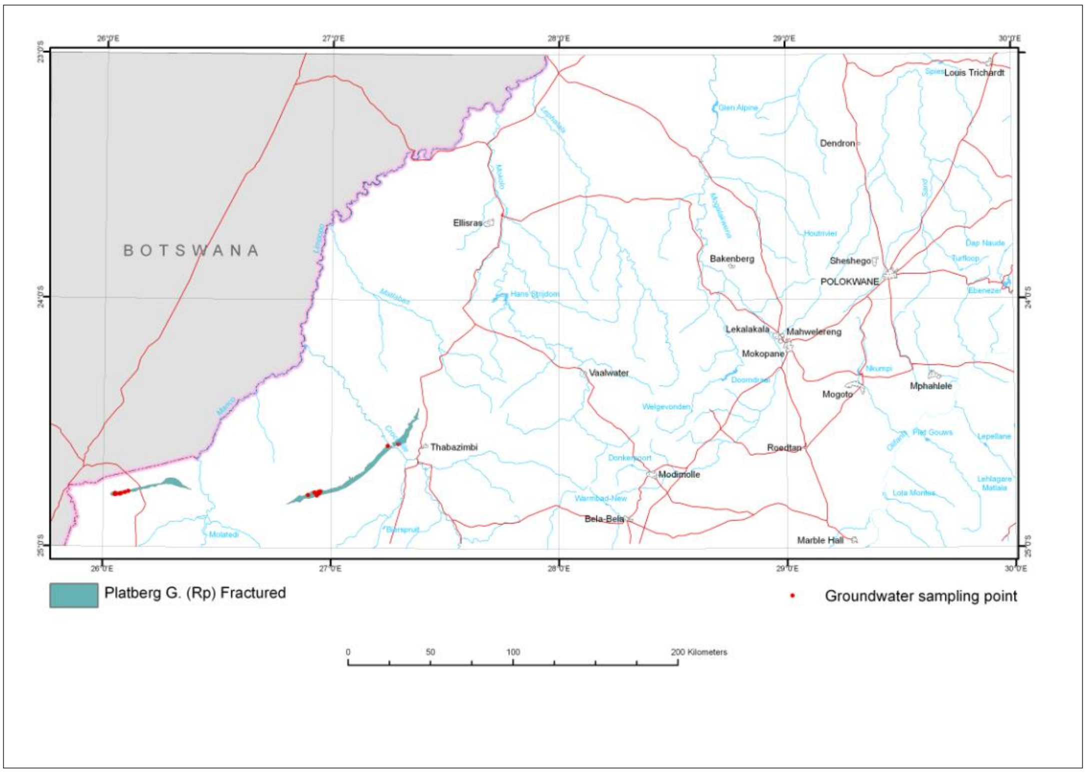

Figure 58: Geographical distribution of the Platberg Group (Rp) (conglomerate and sediments) and the associated groundwater sampling points

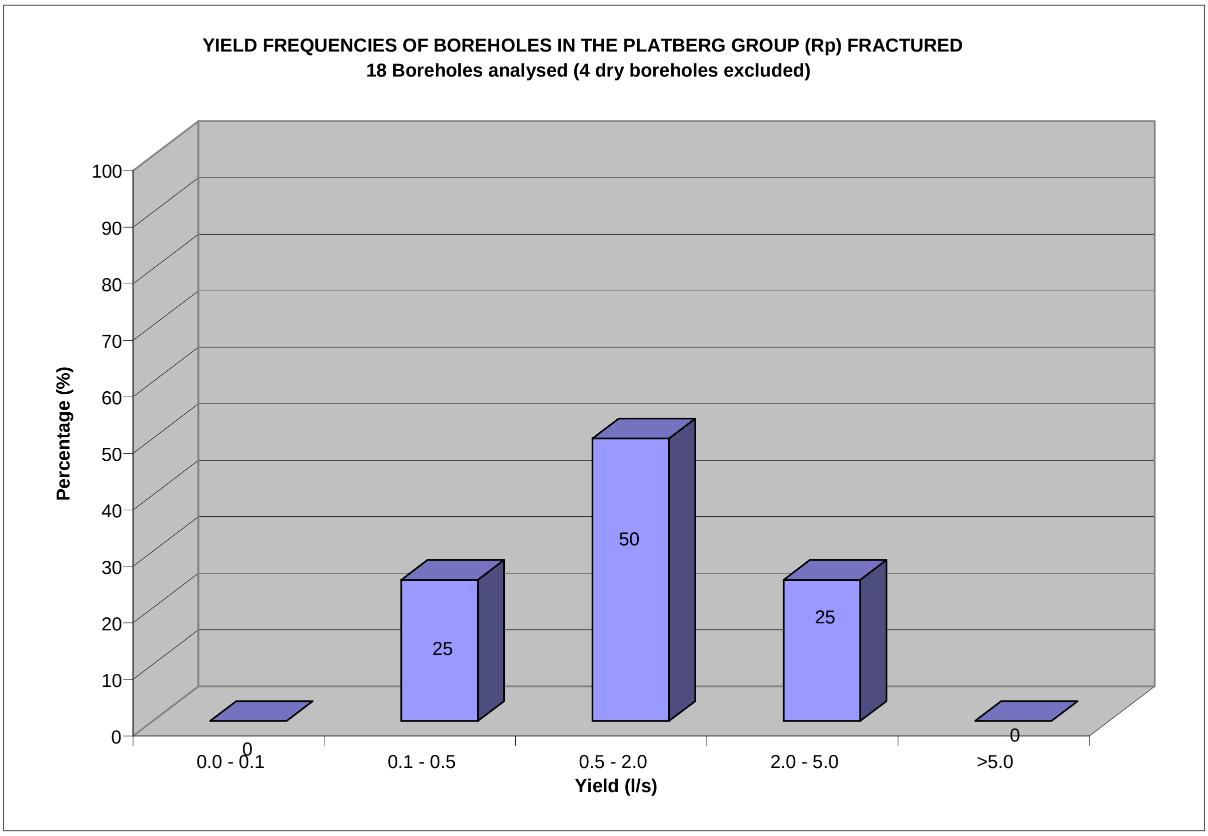

Figure 59: Yield frequency for fractured aquifers of the Platberg Group (Rp) (conglomerate and sediments).

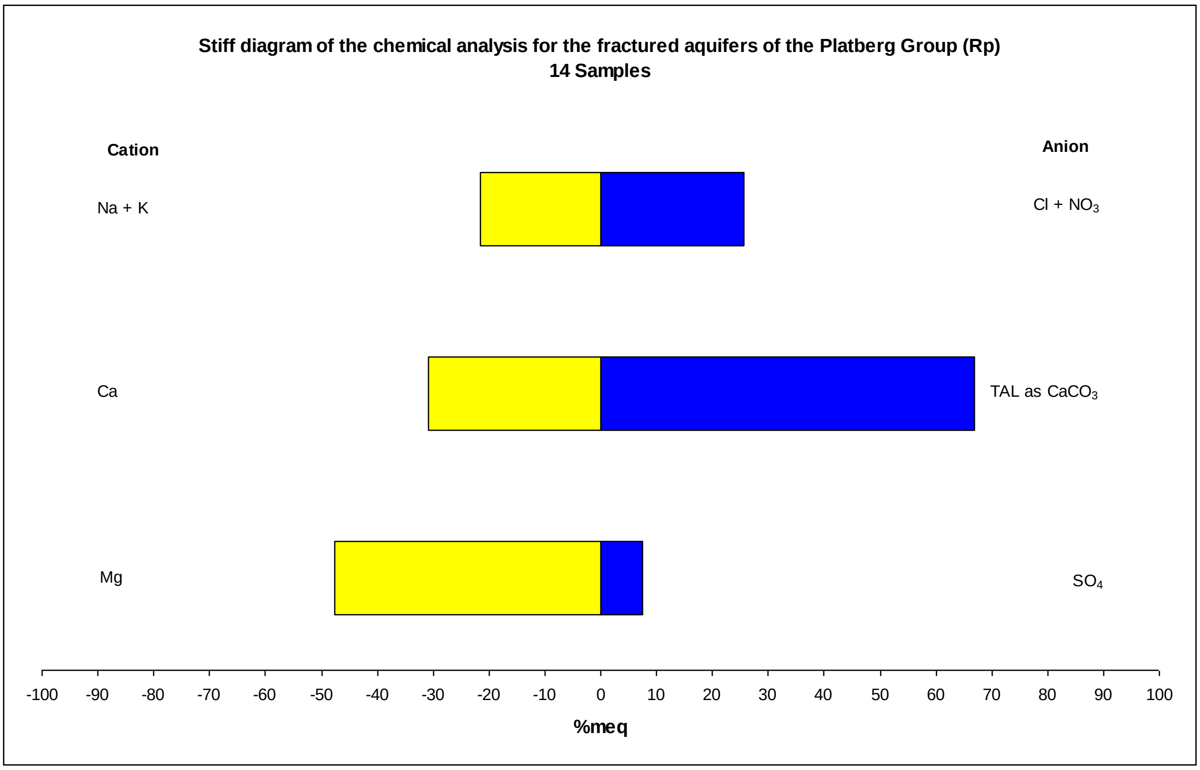

Figure 60: Stiff diagram representing chemical analysis of the Platberg Group (Rp) (conglomerate and sediments).

Although borehole information is limited, the distribution of data points and the results of the frequency diagram give a good indication of the low to moderate aquifer potential of the unit. Low to moderate (0.5 to 2ℓ/s) yielding boreholes dominates (50%) with 25% of the successful boreholes yielding moderate to high yields (2 to 5ℓ/s). Various east and north-easterly trending faults occur that can be targeted for groundwater development.

The results of 14 chemical analyses were available for analysis. The stiff diagram representing the chemistry of the unit (Figure 60) shows the broad classification according to anions and cations. The water displays a magnesium-calcium-sodium-bicarbonate-chloride character.

The EC values ranges between 77-281mS/m with a harmonic mean of 108.9mS/m. In 86% of the samples fluoride concentrations is within the ideal limit for domestic supplies (F <0.7mg/l) with the rest within the acceptable range (F <1mg/l). In 79% of the analysis unacceptable nitrate and nitrite (reported as N) concentrations (N >20mg/l) are reported. The (N) concentrations range between 0.2-302.9mg/l with 57% higher than 40mg/l. The reason for the high nitrate (N) is not known.

7.2.2 CATEGORY C: KARST AQUIFERS

7.2.2.1 CHUNIESPOORT GROUP (Vh) (Carbonate rocks)

The **Chuniespoort Group's** carbonate rock unit which covers approximately 0.3% of the total map area, occurs mainly at two separate localities viz. Thabazimbi, Mokopane (Potgietersrus), and Wolkberg. Smaller occurrences are found in the Bela Bela (Warmbaths), Marble Hall and Northam areas (Figure 61). It consists of an alteration of chert-bearing and chert-free dolomite with the Duitschland Formation consisting of dolomite, shale and limestone at the base with an increase of clastic material towards the top. The Malmani and Duitschland Formation have been grouped together to represent the carbonate rocks of the Chuniespoort Group.

Plate 7: Dolomite of the Malmani Subgroup in a road cutting along the N1 toll road on the farm Planknek 43KS. (Photograph: WH du Toit).

Groundwater occurs along **fault and shear zones** associated with intense deformation resulting in the occurrence of fractures, joints, and cavities subsequently enlarged by dissolution processes in the dolomites. The groundwater potential of the carbonate rocks in primary form is generally poor. Groundwater also occurs in weathered and fractured shales of the **Duitschland Formation**. Borehole yields are generally moderate to high with 29% (Figure 62) in excess of 2ℓ/s. Access to these dolomitic areas is severely hampered by the mountainous terrain especially in the Wolkberg area, which contributes to groundwater in this unit being under-utilized.

Except for the Mokopane (Potgietersrus) occurrence, which has been thoroughly studied and its groundwater resources extensively utilized (3-5m^3/annum), very little is known about the groundwater resources of the other two areas. The abstraction at the Mokopane occurrence is mostly from the Duitschland Formation underlying the Dorps River valley. Regional and local thrust faulting duplicated the Subgroup in the Thabazimbi occurrence rendering it a very complicated local hydrogeological system. Little groundwater is abstracted from the dolomites in this area. Southwest of Thabazimbi a very dense syenite dyke swarm (Pilansberg age) occurs in the dolomites rendering its groundwater potential lower within this area. Virtually no groundwater is abstracted from the Wolkberg dolomites. River base flow studies conducted in the Rooip-B (Tongwane River) sub-catchment indicated an average annual recharge to groundwater of the order of 4.5 x 10^6 m^3 (Fayazi, 1993).

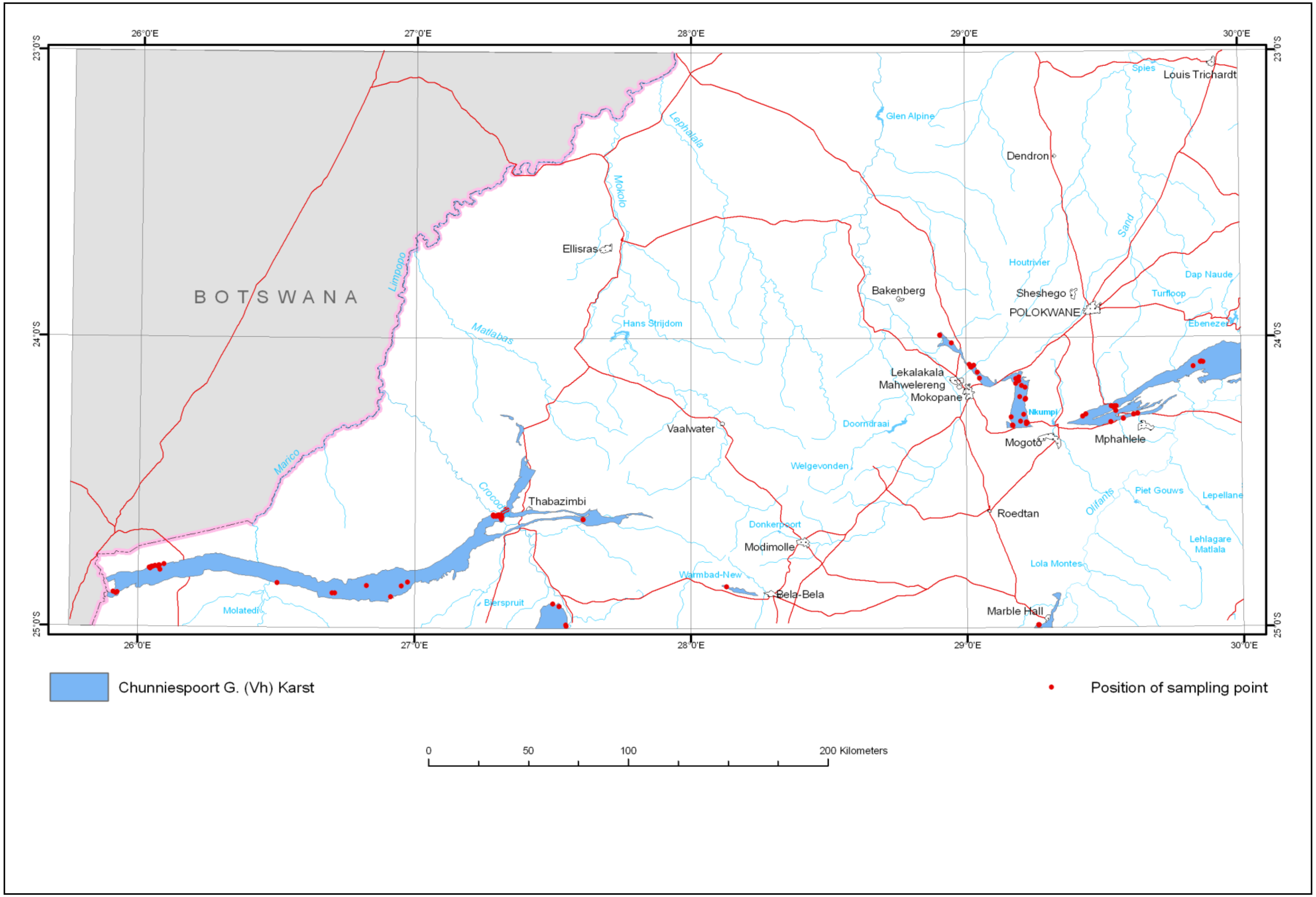

Figure 61: Geographical distribution for the Karst aquifers of the Chuniespoort Group (Vh) (carbonate rocks) and the associated groundwater sampling points

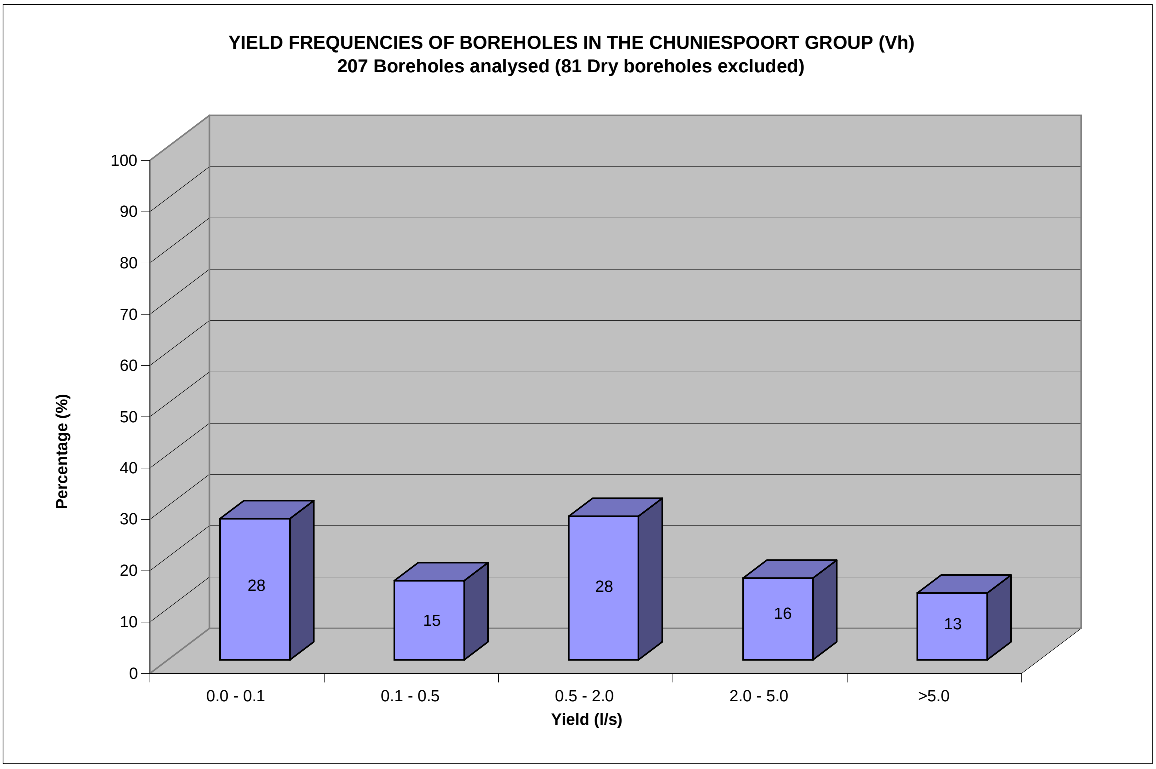

Figure 62: Yield frequency for Karst aquifers of the Chuniespoort Group (Vh) (carbonate rocks).

Numerous seasonal and in many cases perennial springs occur in all three cluster areas contributing significantly to the base flow component in major rivers such as the Olifants and Dorps. Some springs occurring in the lower Dorps River catchment have been effected by abstraction from boreholes for the town of Mokopane (Potgietersrus).

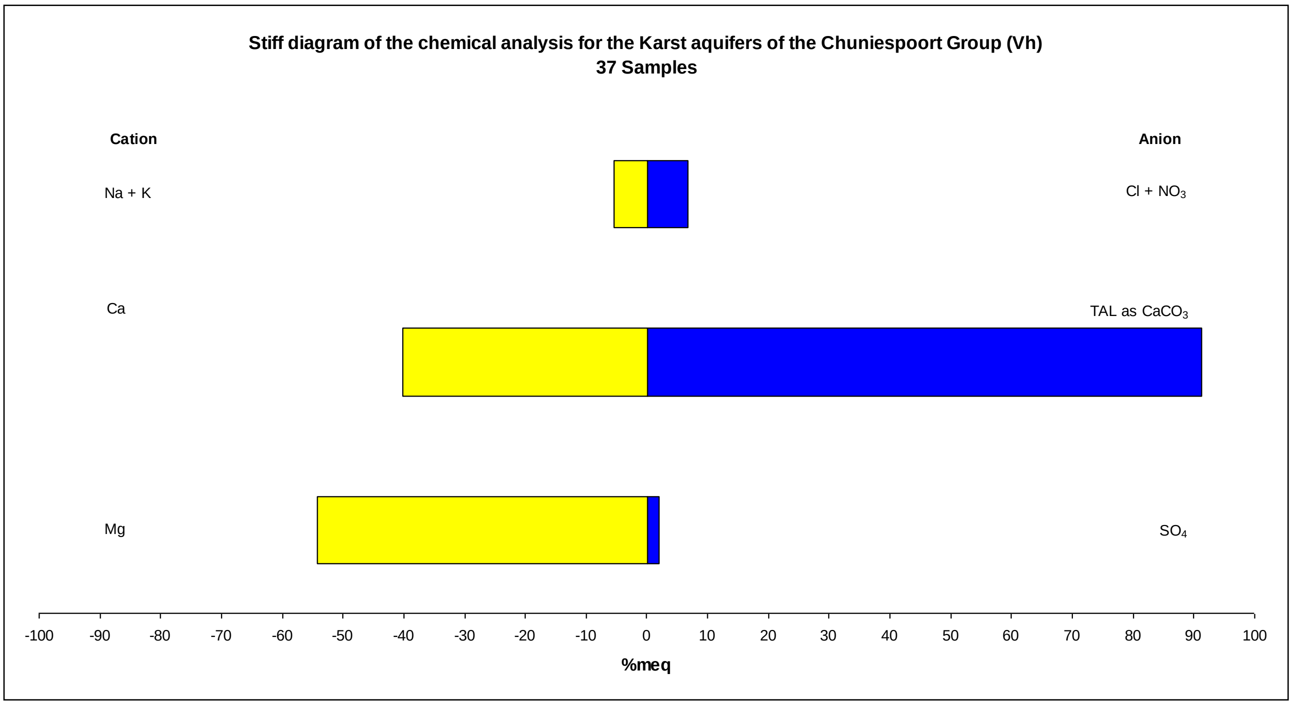

Figure 63: Stiff diagram representing chemical analysis for the Karst aquifers in the Chuniespoort Group (Vh) (carbonate rocks).

As anticipated from the lithology of the unit, the groundwater is classified as a magnesium-calcium-bicarbonate water type (Figure 63). 87% of the chemical data used have acceptable water quality for domestic purposes (SANS 241, 1999) in terms of EC values (<150mS/m) and of nitrate and nitrite (reported as N) concentrations (N <10mg/l). The harmonic mean for the EC and (N) is 66.7mS/m and 0.16 mS/m respectively with the highest reported as 347mS/m and 23mg/l. It seems from a comparison between boreholes close to and far away from rural villages, that the elevated (N) concentrations are located in or near rural villages thus confirming the possibility of pollution from pit latrines or cattle kraals.

7.2.3 CATEGORY D: INTERGRANULAR AND FRACTURED AQUIFERS

- Lebombo Group (Jl)
- Clarens Formation (Trc)
- Irrigasie Formation (P-Tri)
- Ecca Group (Pe) (Shale, grit and sandstone)
- Diabase (N-Zd)
- Spitskop Complex (Msp)
- Soutpansberg Group (Ms) (Basalt)
- Lebowa Suite (Mle)
- Rustenburg Suite (vr)
- Pretoria Group (Vp) (Shale, quartzite and diabase)
- Crocodile River Fragment (Vco)
- Meinhardskraal Granite (Vnh)
- Turfloop Granite (Vtu)
- Unnamed Vaalian Rocks (Vz)
- Matlala Granite (Rat)
- Gaborone Granite (Rga)
- Utrecht Granite (Rut)
- Uitloop Granite (Rui)
- Lunsklip Granite (Rlu
- Moletsi Granite (Rmo)
- Matok Granite (Rma)
- Hugomond Granite Rhu)
- Geyser Granite (Rge)
- Platberg (Rp) (Mostly lavas)
- Kanye Formation (Rka)
- Klipriviersberg Group (Rk)
- Hout River Gneiss (Rho)
- Modipe Complex (Zmo)
- Messina Suite (Zbn)
- Goudplaats Gneiss (Zgo)
- Beit Bridge Complex (Z)
    - Gumbu Group (Zbg)
    - Malala Drift (Zba)
    - Mount Dowe Group (Zbo)
- Bandelierskop Complex (Zga)
- Pietersburg Group (Zp)
- Unnamed Swazian Rocks (Zz)

Intergranular and fractured aquifers cover approximately 23.5% of the total map area. Figure 64 shows the Geographical distribution of the intergranular and fractured aquifers.

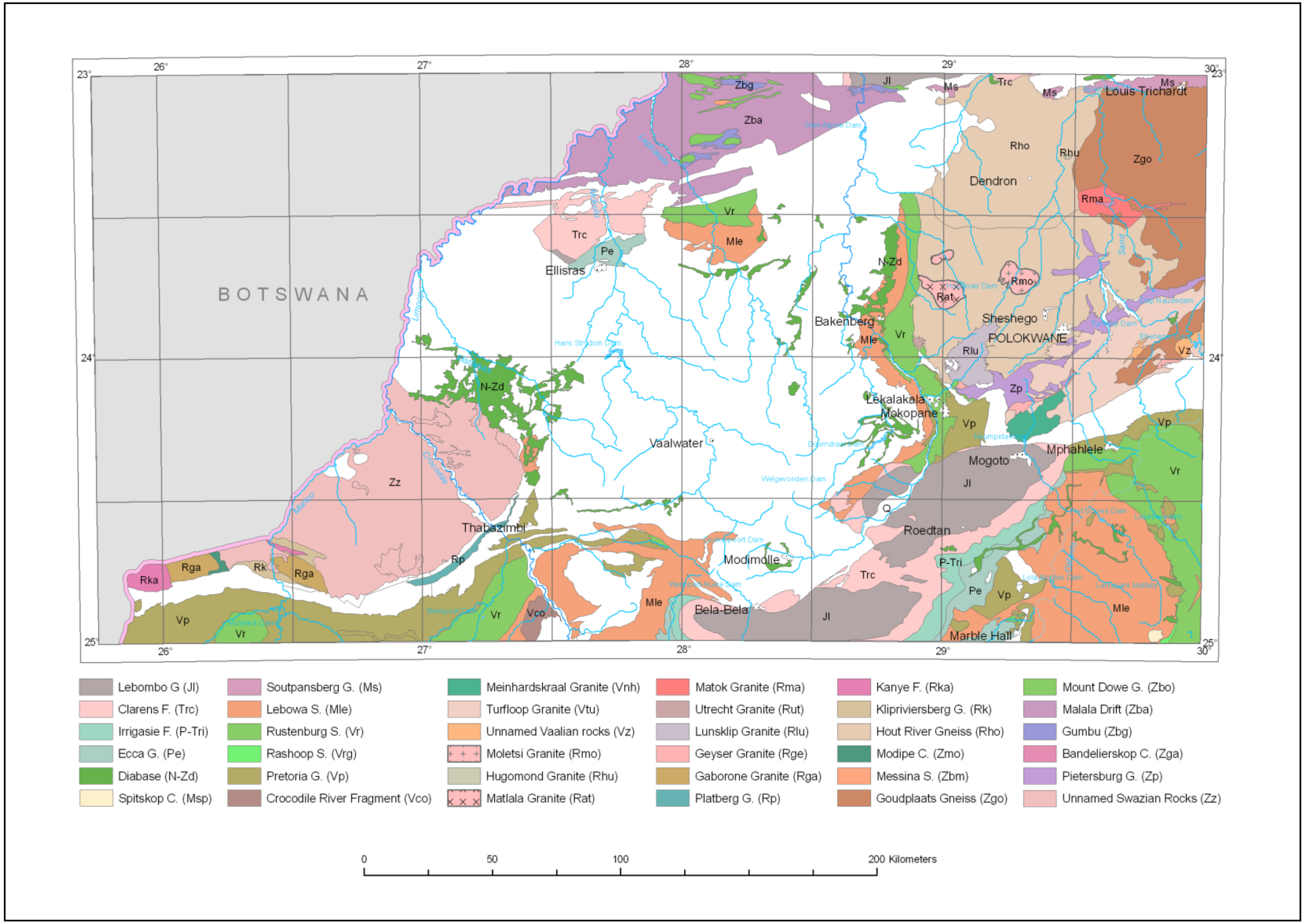

Figure 64: Geographical distribution of the intergranular and fractured aquifers

7.2.3.1 LEBOMBO GROUP (Jl)

The Lebombo Group which is completely made up of the Letaba Formation occurs in three areas on the map sheet i.e. the northern and southern Springbok Flats respectively and a small occurrence along the 23º latitude (Figure 65). It comprises a succession of several amygdaloidal lava flows. The amygdales (pine-like cavities of gas chambers) are filled with zeolites and secondary products. The Formation is extensively covered by black clayey soil resulting in limited outcrop, the fresh rock being typically basalt. The Letaba Formation, a name applied to all basaltic lava of Karoo age in Limpopo province prominently follows and overlies the Clarens Formation. The Springbok Flats occurrence is delineated on its northern boundary by major fault zones known as the Zebediela and Welgevonden faults respectively. The occurrence along the 23º latitude is partly delineated by the Melinda fault zone. The unit covers approximately 4.5% of the total map area.

Plate 8: View of the Springbok Flats from the R101 about 20 km north of Naboomspruit (Mookgophong)). The Springbok Flats is a well-known geographical landmark in Limpopo and regarded by many in the region as the breadbasket of the province. Groundwater is abstracted extensively from Karoo lavas and sediments underlying the Flats for irrigation purposes. (Photograph: WH du Toit).

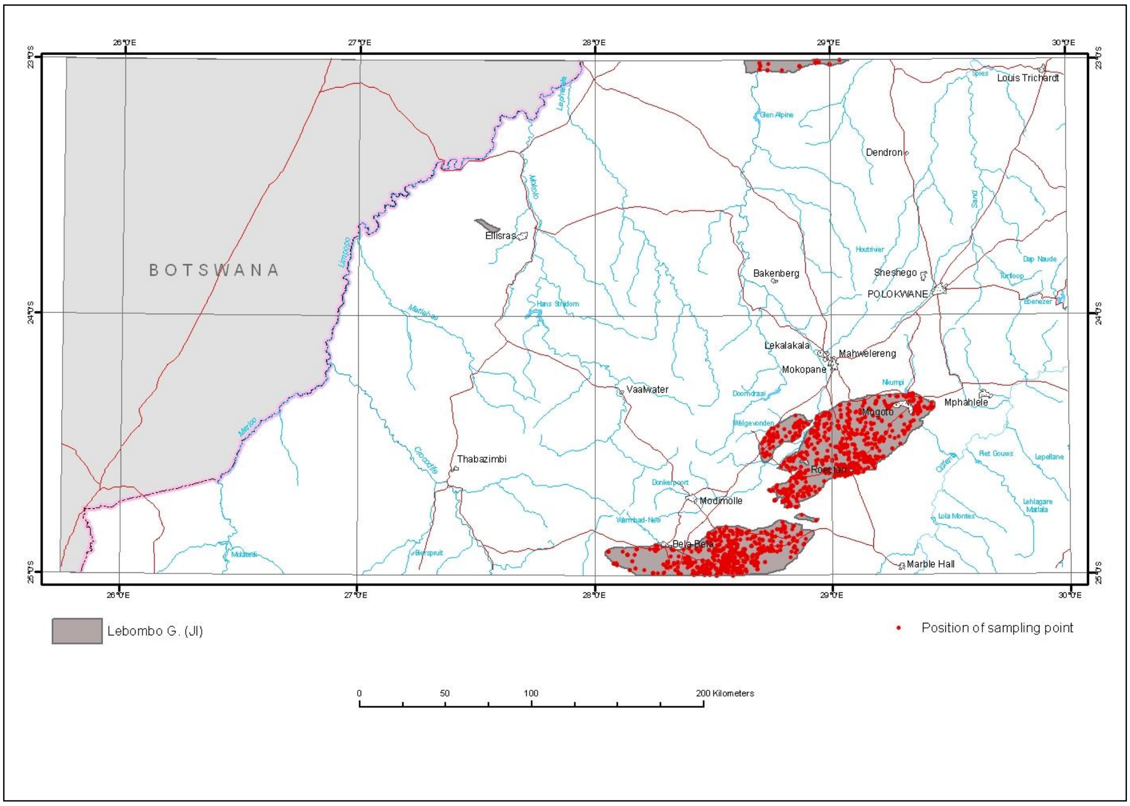

Figure 65: Geographical distribution for the intergranular and fractured aquifers of the Lebombo Group (Jl) and associated groundwater sampling points.

This high potential basaltic aquifer is of great agricultural importance in the area. During 1987 a study estimated groundwater abstraction to be as much as 40.6 x 10^6 m^3/a for irrigation purposes. Water is obtained in shallow weathered and fractured basalt (up to 50m from the surface) and deep fractures within the fresh basalt, which occur at depths of 150m (Fayazi, 1994). The weathering and fracturing resulted in the development of secondary porosity and permeability, which control the storage and movement of the groundwater in this formation. Water also occurs on the contact between different lava flows and the contact between the basalt and underlying Clarens Formation.

Statistics revealed that 69% (Figure 66) of the successful boreholes yield more than 2ℓ/s. The depth to groundwater level varies between 10 and 20m. Some of the deeper groundwater levels are related to over-pumping effects in the area. A study of the results from groundwater level recorders situated in the area revealed that the annual rise in the groundwater level in the basalt and basalt/sandstone (underlying Clarens Formation) aquifer varies with the annual rainfall where a minimum annual rainfall of 300mm and a maximum of 600mm is required to generate a rise in the groundwater level (Fayazi, 1994).

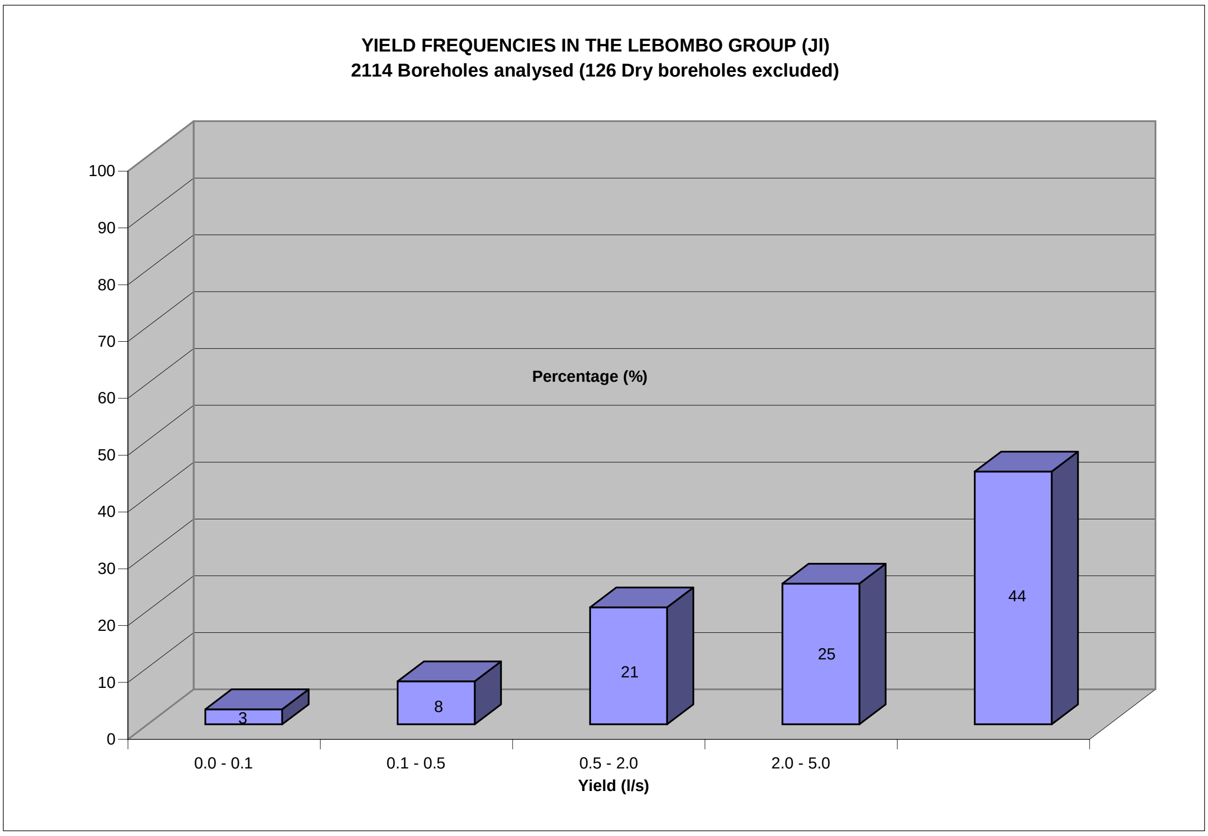

Figure 66: Yield frequency for the intergranular and fractured aquifers of the Lebombo Group (Jl).

As discussed agriculture (irrigation) is the biggest user of groundwater in the area. Water is also used for livestock watering and domestic purposes. In many places it is the only source of water despite the high nitrate concentration that is evenly distributed throughout the unit.

48% of the reported EC values (EC <150mS/m) falls within the acceptable limits and additionally to this another 39% (EC <370mS/m) falls within the maximum allowable limits for domestic use. The chemical results available for nitrate and nitrite concentrations (reported as N), shows that 50% falls within the acceptable limits (N <6mg/l) and 16% within the maximum allowable limit (N <20mg/l). The concentration for (N) varies between 0.02 to 250mg/l with a harmonic mean of 35mg/l for the unit. Isotopic studies done by the Council for Scientific and Industrial Research (Heaton, 1985) on the source of the elevated nitrate content indicated that the nitrate was derived solely from nitrification of the soil and not from the use of fertilizer or other sources. The combined chemical analysis presented in Figure 67 indicates that the water is of a sodium-calcium-bicarbonate-chloride type. The high chloride concentration is a result of irrigation practices and a shallow groundwater level (Fayazi, 1994). Where this unit is in contact with dolomitic aquifers (Zebediela area) the water is a calcium-magnesium-bicarbonate type.

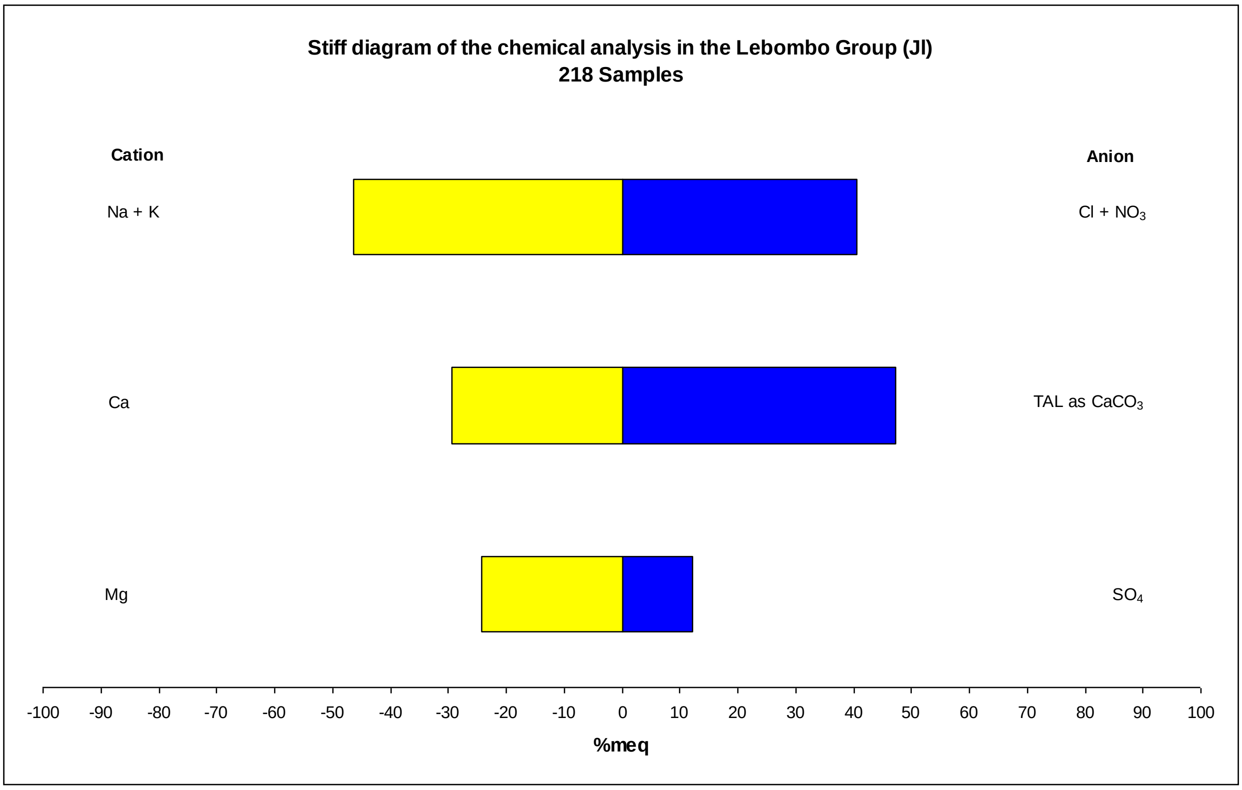

Figure 67: Stiff diagram representing chemical analysis of the Lebombo Group (Jl)

7.2.3.2 CLARENS FORMATION (Trc)

This Formation occurs north of Lephalale (Ellisras) and on the Springbok Flats where it encircles and underlies the basaltic rocks occupying the central part of the basin (Figure 68). The Formation consists essentially of fine-grained, aeolian sandstone. Some dolerite dykes and sills have intruded the Formation. It covers approximately 2.8% of the total map area.

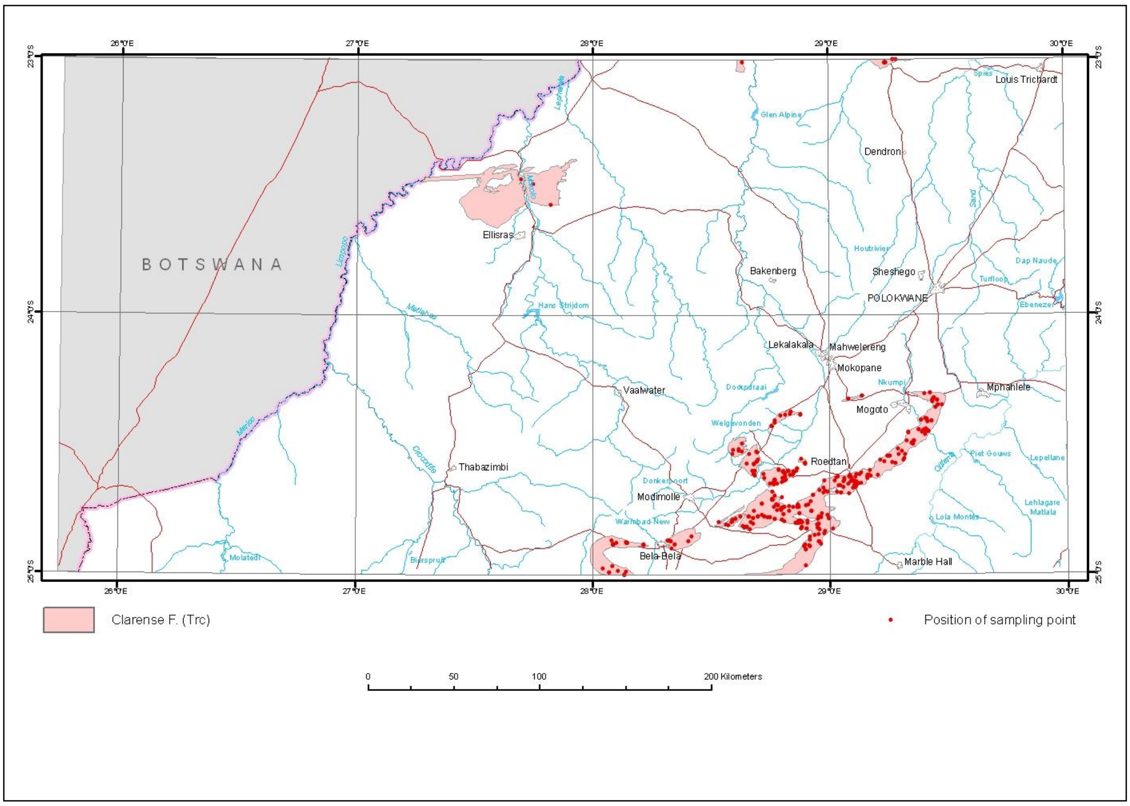

Figure 68: Geographical distribution of the Clarens Formation (Trc) and the associated groundwater sampling points.

The sandstone has a low to very low primary permeability with low storage potential. Statistics reveal that 67% (Figure 69) of the successful boreholes yields less than 2ℓ/s. The relative moderate to high yielding boreholes which penetrated the sandstone of the Clarens Formation in the Crecy area are related to fractures in hard re-crystallised layers within the massive sandstone, or locally developed primary permeability (Fayazi, 1994). The contact zone with the overlaying basaltic rock yield water of varying quantity. Dolerite intrusions in the form of dykes and sills also created secondary fractures and joints at the contact with the host rock. These intrusions are limited when comparing it with the main Karoo Basin. High yielding boreholes also occurs in fault zones although exploratory drilling in the Crecy area revealed that the fault zone has been calcified and brecciated, reducing its groundwater storage potential considerably. The static water level varies between 10 and 30mbgl.

Studies conducted on the equivalent of this sandstone north of Vivo (Verhagen et. al., 2002, Van Wyk, 2002) and in the Kruger National Park (Du Toit, 1998) revealed the sandstone to have a significant primary porosity. In the Vivo study it was specifically found to occur where the sandstone was covered with a thick layer of basalt. Further studies are planned in the Vivo area in the near future. This phenomenon has not yet been investigated in the Springbok Flats area and is something to consider in future groundwater studies.

North of the Soutpansberg thin Letaba basalt sills are occasionally found to have intruded the sandstone, usually near the main basalt/sandstone contact. The contact zone between basalt and sandstone yields varying quantities but are usually <0.5ℓ/s. However, higher yielding water strikes is generally intercepted in the sandstone between 40 and 75m below the main basalt/sandstone contact which could be related to the phenomenon described above. The EC values are lower in the sandstone than the overlaying basalt.

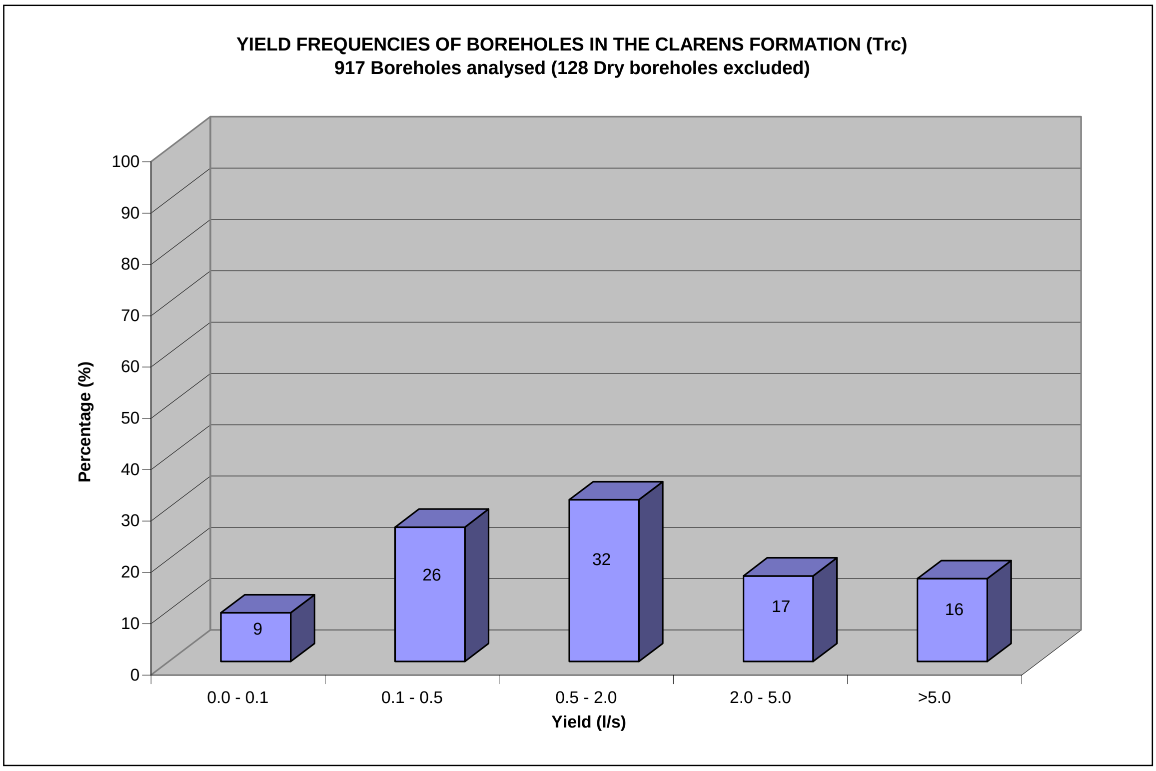

Figure 69: Yield frequency for the intergranular and fractured aquifers of the Clarens Formation (Trc).

Water is abstracted for domestic use, livestock watering and in certain areas for irrigation. The quality of the water is generally good to moderate with 79% of the EC values less than 150mS/m (harmonic mean for unit = 46.2mS/m) and 8% with values exceeding 370mS/m. More frequent occurrences of high EC values occurs within the unit in a zone extending from just south of Roedtan towards the northwest for approximately 50km. Values ranging from 16-1210mS/m (harmonic mean = 211mS/m) are reported in this zone. High fluoride (16% >1.5mg/l) and nitrate and nitrite (reported as N), (7% >20mg/l) concentrations occur randomly throughout the unit but not as frequently as within the Irrigasie Formation. The groundwater in the unit is a sodium-calcium-bicarbonate-chloride water type. (Figure 70)

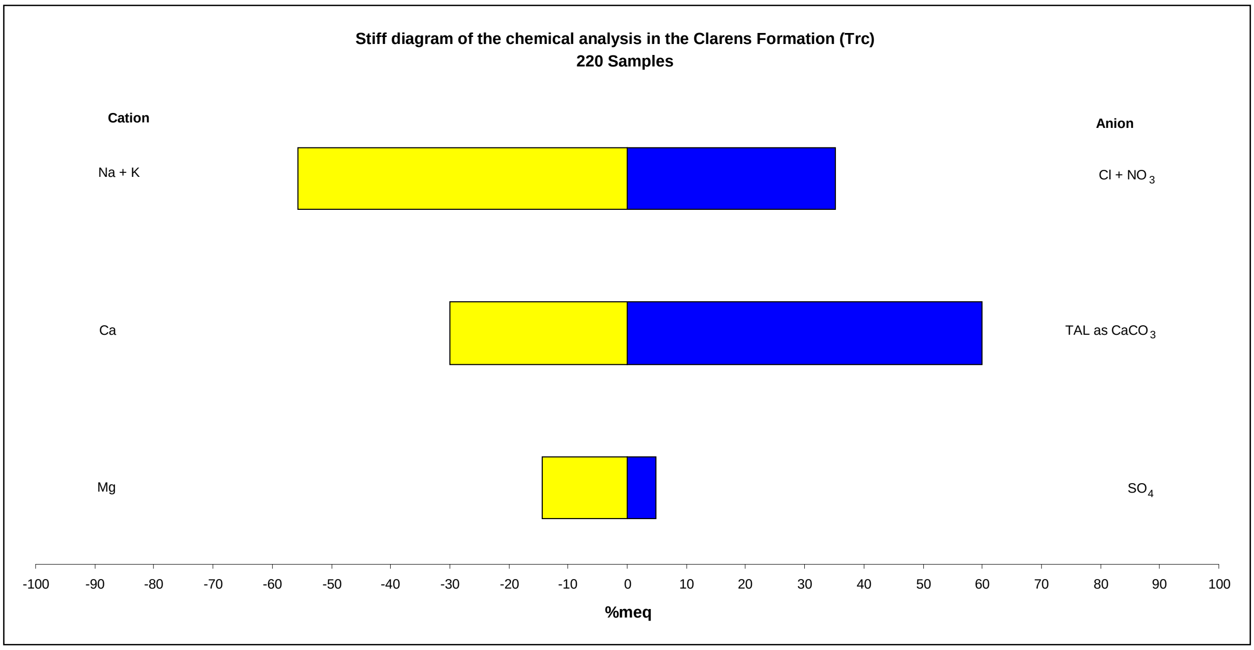

Figure 70: Stiff diagram representing chemical analysis of the Clarens Formation (Trc)

7.2.3.3 IRRIGASIE FORMATION (P-Tri)

The unit occurs as two clusters within the south-eastern quarter of the map sheet. The eastern cluster forms part of the south-eastern rim of the Springbok Flats (Figure 71). The unit consists of a succession of mudstone, siltstone, sandstone, conglomerate, shale, grit and marl intruded by minor dolerite dykes and sills. It covers approximately 4.7% of the total map area.

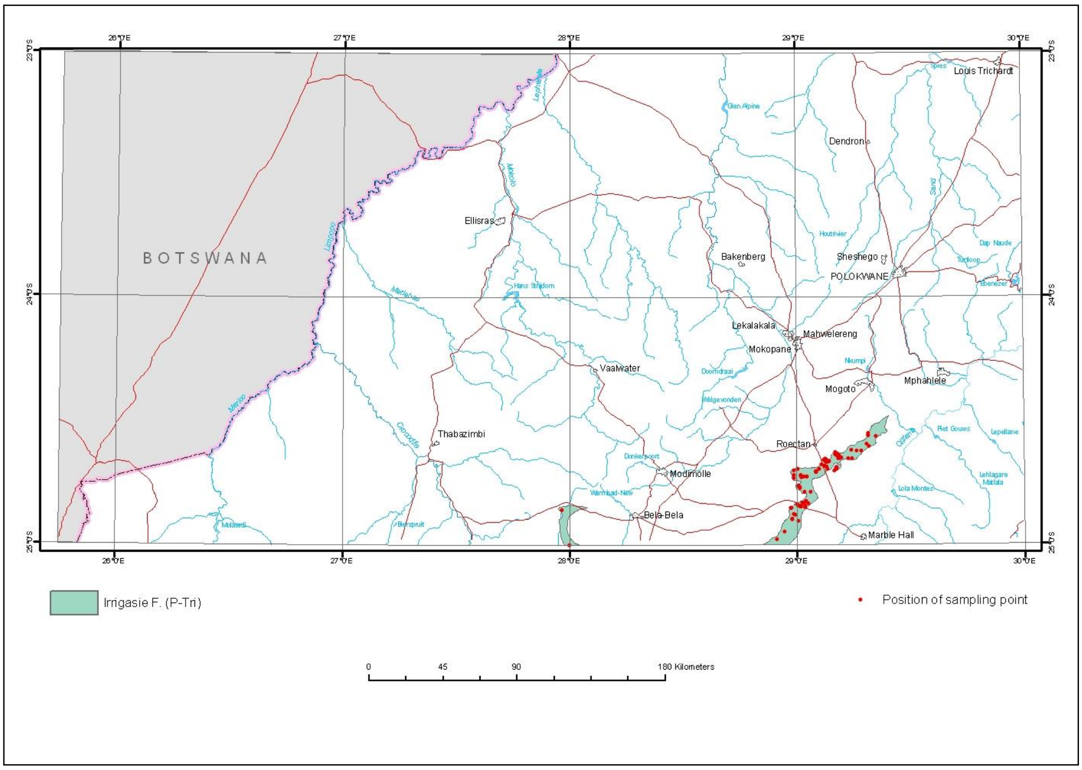

Figure 71: Geographical distribution of the Irrigasie Formation (P-Tri) and the associated groundwater sampling points

The sedimentary rocks of this Formation have low to very low primary permeability with low storage potential. Statistics indicate that 79% (Figure 72) of the successful boreholes yield less than 2ℓ/s, 13% yield between 2-5ℓ/s and 8% is more than 5ℓ/s. The high number of successful boreholes even though many are low yielding signifies that it is not difficult to find water for a single household or for livestock watering.

In general the groundwater occurrence in the sedimentary rocks is either controlled by lithology such as the contact zones between various sediments or by secondary structures such as fractures or joints locally developed along bedding planes. Groundwater can also be found in extensively developed fractures and joints within the sediments including faulting and associated shear zones. These were created through regional tectonics of the two synclinal flexures and post Karoo tectonic episodes (Fayazi, 1994). Minor dolerite intrusions occurring as dykes and sills created secondary fractures and joints at the contact with the host rock. The depth to groundwater level varies between 10 and 20m (Fayazi, 1994).

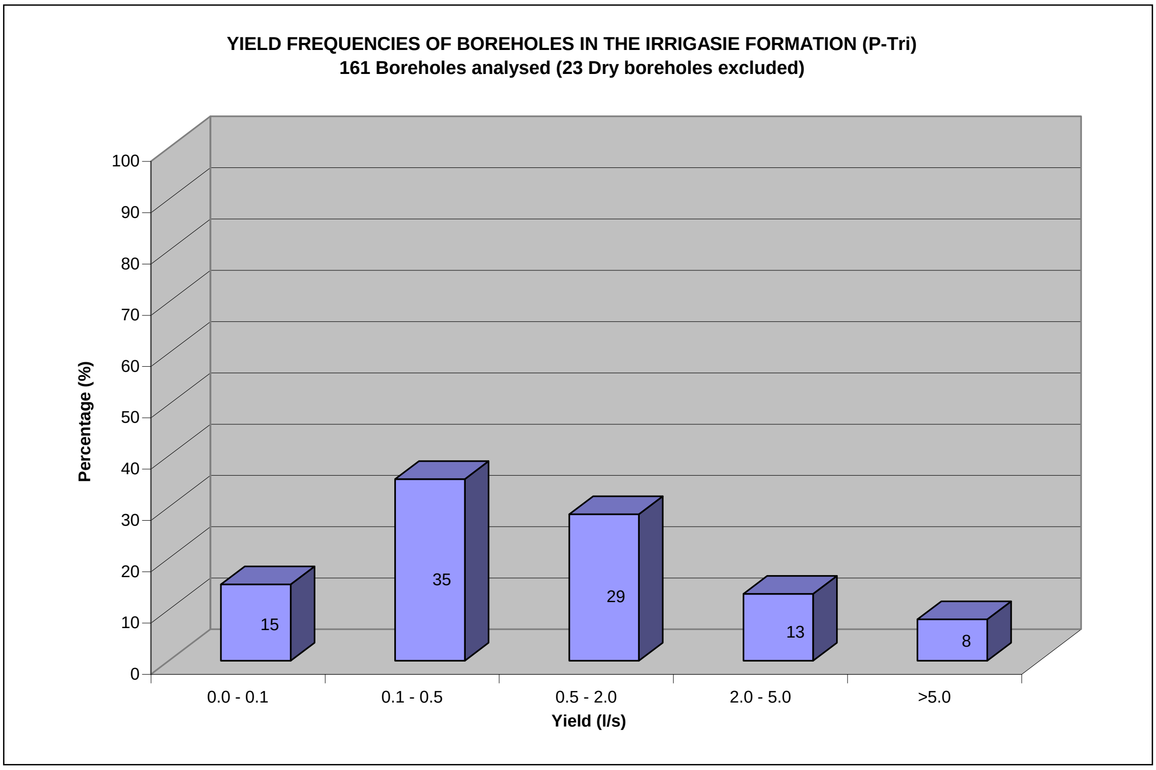

Figure 72: Yield frequency for the intergranular and fractured aquifers of the Irrigasie Formation (P-Tri).

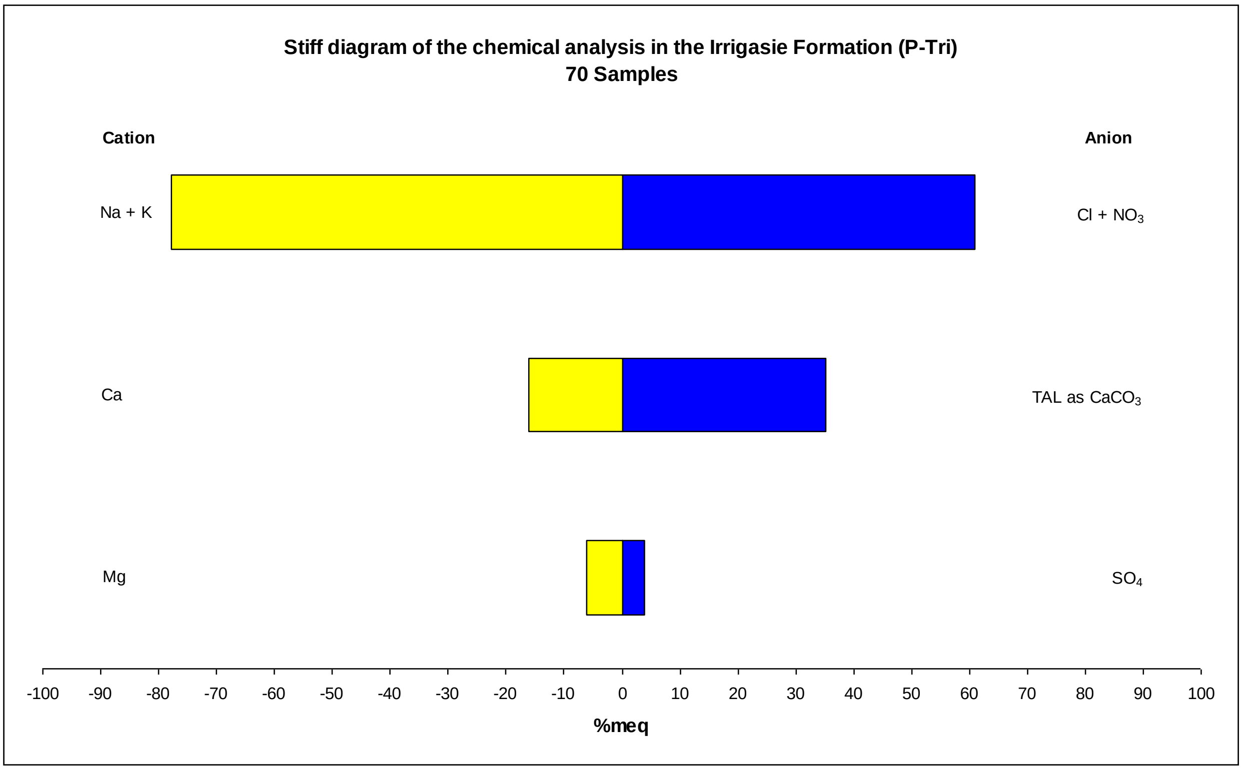

Figure 73 : Stiff diagram representing chemical analysis of in the Irrigasie Formation (P-Tri)

The water is abstracted for livestock watering and domestic purposes and where the quality and yield permits, also for irrigation. The quality of the water is generally poor and can vary over short distances. 30% of the water samples exceeding the maximum allowed quality for domestic use.

EC values range from 68-753mS/m with 41% of the samples having EC values <150mS/m and 17% >370mS/m. Nitrate and nitrite (reported as N) concentrations range between 0.02 to 35.5mg/l with one sample reported with a concentration of 236mg/l. 70% of the samples have (N <6 mg/l) concentrations and 7% exceeding the maximum allowable limit of 20mg/l. 30% of the samples have fluoride concentrations exceeding 1.5mg/l. The water is a sodium-chloride-bicarbonate water type (Figure 73)

7.2.3.4 ECCA GROUP (Pe) (Shale, grit and sandstone)

The Ecca Group occurs on the map sheet as both a fractured aquifer and an intergranular and fractured aquifer. The former is discussed in chapter 7.2.1.3. The **intergranular and fractured** aquifer unit occur predominantly in the marginal areas of the Springbok Flats basin viz. west of Bela Bela (Warmbaths) and northwest of Marble Hall. A small occurrence, the Swartrand Formation underlies an area northeast of Lephalale (Ellisras) (Figure 74). The Bela Bela and Marble Hall occurrences consist of an unclassified succession of shale, shaly sandstone, grit, sandstone, conglomerate at the base and in places coal near the base and top. High fluoride levels occur throughout this cluster although more elevated levels are reported near the contact with sediments of the Pretoria Group. It most probably originates from the Bushveld Granites which is known for high fluoride concentrations. The Lephalale (Ellisras) occurrence is divided into three zones with a total maximum thickness of 130m consisting of sandstone, siltstone, coal, and mudstone. Almost all the captured boreholes within this cluster have high fluoride levels. The reason for these high fluoride concentrations is still unknown.

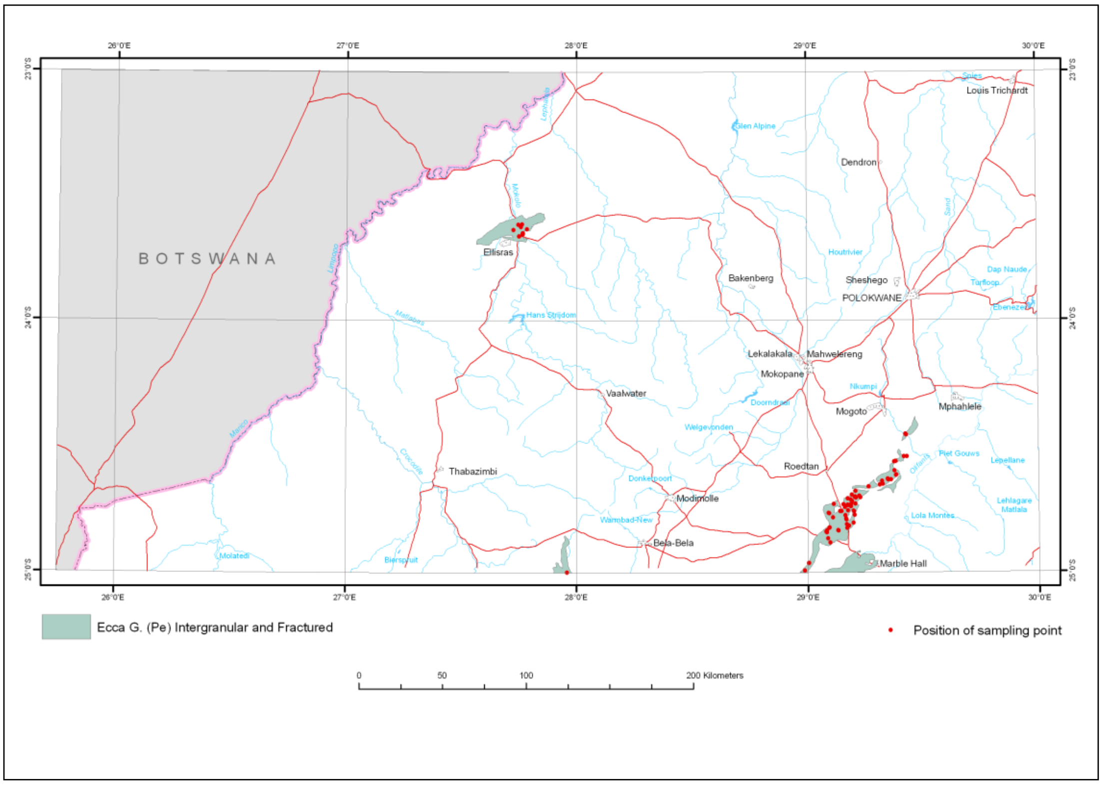

Figure 74: Geographical distribution of the Ecca Group (Pe) (shale, grit & sandstone) and the associated groundwater sampling points.

Rocks in this unit have a low to very low primary permeability with low storage potential. Statistics indicate that 64% (Figure 75) of the successful boreholes yield less than 2ℓ/s. Some high yields were obtained in the Bela Bela (Warmbaths) area on the contact zone between the overlying Irrigasie Formation and Ecca Group. 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. An impervious thick intrusive dolerite sill causes artesian conditions on the eastern part of the northern Springbok Flats. The depth to the static groundwater level is generally between 10 and 20mbgl.

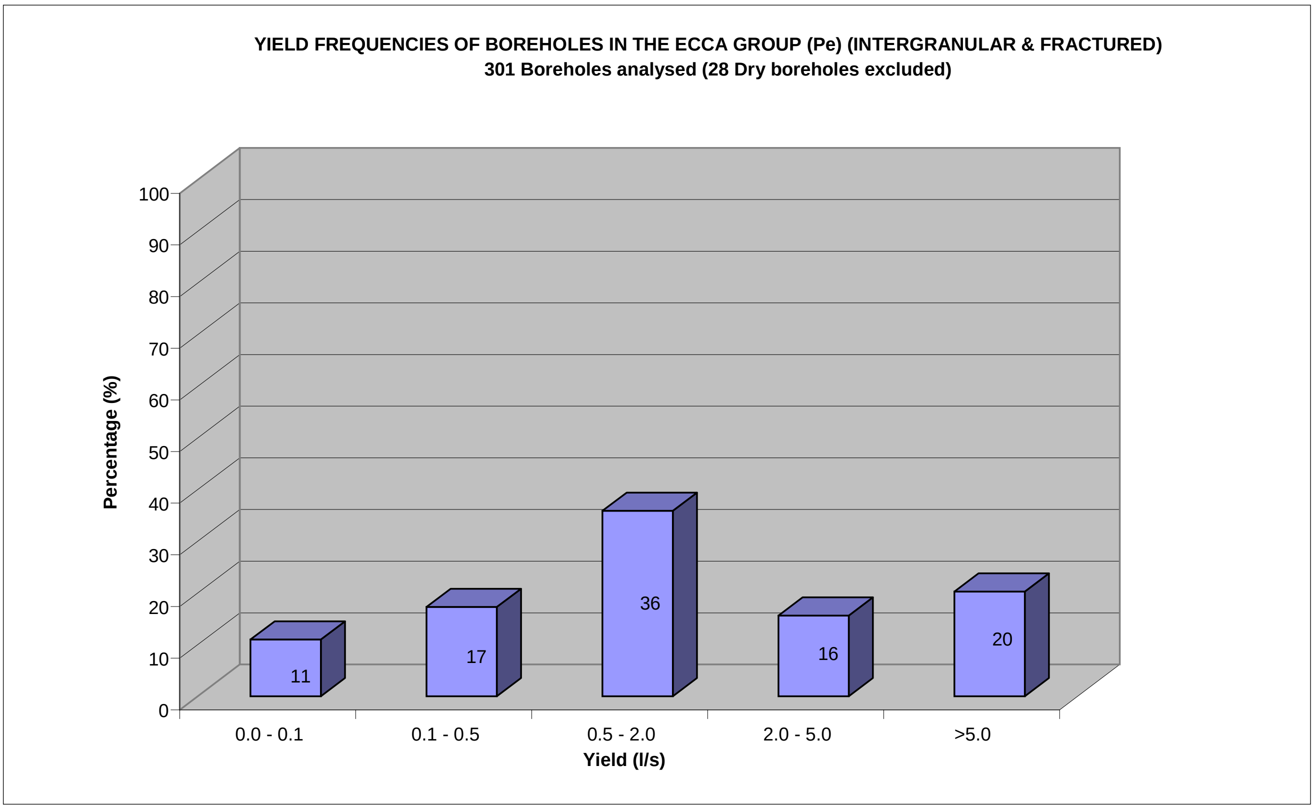

Figure 75: Yield frequency for the intergranular and fractured aquifers of the Ecca Group (Pe) (shale, grit & sandstone).

The water is abstracted for livestock watering and domestic purposes and where the quality and yield permits, for irrigation. The quality of the water is generally poor with EC values ranging from 52-625mS/m with a Harmonic mean of 121.5mS/m. Samples exceeding the maximum allowed limits is 13% for EC values (EC >370mS/m), 23% for fluoride (F >1.5mg/l) and only 4% for nitrate and nitrite (reported as N >20mg/l). The water is of sodium-chloride type (Figure 76). The general quality of the water can vary over short distances. The quality was not correlated with borehole depth or intersected lithology.

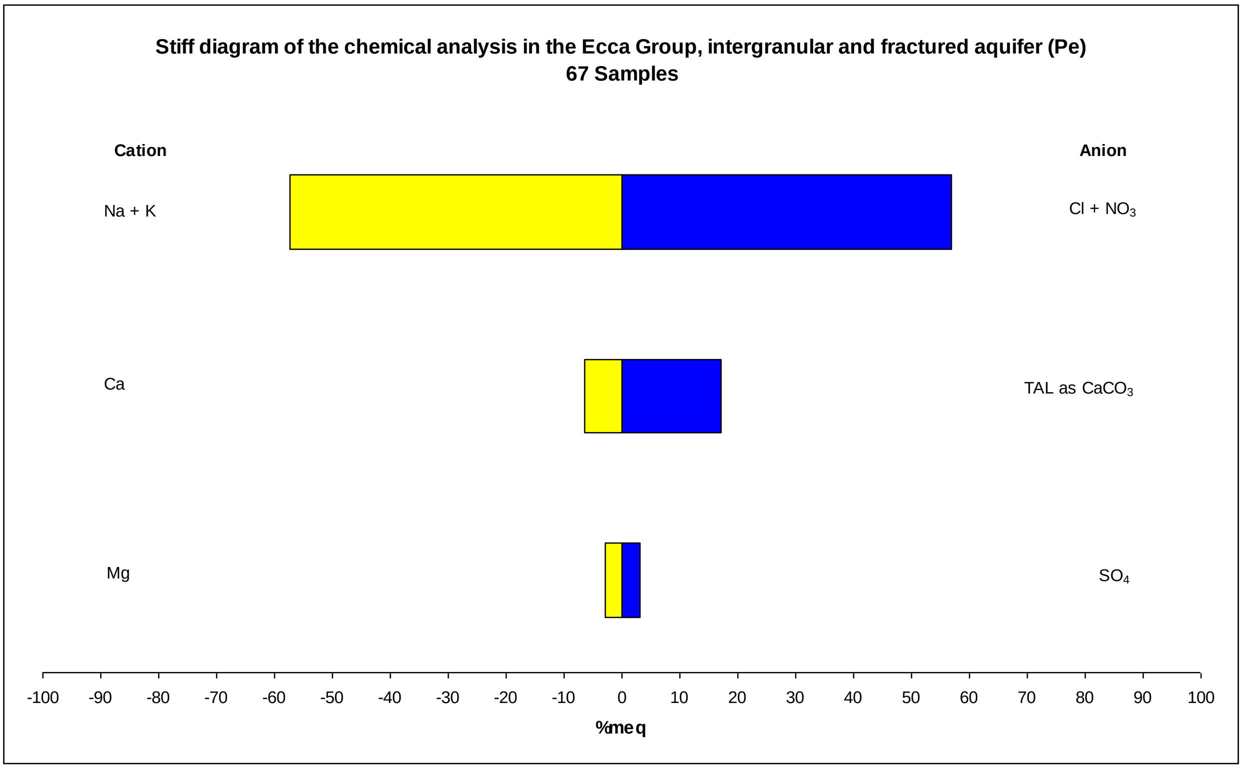

Figure 76: Stiff diagram representing chemical analysis of the Ecca Group (Pe), (shale, grit & sandstone).

7.2.3.5 DIABASE (N-Zd)

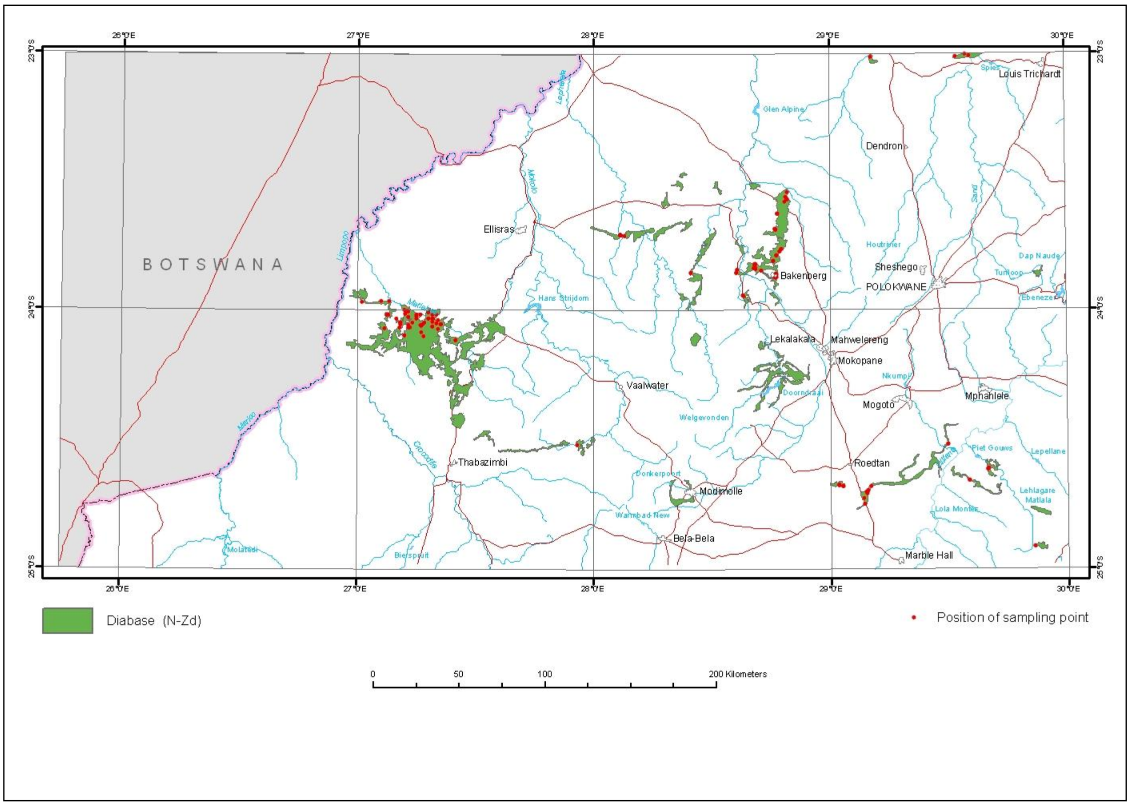

Figure 77: Geographical distribution of the Diabase intrusions (N-Zd) and the associated groundwater sampling points

This unit consists of diabase intrusions that includes sills and dykes that occur in almost all the pre-Karoo formations in the area. Sills in particular occur widely in the central parts northwest of Polokwane (Pietersburg) and east of Lephalale (Ellisras) as well as north of Marble Hall and northwest of Thabazimbi (Figure 77). In the Swazian rocks and in the Hout River Gneiss, dykes often give rise to ridges but in the sedimentary rocks they usually form negative topographic features. The scale of maps prohibits the inclusion of all dyke intrusions (Figure 6) but it gives some indication of frequency and trend of occurrence in certain areas as discussed in chapter 5. Diabase occurrences within the map sheet vary from aphanitic to coarse-grained, are greenish black, of gabbroic composition and have an ophitic texture. A specimen from north of Villa Nora consists typically of augite, calcic plagioclase and hornblende with accessory hypersthene, quartz, biotite and iron ore (Geological map sheets explanatory booklets). The unit underlies approximately 1.8% of the map sheet area.

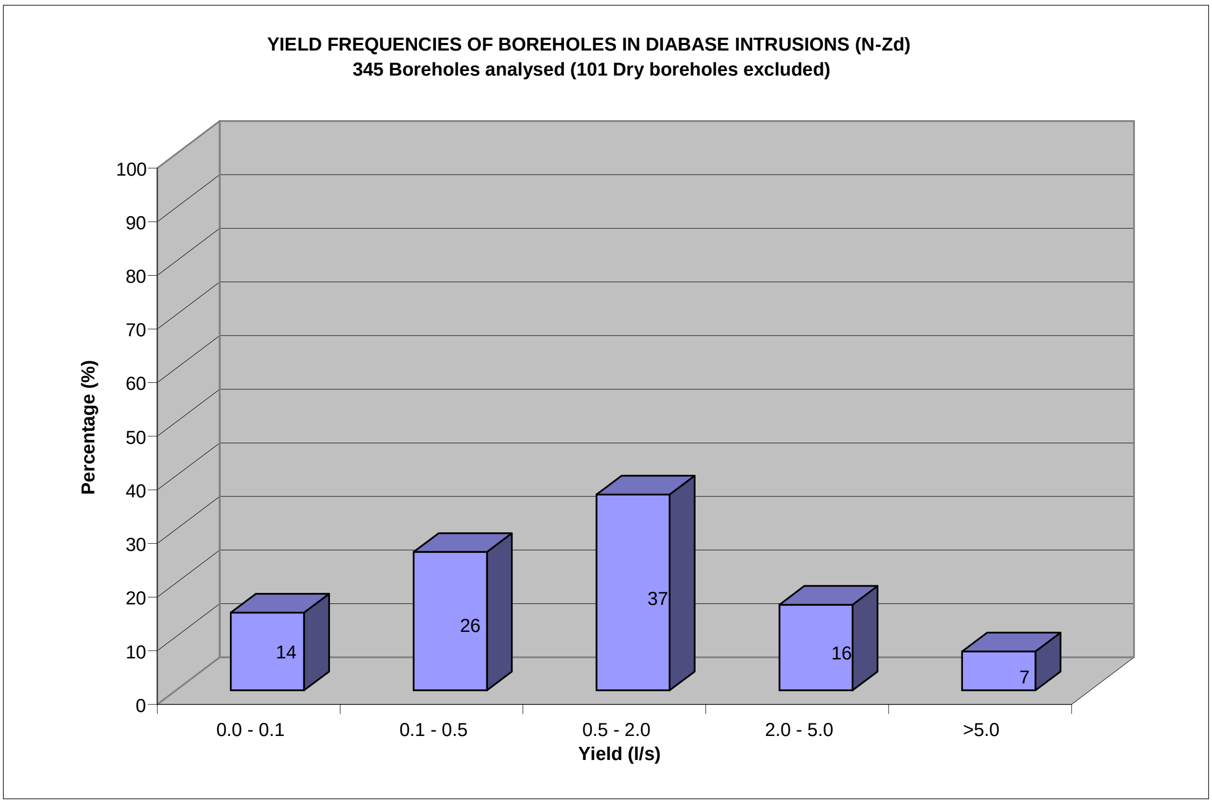

Figure 78: Yield frequency for the intergranular and fractured aquifers of Diabase intrusions (N-Zd).

Figure 78 shows the yield frequency diagram indicating that 77% of the successful boreholes yield less than 2ℓ/s and 7% more than 5ℓ/s. In the search for groundwater, secondary fractures in the host rock associated with the diabase intrusion are sometimes targeted. Important detail to consider when choosing a drilling site in the vicinity of a dyke intrusion is width, strike, dip and lateral extend thereof. Drilling positions in thin dykes (less than 7m) are positioned with the expectancy to find water within the dyke. With wider dykes (7-15m) the most successful zone is usually within 2m of the contact zone. Very wide dykes are usually not good targets. Yields can differ on each side of the dyke as well as along the strike. When using aerial magnetic data, dykes are usually targeted on the ground in areas along the strike where there is possible weathering or where joints or fracture zones transect the dyke. Sills are usually more difficult to drill successfully but the contact with the host rock can be targeted or weathered and fractured zones within the sill or the lower contact zone. The above is a general approach and depends on the geological, hydrogeological and physiographical settings of the target area.

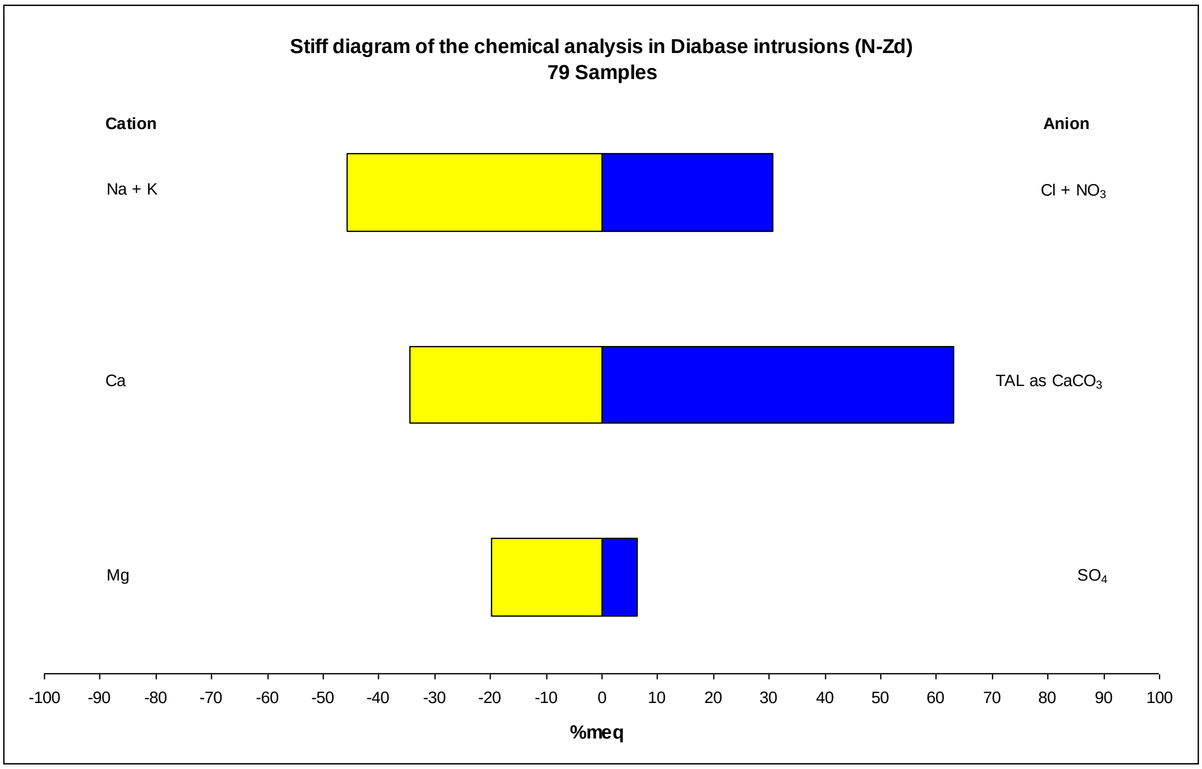

Figure 79: Stiff diagram representing chemical analysis of the Diabase intrusions (N-Zd).

Figure 79 shows the broad classification according to anions and cations of the unit. The water displays a sodium-calcium-bicarbonate-chloride character. Elevated concentrations of magnesium occur in 14% of the samples (Mg > 100mg/l), fluoride (F >1.5mg/l) in 33% of the holes and nitrate (N >20mg/l) in 10% of the samples. The above statistics will differ in each of the major cluster occurrences as the geological and hydrogeological conditions are different.

7.2.3.6 SPITSKOP COMPLEX (Msp)

The Complex is intrusive into the Nebo Granite and consists predominantly of alkaline rocks with a wide range of composition. The outer zones comprise fenite and umptekite and the inner ones gabbroic rocks (theralite, fayalite diorite) which are probably fenitised gabbroic and pyroxenitic rocks. The Complex is located east of Marble Hall (Figure 80) and covers approximately 0.3% of the map area. Ring dykes and cone sheets consist mainly of foyaitic rocks and radial dykes of microijolite and foyaitic rocks. Although the lateral extent of this unit is relatively small, it is regarded as an important groundwater aquifer as its potential is much higher than the surrounding granite.

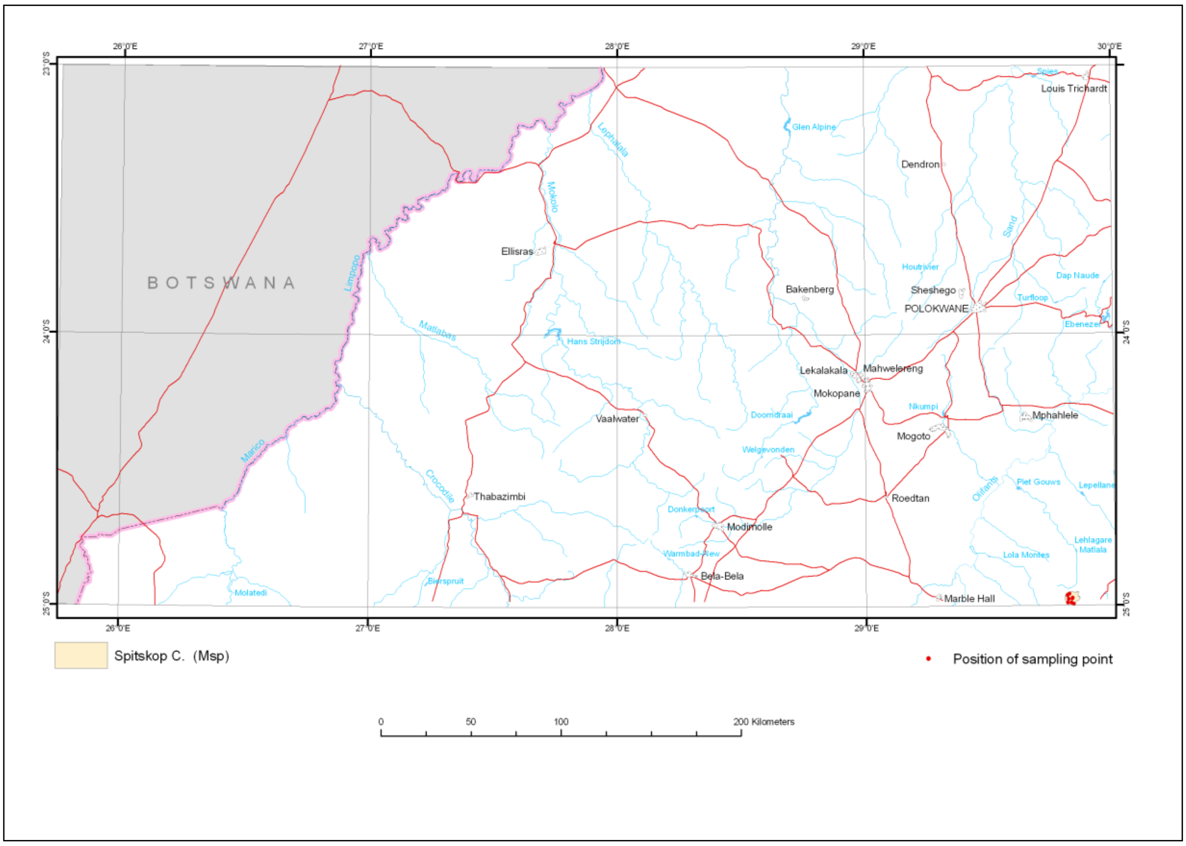

Figure 80: Geographical distribution of the Spitskop Complex (Msp) and the associated groundwater sampling points.

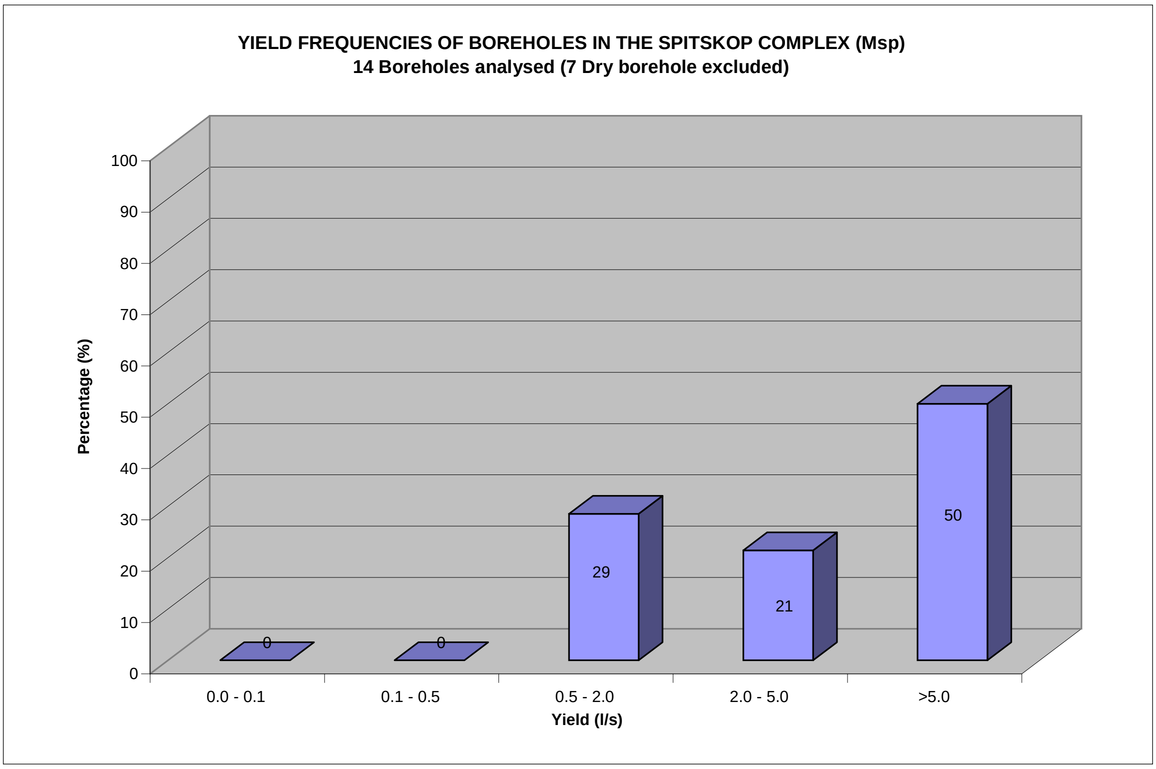

Figure 81: Yield frequency for the intergranular and fractured aquifers of the Spitskop Complex (Msp).

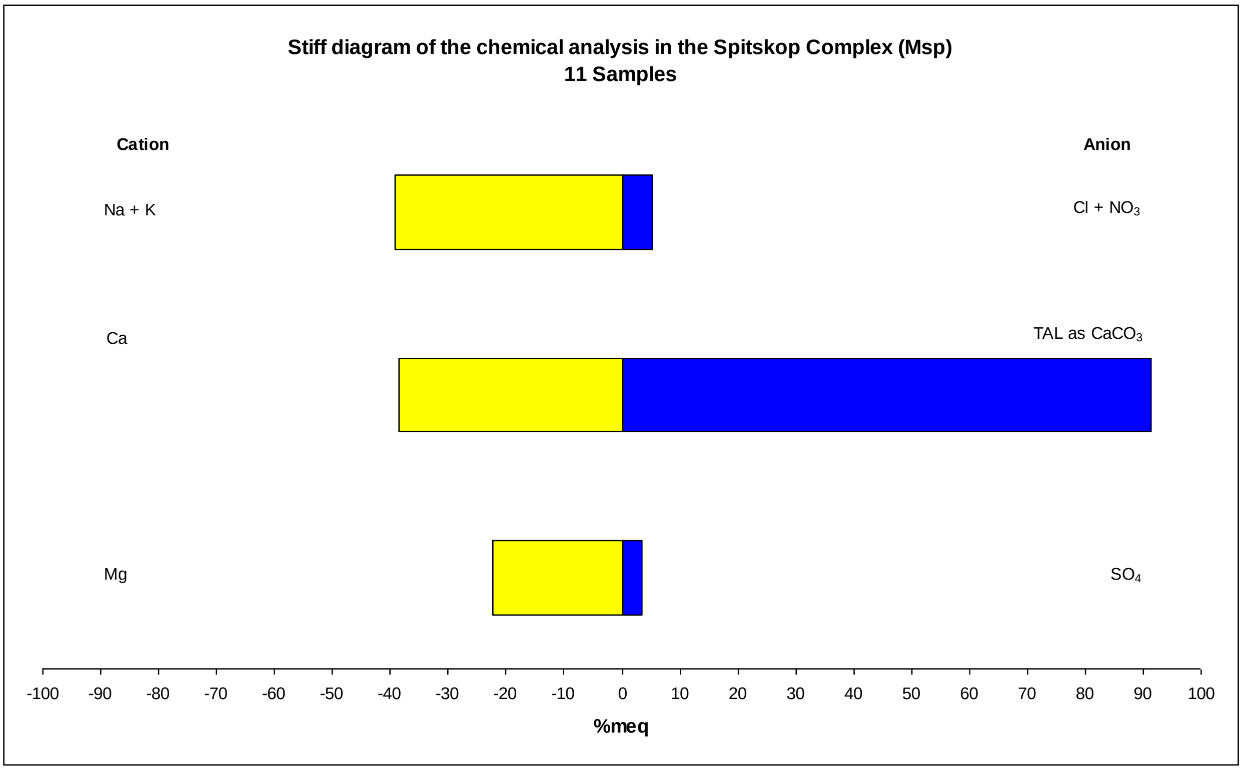

Figure 82: Stiff diagram representing chemical analysis of the Spitskop Complex (Msp)

Although only 14 boreholes occur within this unit, the yield frequency diagram (Figure 81) provides a good indication of expected conditions. The possibility of drilling a high yielding borehole is high as 50% of the successful boreholes yields more than 5ℓ/s. Fluoride concentrations exceed the maximum allowed limit in 18% of the boreholes with 72% in the ideal quality range (F <0.7mg/l). This can be an indication that groundwater flow from the surrounding Nebo granite is limited as the granite is characterized by high fluoride concentrations. The water is classified as a sodium-calcium-bicarbonate type (Figure 82).

7.2.3.7 SOUTPANSBERG GROUP (Ms) (Basalt)

The Soutpansberg Group is divided into various formations of which only two occur on the Polokwane map sheet. The Sibasa Formation consists predominantly of lava flows and the Wyllies Poort Formation in turn of quartzite and sandstone with interbedded grit, conglomerate, shale, mudstone, siltstone and lava. Only the Sibasa Formation will be discussed here due to the intergranular and fractured characteristics of the basalt. The unit occupies only a small area north of Blouberg and Louis Trichardt (Figure 83). The Wyllies Poort Formation has been classified as a fractured aquifer and is discussed in chapter 7.2.1.6.

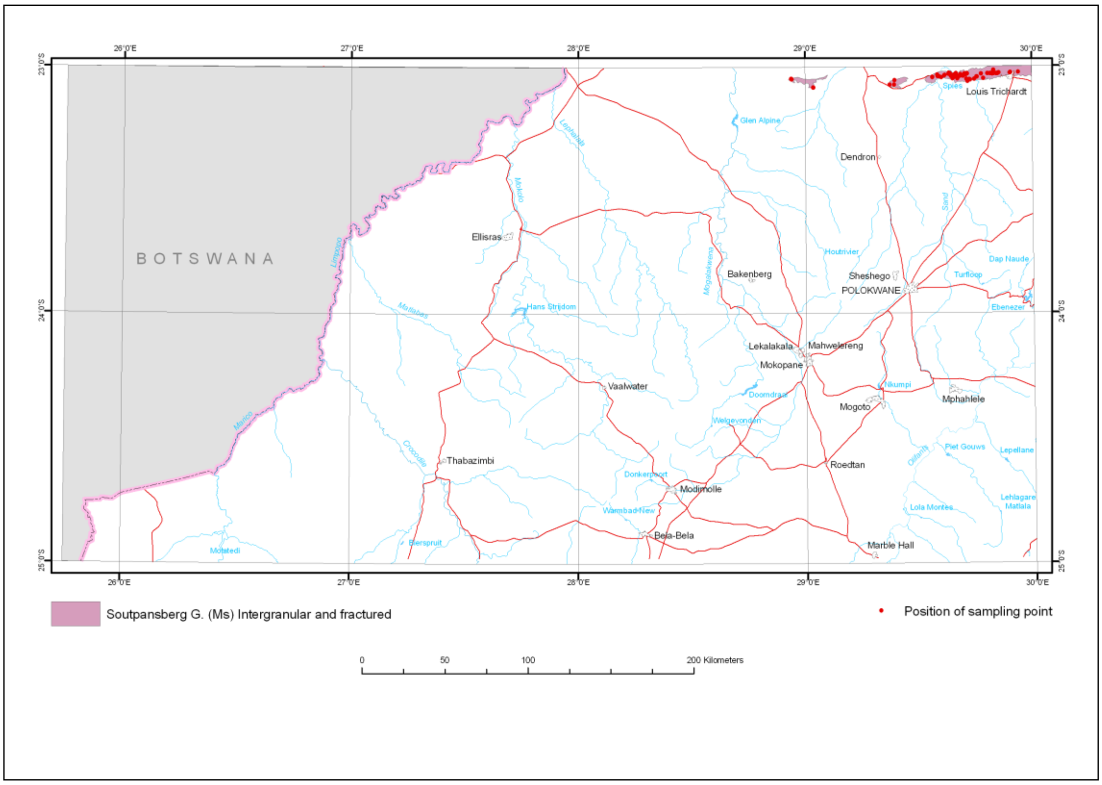

Figure 83: Geographical distribution for the intergranular and fractured aquifers of the Soutpansberg Group (Ms) (basalt) and the associated groundwater sampling points

Numerous faults cut through the formation, which are also the main target for sustainable groundwater development. Other targets include deep weathered and fractured basins where groundwater is usually intercepted in the transitional zone between the weathered and solid basalt. The latter is fed from the overlying weathered zone in which the water is stored. The unit occurs in a high rainfall area with chemical weathering the dominating process. Where weathering is intensive, clay is produced reducing the permeability and subsequent yielding potential significantly. From drilling records and information from drilling contractors familiar with the area highly weathered, almost completely decomposed material of up to 40mbgl can be expected in the Louis Trichardt area increasing east-wards towards Thohoyandou with depths of weathering as deep as 90mbgl. Strong yields are associated with the unconformity between this Group and the underlying gneiss (Fayazi, 1995). Water is also obtained on the contact between the basalt and the overlying sandstone. However, due to the mountainous topography this option is not always feasible. The depth to groundwater level is generally <30m.

The groundwater potential of this Group is moderate to good with 23% (Figure 84) of the successful boreholes yielding >5ℓ/s. The relative high number unsuccessful boreholes (25%) are an indication that the selection of drilling positions for new source development must be done carefully. A scientifically approach using remote sensing and geophysical methods are recommended.

Water is mainly abstracted for livestock watering, rural domestic supplies and to a lesser extent for the irrigation of fruit orchards. In general, the quality is good to moderate with 81% of the EC values ranging between 14.3 and 150mS/m with only 2% exceeding the maximum allowed limit of 370mS/m. The Harmonic mean is calculated as 50.4mS/m and the arithmetic mean as 87mS/m. 99% of the fluoride and 72% of the nitrate and nitrite (reported as N) concentrations fall within the ideal class (F <0.7mg/l) and (N <6mg/l). 11% of the nitrate (N) concentrations are between 20 and 30.5mg/l. The maximum allowed limit for domestic use is 20mg/l, (SANS 241, 1999). The water has a magnesium-calcium-bicarbonate and chloride character.

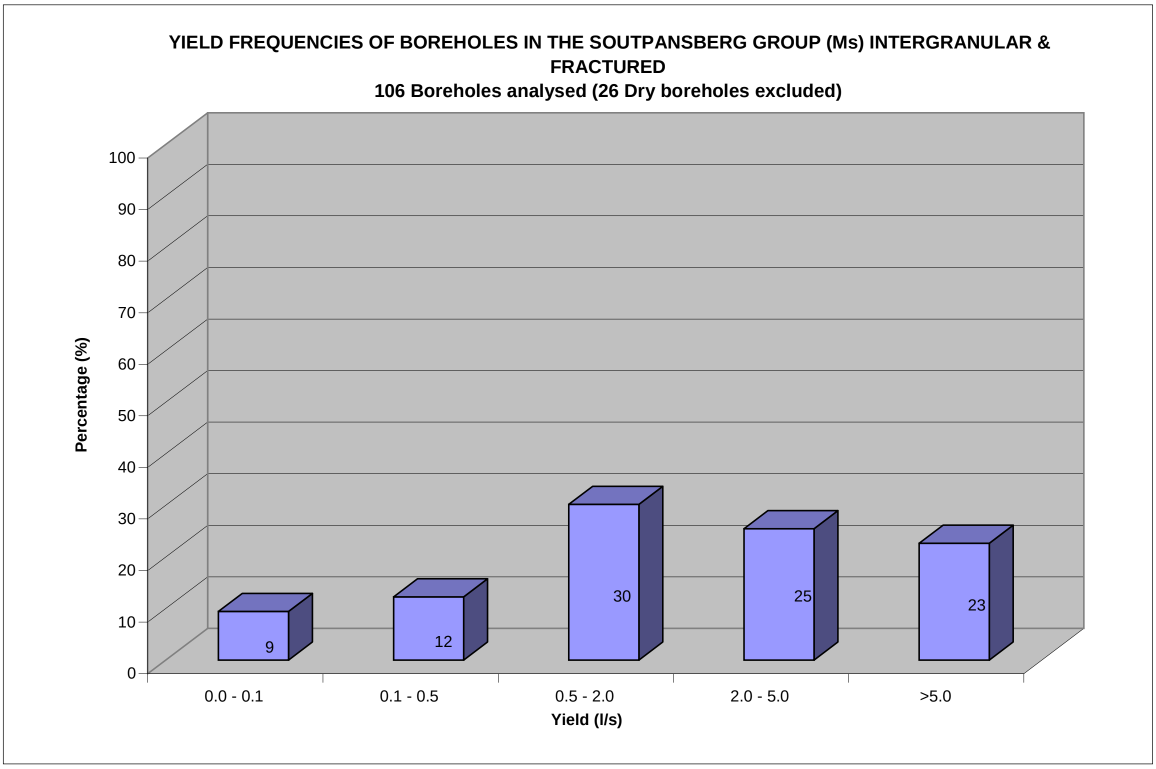

Figure 84: Yield frequency for intergranular and fractured aquifers of the Soutpansberg Group (Ms) (basalt)

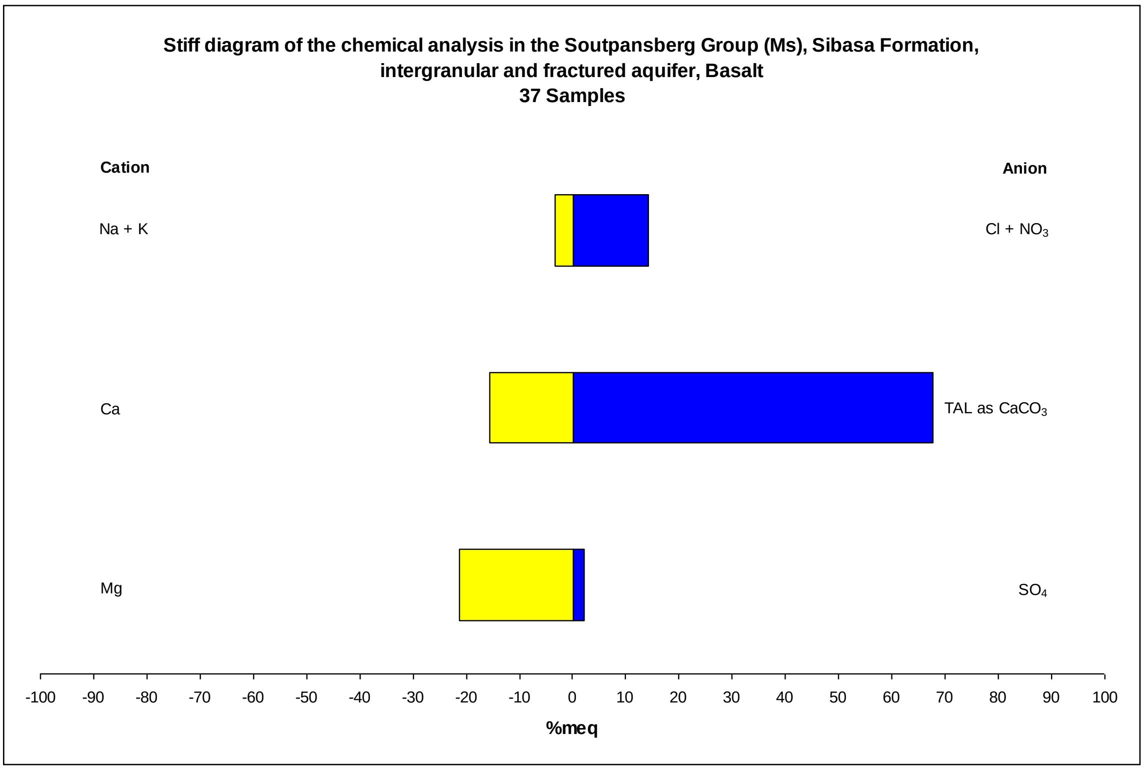

Figure 85: Stiff diagram representing chemical analysis of the Soutpansberg Group (Ms) (basalt)

7.2.3.8 LEBOWA SUITE (Mle)

This Suite includes all the granite rocks of the Bushveld Complex. Several types of granite ranging from very coarse-grained to fine-grained may be distinguished but have not been separated on the map sheet. Occurrences are north of Marble Hall, north of Mokopane (Potgietersrus), east of Lephalale (Ellisras), and south of Thabazimbi (Figure 86). It covers approximately 8.4% of the total map area.

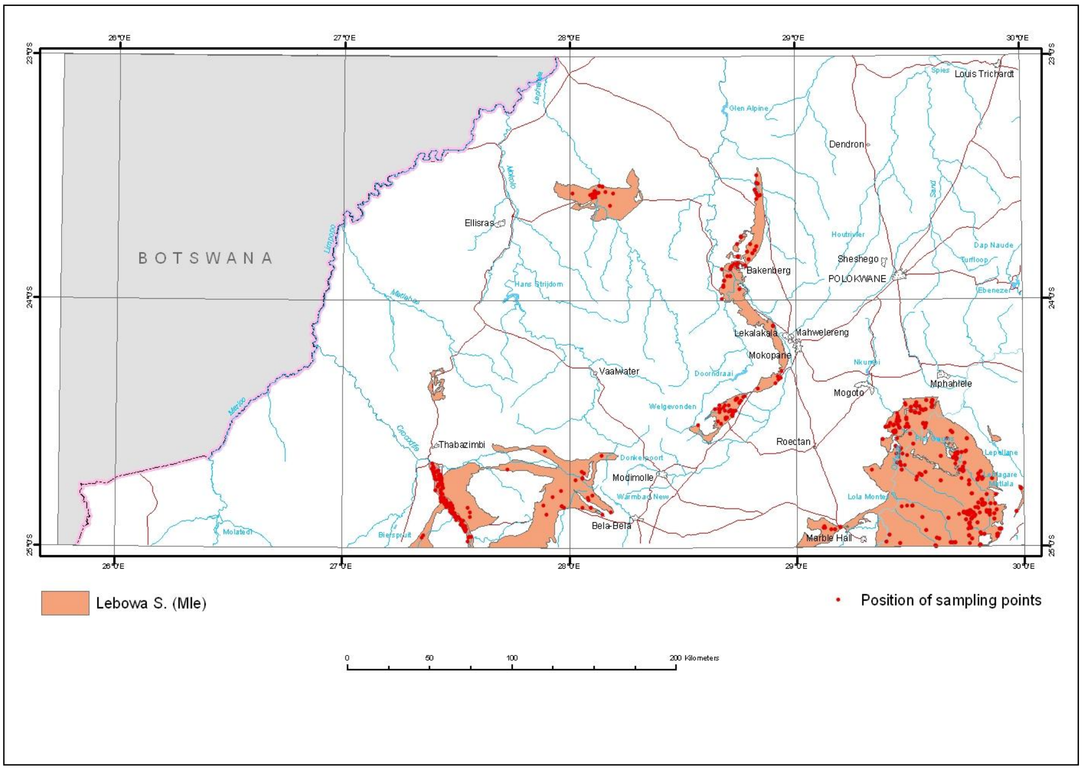

Figure 86: Geographical distribution of the Lebowa Suite (Mle) and the associated groundwater sampling points

The granitic rocks are less prone to weathering and jointing, and also lack the occurrence of pegmatitic bodies (which tends to contribute extensively to the groundwater potential in the Hout River and Goudplaats Gneiss). The groundwater potential and storage capacity of the unit is generally poor although the occasional good yield (>5ℓ/s) does occur. The DWA drought relief programme (1992/93 and 1995) statistics indicate that only one out of every five boreholes drilled were successful thus representing a success rate of only 20%. Comparing this with the 45% dry boreholes recorded in the area shows that a scientific approach results in a higher success rate.

After recharge events, the water level tends to rise in places to above ground level forming numerous springs and seepages (Elandskraal approximately 20km north of Marble Hall). This causes engineering problems and hampers development in some of the more densely populated areas. Possible pollution especially microbiologic from surface or near surface sources (pit latrines) is a threat to nearby sources due to thin overburden development and high permeable top sandy soil combined with a shallow static water table. Nitrate and nitrite (reported as N) exceed the maximum allowable limit (N >20mg/l) in only 7% of the available groundwater analysis. Water is found in faults, fracture zones and within the dyke contact/metamorphosed zone. Deep drilling (>180m) 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 is found at depths usually between 90-120m provided that a proper scientific survey was done in determining the drilling position. The depth to groundwater level is very shallow and seldom exceeds 15m. Statistics indicate that 81% (Figure

87) of the successful boreholes yield less than 2ℓ/s. Groundwater in the area is mainly abstracted for livestock watering and domestic purposes. The cost implications taking in account the 8% chance to develop a borehole yielding more than 5ℓ/s with a 45% probability of finding water limits the use for irrigation purposes.

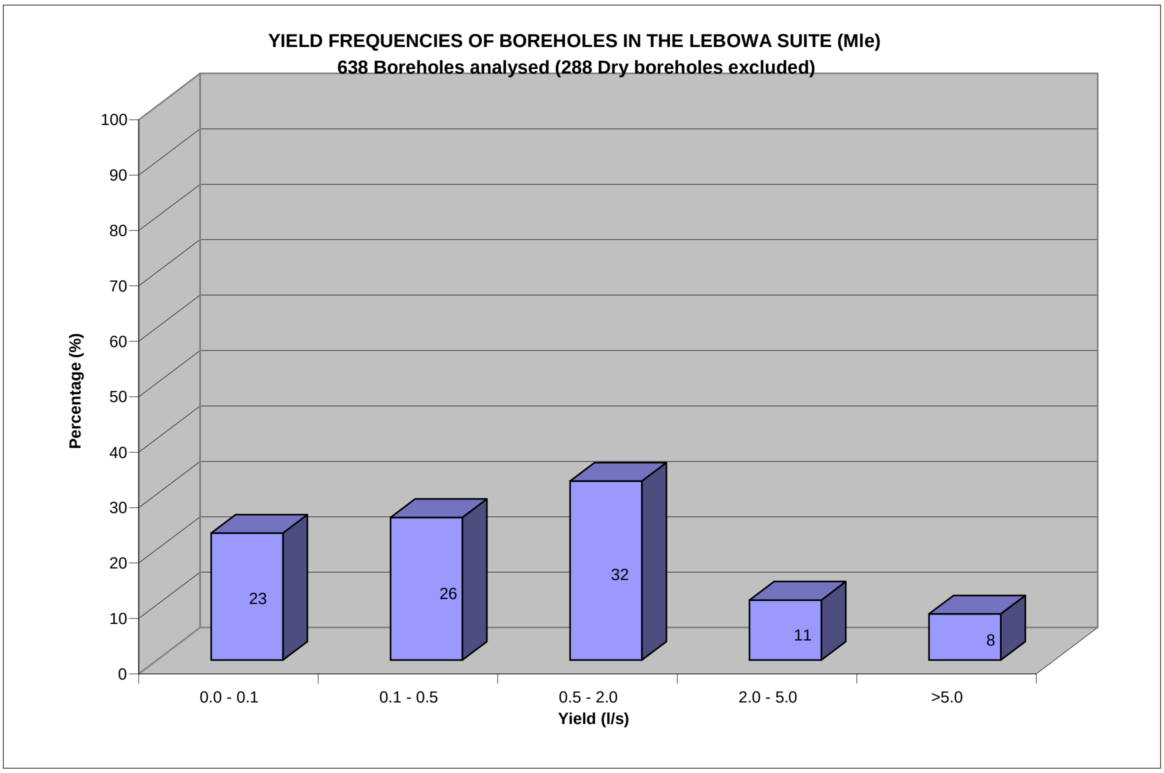

Figure 87: Yield frequency for the intergranular and fractured aquifers of the Lebowa Suite (Mle).

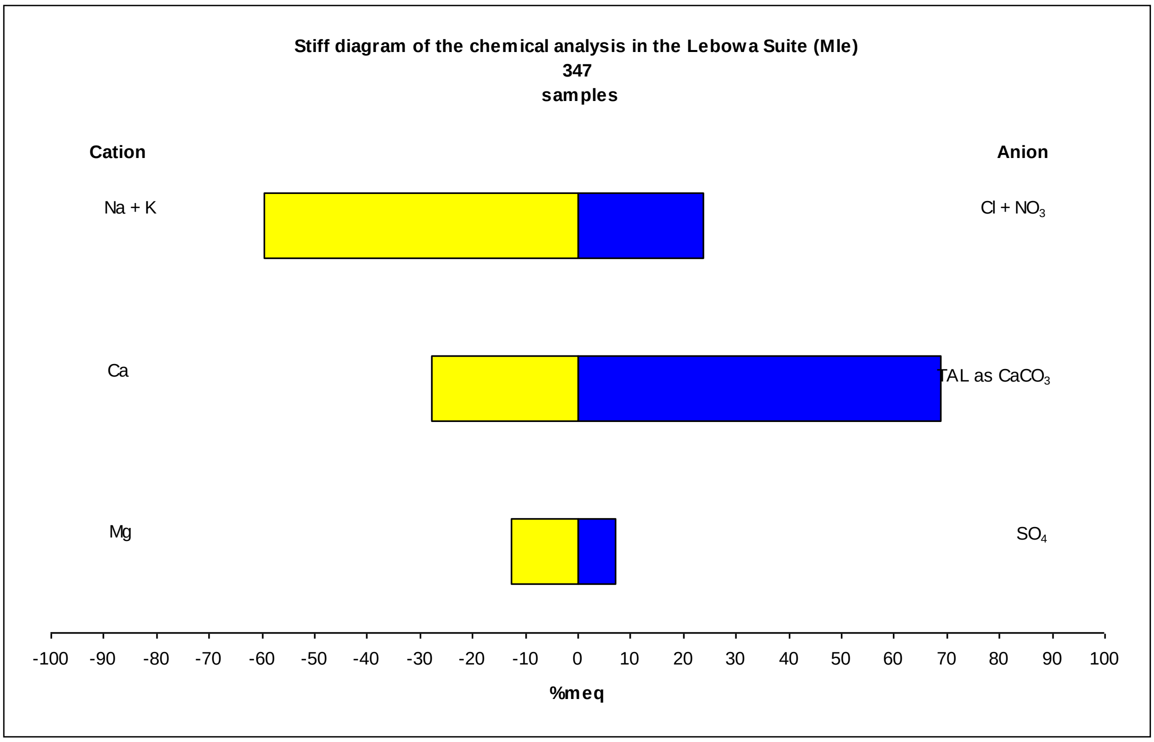

Figure 88: Stiff diagram representing chemical analysis of the Lebowa Suite (Mle)

The EC values exceeds the maximum allowable limit (EC >370mS/m) only in 4.8% of the groundwater samples analysed with 76% within the ideal quality range (EC <150mS/m). In 7% of the samples, sodium (Na >400mg/l) and in 9%, chloride (Cl >600mg/l), exceed the maximum allowable limits (SANS 214, 1999). A characteristic of this unit is the relative high fluoride content, with 52% of the sampled boreholes exceeding the 1,5mg/l (for human consumption) guideline category. The water is of a sodium-chloride-bicarbonate type (Bond, 1947). From the stiff diagram in Figure 88, the water has a sodium-calcium-bicarbonate-chloride character.

7.2.3.9 RUSTENBURG SUITE (Vr)

Rocks belonging to this Suite are characterised by a well-developed igneous layering and various rock units which form part of it, have a fairly uniform composition and may be traced over appreciable distances. Occurrences are found west and north of Northam, north of Villa Nora, south and northwest of Mokopane (Potgietersrus) and east of Marble Hall (Figure 89). The Suite consists mainly of mafic rocks including norite, gabbro, magnetite gabbro, anorthosite, pyroxenite and others. It covers approximately 5.4% of the total map area.

Plate 9: Western view of the Nyl River near Moorddrif 289 KR. The mountains in the background comprise Bushveld Granite with gabbro of the Rustenburg Layered Suite in the foreground (Photograph: WH du Toit).

Plate 10: Calcrete veins criss-crossing through mafic rocks of the Rustenburg Layered Suite in a road cutting between Chuniespoort and Burgersfort (Photograph: WH du Toit).

Plate 11: Eastern view of the Critical Zone of the Rustenburg Layered Suite outcropping in the foreground with the Pretoria Group dominating the background (Photograph: WH du Toit).

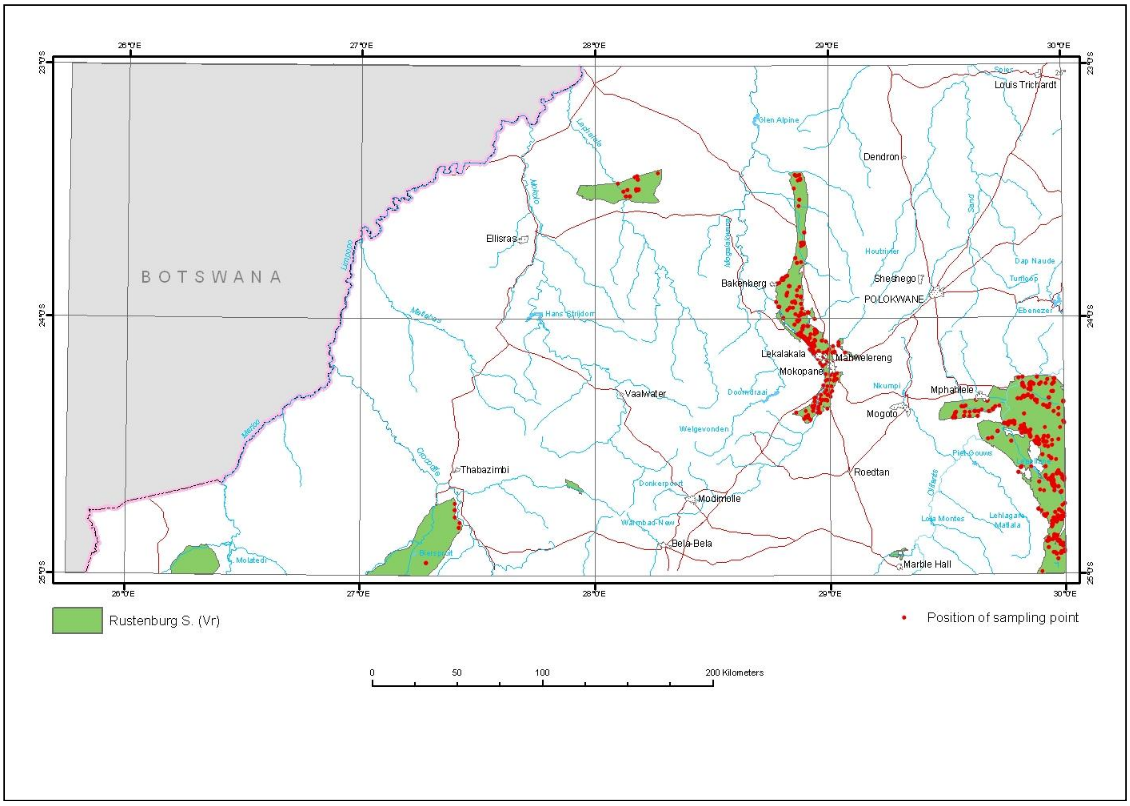

Figure 89: Geographical distribution of the Rustenburg Suite (Vr) and the associated groundwater sampling points

The groundwater potential is generally good with 38% (Figure 90) of the successful boreholes yielding more than 2ℓ/s. In the Northam and Mokopane (Potgietersrus) areas groundwater occurs in deep weathered and fractured mafic rocks. Due to the relative high permeability of the weathered and fractured rock, these basins can be extremely good aquifers. North of Mokopane (Potgietersrus) drilling on east to northeast trending fault zones produced high yielding boreholes. In the Northam area problems are experienced in some of the mines where large volumes of water are intercepted in fractured anorthosite at depths of 300m. Water is also obtained in fault and associated shear or fracture zones, contact zones and dyke contacts. In the south-eastern sector of the map water strikes in shallow fractured and weathered zones (12-25m) with yields more than 2ℓ/s can be found. This is in many cases the only strikes in these boreholes as the formation change rapidly with depth to fresh rock. Minor highly fractured visible dolerite dykes were targeted in the same area resulting in high yielding boreholes that is used to supply rural villages. Quartzite xenoliths of the Transvaal Supergroup occurring near the contact zone between the Lebowa Granite and Rustenburg Layered Suite were successfully explored for rural water supply. More research work needs to be done to determine the storage capacity and true potential of these localized aquifers.

The groundwater level in this unit is usually less than 30m but limited de-watering has taken place in areas where large-scale abstraction is poorly managed such as at Mawelareng just outside Mokopane (Potgietersrus), (Fayazi, 1995). Groundwater is mainly abstracted for livestock watering, irrigation, domestic purposes and mining activities.

The quality of the water is moderate to poor with EC values ranging between 8.6 and 1041mS/m. The harmonic mean is of 108mS/m. Nitrate and nitrite (N) problems are reported with 21% of the analysis with concentrations exceeding the maximum allowable limit (N >20mg/l) compared with 41% classed as ideal (N <6mg/l). The elevated concentrations were plotted on GIS compared to village polygons and found to relate in most cases to the vicinity of the source to rural villages. Unlike the Lebowa Suite fluoride is not a major problem as high concentrations (>1.5mg/l) are only reported in 9% of the chemical results. The groundwater is displaying a magnesium-calcium-sodium-bicarbonate-chloride character (Figure 91).

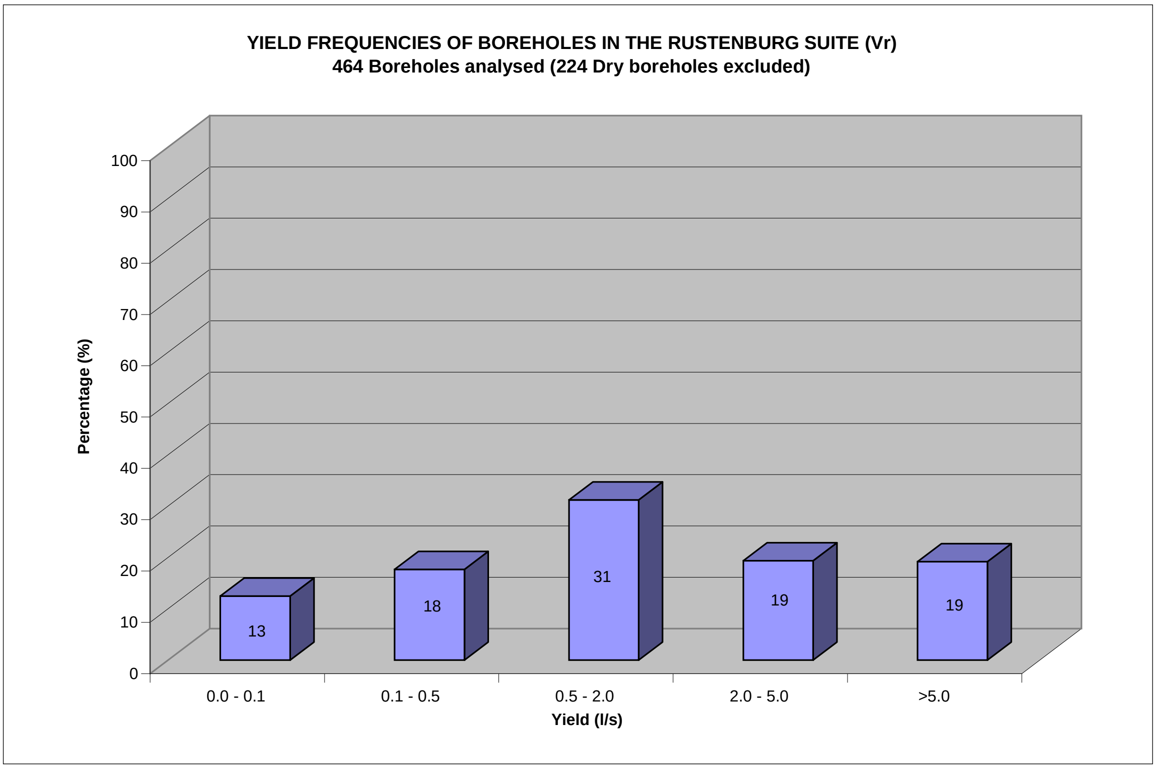

Figure 90: Yield frequency for the intergranular and fractured aquifers of the Rustenburg Suite (Vr).

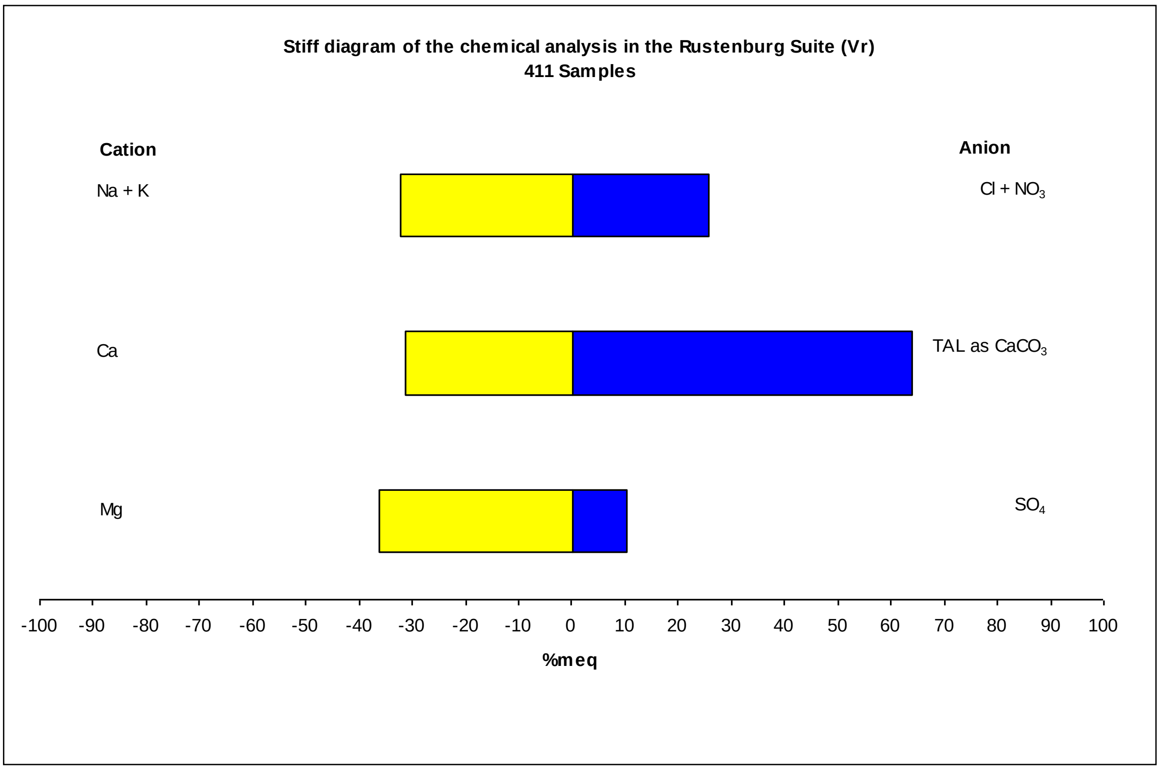

Figure 91: Stiff diagram representing chemical analysis of the Rustenburg Suite (Vr)

7.2.3.10 PRETORIA GROUP (Vp) (Shale, quartzite and diabase)

Due to similar hydrogeological characteristics and also because of cartographic reasons, the different formations of the Pretoria Group have been grouped together. It is mainly composed of shale and clastic rocks including quartzite, conglomerate and sandstone. Except for a small occurrence south of Thabazimbi (Figure 70), the Pretoria Group has been classified as intergranular and fractured. The Pretoria Group in particular was intruded on a large scale by diabase in the form of sills and dykes. The lithological boundaries within the Pretoria Group including the diabase, is not shown on the map. The diabase intrusions play a significant role in the occurrence of groundwater in the Pretoria Group. In general the shaly groups with the associated diabase tend to occupy the lower ground while the quartzite stands out as ridges. The Pretoria Group covers 6.1% of the total map area and is situated in different locations viz. west of Thabazimbi, Mokopane (Potgietersrus)/Zebediela area, east of Zebediela and north of Marble Hall (Figure 92). A few scattered occurrences also appear in the south-eastern corner of the map area.

Plate 12: A beautiful example of a fault cutting through sediments of the Pretoria Group. Faults are generally good targets for groundwater exploration in Limpopo, but can also under certain circumstances act as impermeable barriers to groundwater flow (Photograph: WH du Toit).

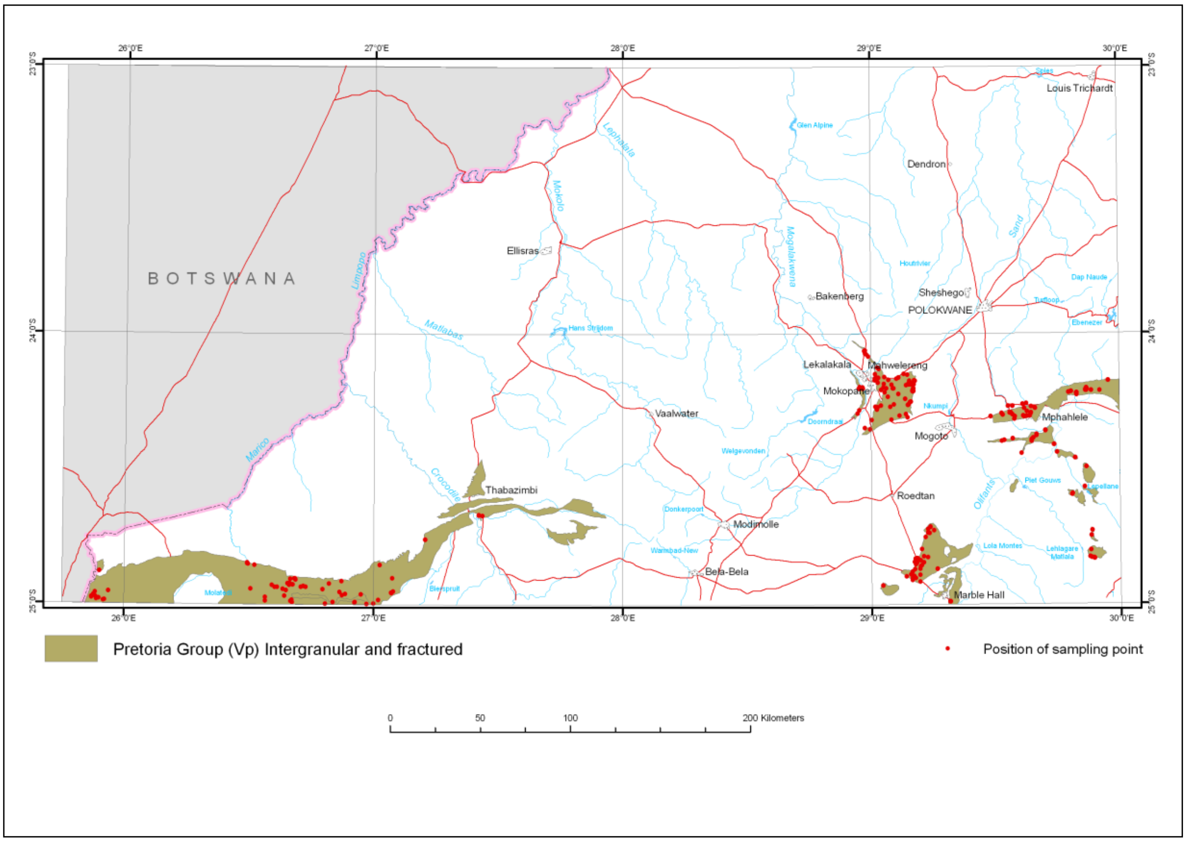

Figure 92: Geographical distribution of the Pretoria Group (Vp) (shale, quartzite & diabase) and the associated groundwater sampling points

The water-bearing properties of the quartzite and shale are dependent on fracturing. The shale is in general far more favourable than the quartzite although the quartzite constitute good aquifers where fractured. Where the shale have been metamorphosed and converted to hornfels by the heat of the Bushveld Complex, its water bearing properties diminished. The hornfels are usually very hard, equigranular and homogenous with limited fractures and joints. Water also occurs in fault and associated shear zones, upper and lower contact zones between diabase and overlying and underlying shale and quartzite as well as dyke contacts. Water is also obtained in the diabase sills where these are weathered to below the groundwater level. Water may also be obtained in fresh intrusive diabase in occasional joints and other fractures. The groundwater potential of the Pretoria Group is low to moderate as 68% (Figure 93) of the successful boreholes yield less than 2ℓ/s. The depth to groundwater level is in general less than 30m but in places west and south of Thabazimbi it varies between 30 and 60m. The water is in general abstracted for domestic purposes and livestock watering and to a lesser extent for mining and irrigation.

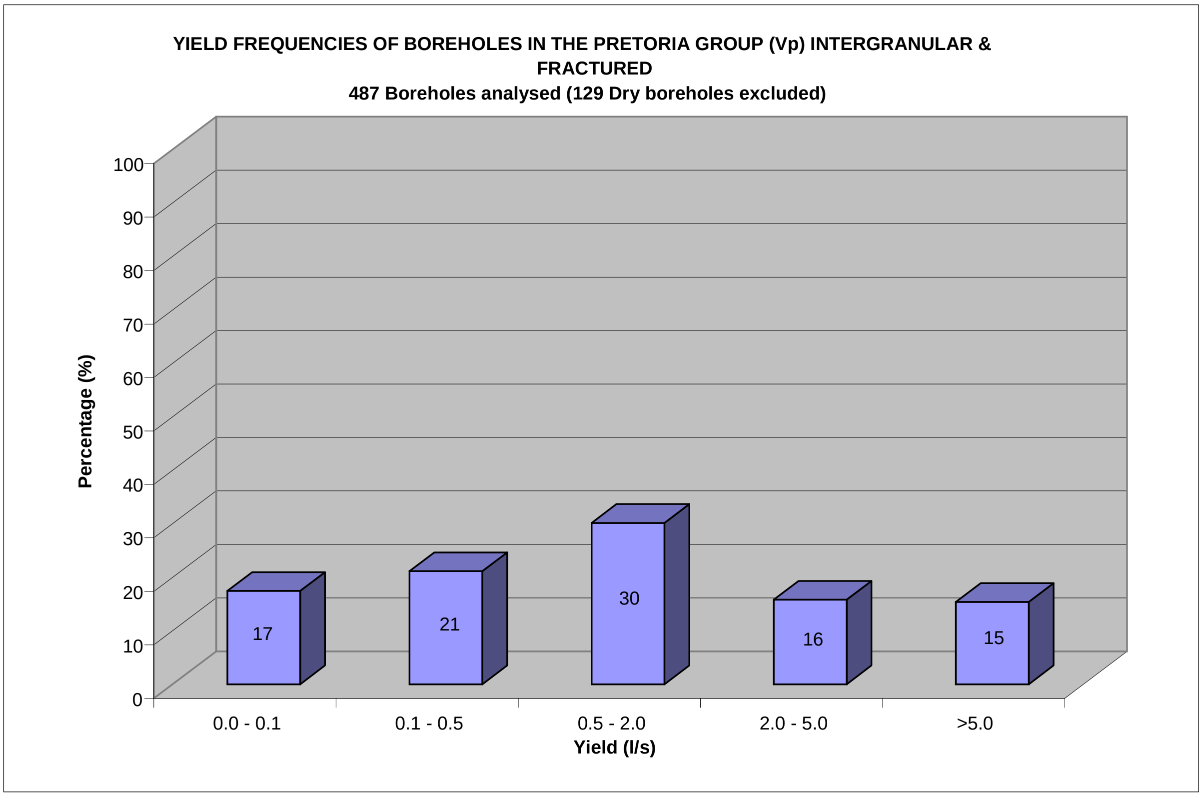

Figure 93: Yield frequency for the intergranular and fractured aquifers of the Pretoria Group (Vp) (shale, quartzite & diabase).

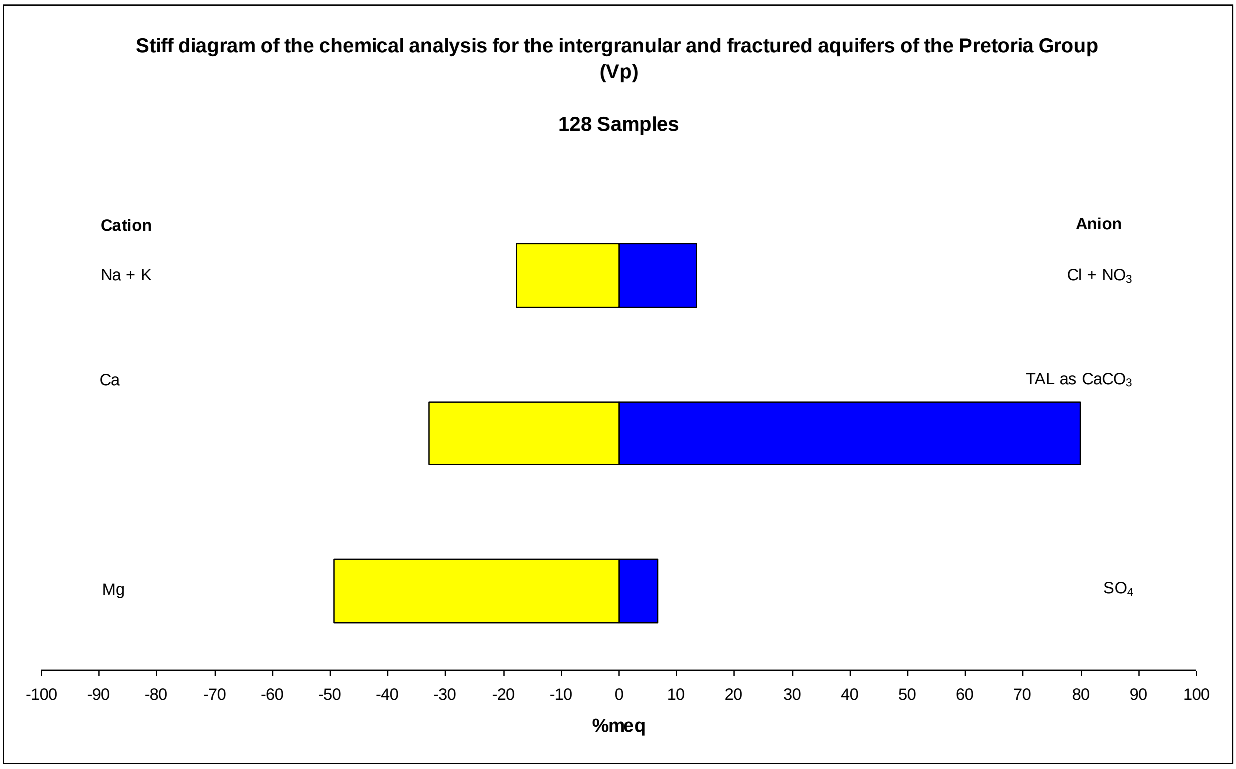

Figure 94: Stiff diagram representing chemical analysis of the Pretoria Group (Vp) (shale, quartzite & diabase)

The overall quality is good to moderate with EC values ranging from 4.7 to 1089mS/m and a harmonic mean of 57.2mS/m. 66% of the chemical analysis falls within the ideal water quality (EC <150mS/m) and 17% within the maximum allowed limit (EC <370mS/m). 22% of the fluoride concentrations fall outside the maximum allowed limit (F <1.5mg/l). Nitrate and nitrite (reported as N) concentrations is in 73% of the samples within ideal quality range (N <6mg/l) and in 7% more than the maximum allowed limit of 20mg/l. The water is predominant a magnesium-calcium-bicarbonate water type with high sodium (16% samples with Na >400mg/l) and chloride (18% samples Cl >600mg/l) concentrations.

7.2.3.11 CROCODILE RIVER FRAGMENT (Vco)

This unit occurs as a single cluster south of Thabazimbi within the southwestern quarter of the map sheet (Figure 95). It consists primarily of shale and hornfels. The cluster is bounded by fault zones in the northeast and southwest and dolomitic rocks of the Chuniespoort Group in the southeast and rocks of the Bushveld Complex in the northwest. Existing data points used for the interpretation of the expected hydrogeological conditions are poorly distributed throughout the aquifer. It is not known if any boreholes drilled in the unit targeted any of the various structural lineaments occurring near the boundaries. The yield frequency diagram (Figure 96) gives some indication of the expected yields of the unit. The existing information indicates that 83% of the successful boreholes are yielding less than 2ℓ/s. Water quality varies and it is most probably controlled by influences from the surrounding geology. The calcium-magnesium-bicarbonate character of the water most probably relates to dolomitic aquifers as occurring on the south-eastern boundary of the unit. The stiff diagram (Figure 97) shows the broad classification according to anions and cations. From that the groundwater is regarded as a magnesium-sodium-chloride-bicarbonate water. The water quality is moderate with EC values ranging from 82.8 to 320mS/m and the harmonic mean calculated as 164.7mS/m, which is just outside the acceptable limit (EC <150mS/m). It is, however, considerable lower than the maximum allowable limit (EC <370mS/m). In 36% of the sampled boreholes the concentration of magnesium falls outside the maximum allowed limit (Mg <100mg/l).

One sample has a fluoride concentration of 3.6mg/l with the rest within the accepted limit (F <1.5mg/l). Nitrate and nitrite (reported as N) is higher than the maximum allowed limit in 18% of the samples (N >20mg/l).

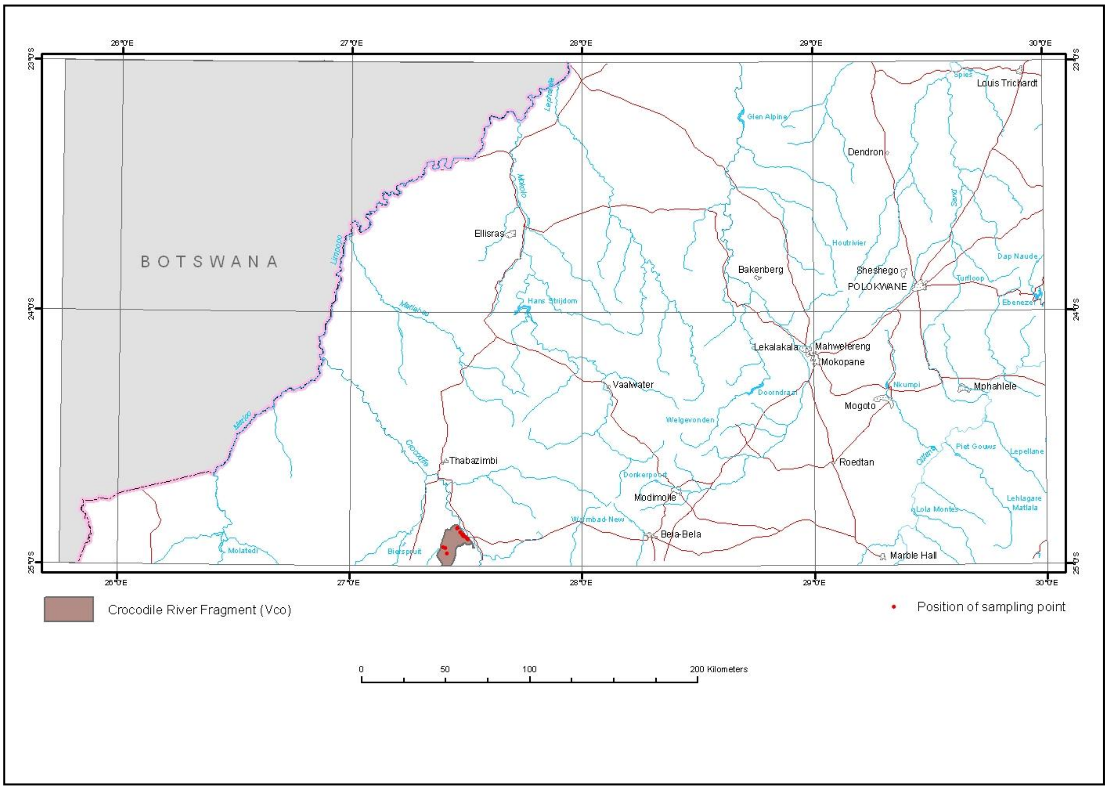

Figure 95: Geographical distribution of the Crocodile River Fragment (Vco) and the associated groundwater sampling points

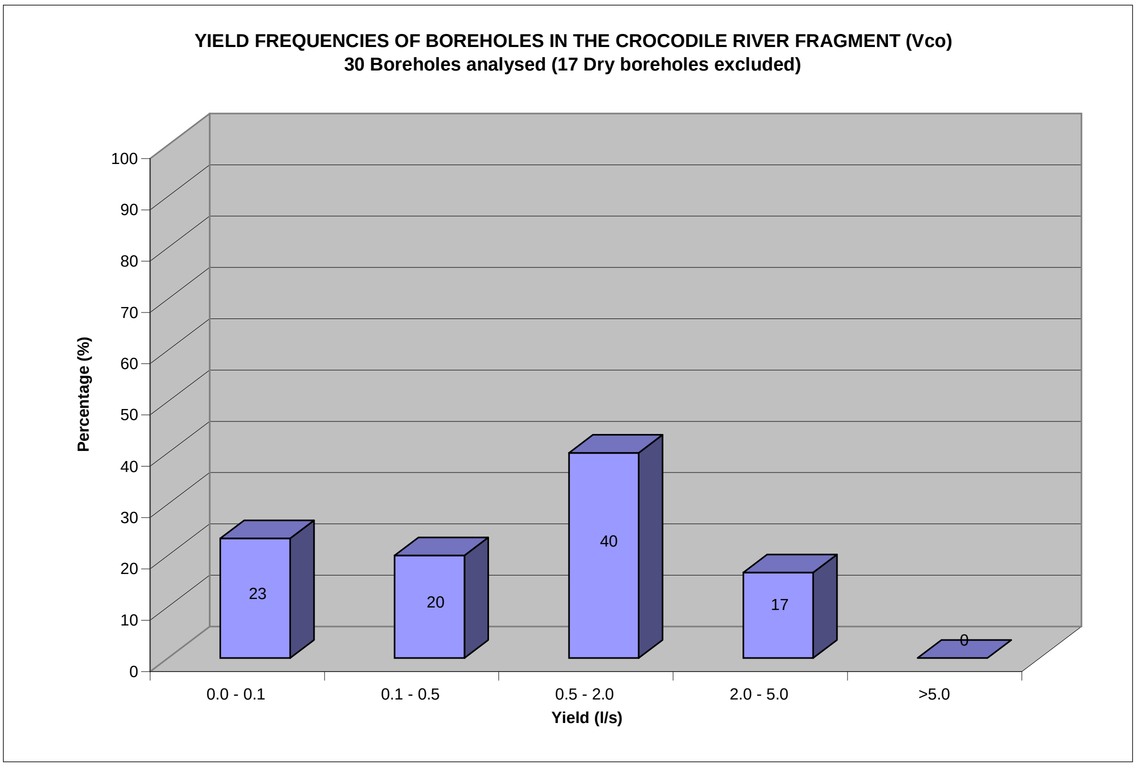

Figure 96: Yield frequency for the intergranular and fractured aquifers of the Crocodile River Fragment (Vco).

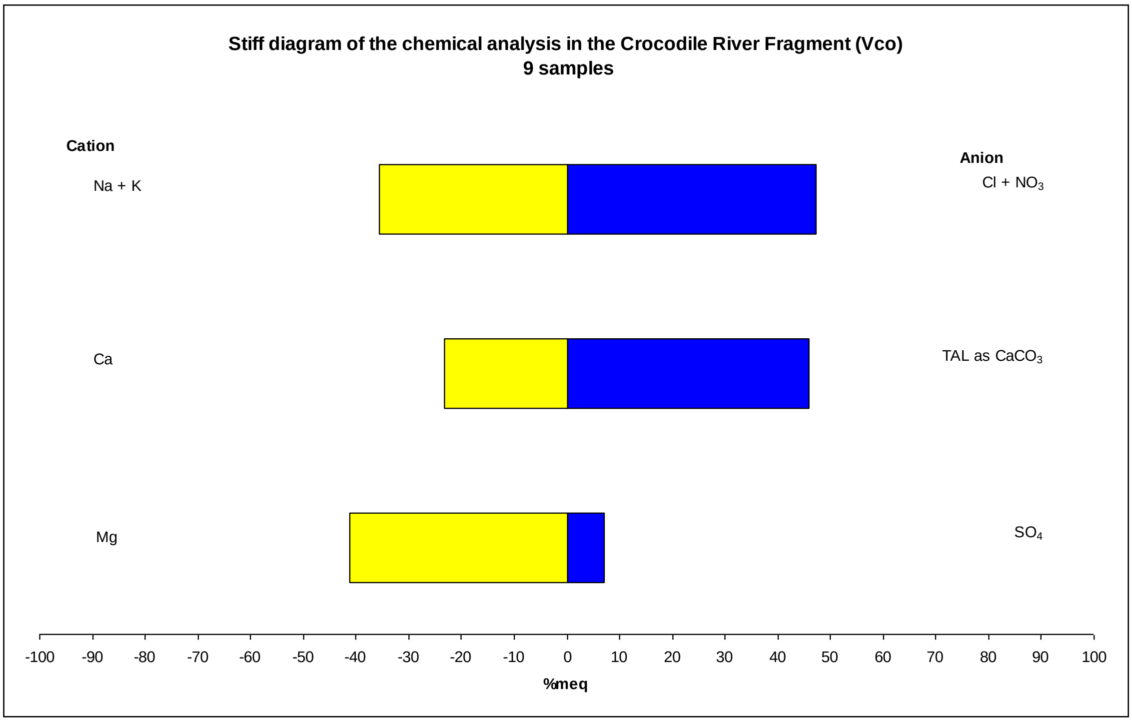

Figure 97: Stiff diagram representing chemical analysis of the Crocodile River Fragment (Vco)

7.2.3.12 MEINHARDSKRAAL GRANITE (Vnh)

Intrusive into the Turfloop Granite and Wolkberg Group, the Meinhardskraal Granite is described as a medium to coarse grained, pink to red granite with pegmatite and subordinate grey granite and granophyre. It occurs north of Zebediela (Figure 98).

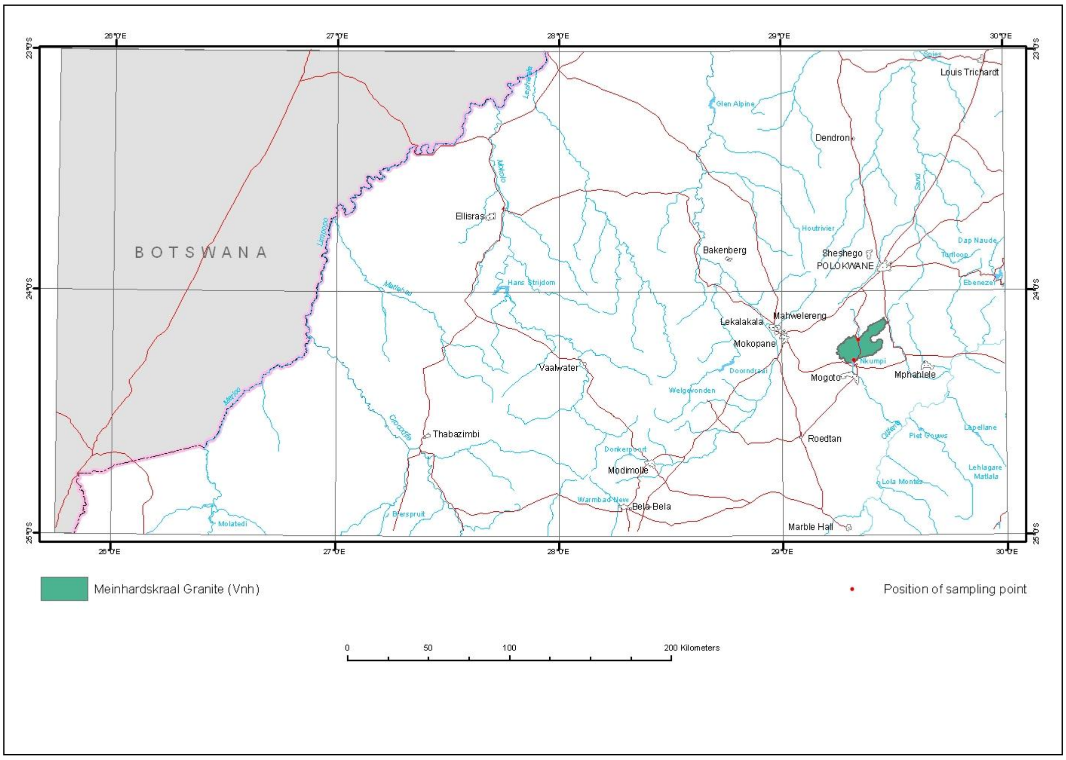

Figure 98: Geographical distribution of the Meinhardskraal Granite (Vnh) and the associated groundwater sampling points.

The groundwater potential of this granite is generally low as 88% of the successful boreholes yield less than 2ℓ/s (Figure 99). Water occurs mainly in fractured zones, quartz veins, pegmatites and contact zones with the host rock. Water also occurs occasionally in minor fractures related to dyke intrusions. The contact zone between the intrusive and host rock was subjected to metamorphism and in some cases to such a degree that no open fractures occurs as the two rocks are virtually fused together.

Figure 100 shows the dominant anions and cations present. Only one sample was available for the assessment of the water quality which shows the water to be a sodium-calsium-magnesium-bicarbonate water type that is generally related to the movement of groundwater from intensive recharge areas (fault zones) and normally indicates a cation exchange process. The highish but less dominant Ca^{2+} and Mg^{2+} can be related to the close proximity of the Chuniespoort Group and a fault zone that extend through this unit into the dolomite. Additional samples within the centre of the group not related to faults or closeness to dolomite will most probably result in a different water character.

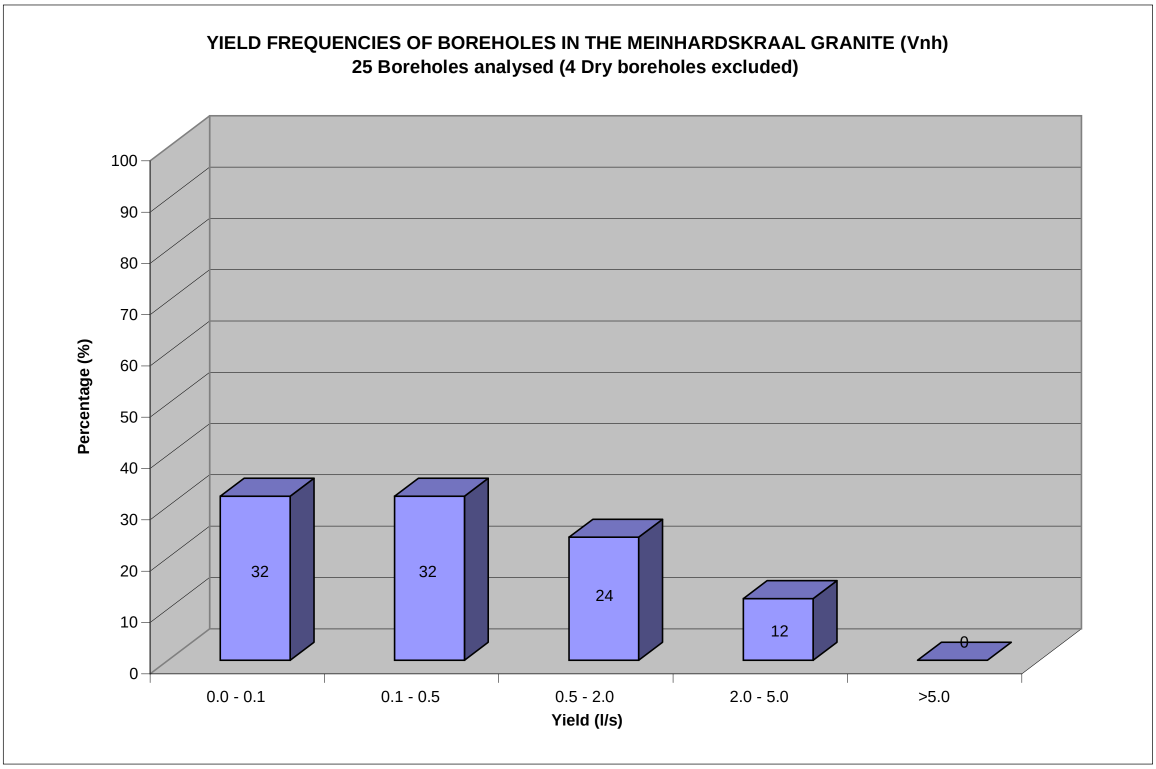

Figure 99: Yield frequency for the intergranular and fractured aquifers of the Meinhardskraal Granite (Vnh).

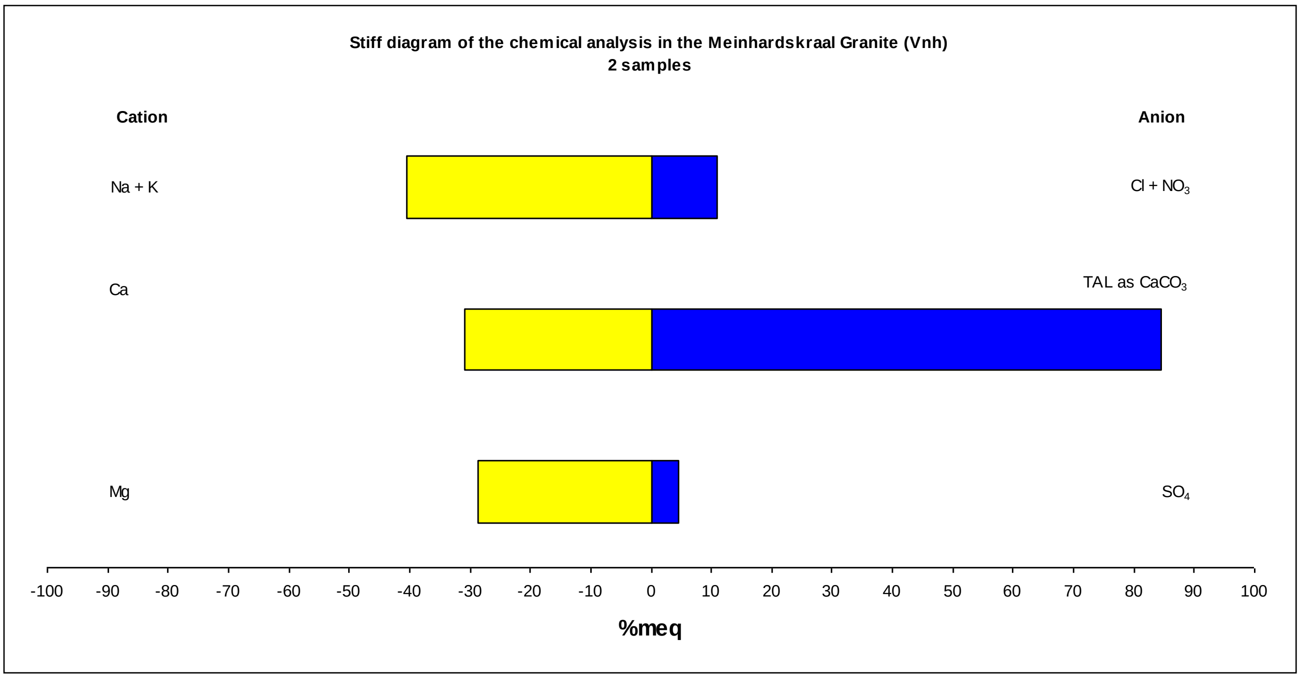

Figure 100: Stiff diagram representing chemical analysis of the Meinhardskraal Granite (Vnh)

7.2.3.13 TURFLOOP GRANITE (Vtu)

This granite, a major batholithic intrusion, flanks the southern edge of the Pietersburg Group forming numerous isolated hills (Figure 101). It is a medium to coarse-grained, grey to pinkish biotitic rock of adamellitic to granodioritic composition and contains orthoclase, microcline, quartz, sodic plagioclase and biotite with sphene and zircon as accessories. It underlies approximately 1.2% of the map sheet area.

Like most of the granite intrusions in the map area, the potential of the Turfloop Granite is generally low with 76% of the successful boreholes yielding <2ℓ/s (Figure 102). The higher yielding boreholes especially the 10% boreholes yielding >5ℓ/s usually relate to the Boyne shear zone or deep weathering and sediment formed at the base of lengthy valleys characteristic of the area. Water also occurs in weathered and fracture zones or occasionally in minor fractures related to dyke intrusions. Figure 103 shows the dominant anions and cations presented as a stiff diagram with a sodium-calcium-bicarbonate character. 87% of the samples are within the ideal quality regarding EC values.

Only one groundwater sample with a measured EC of 512mS/m falls outside the maximum allowed limit (EC >370mS/m). 3% of the samples have nitrate (N >20mg/l) concentrations.

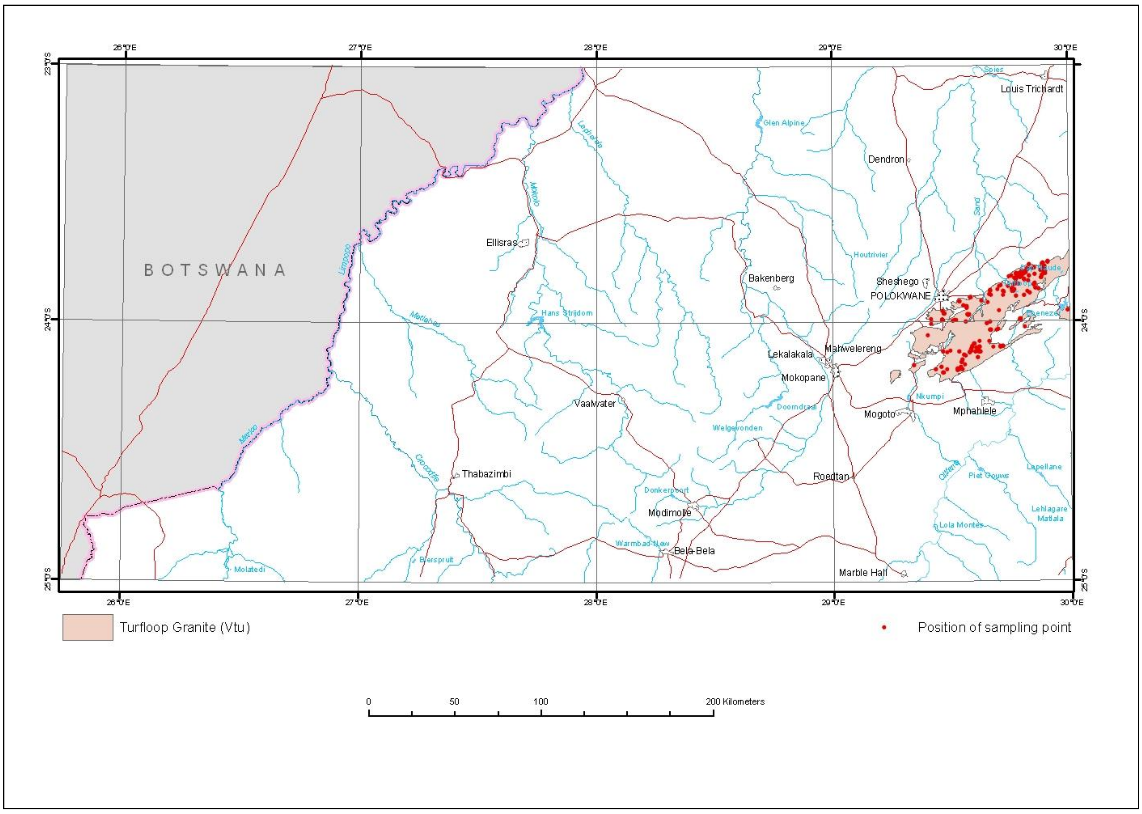

Figure 101: Geographical distribution of the Turfloop Granite (Vtu) and the associated groundwater sampling points

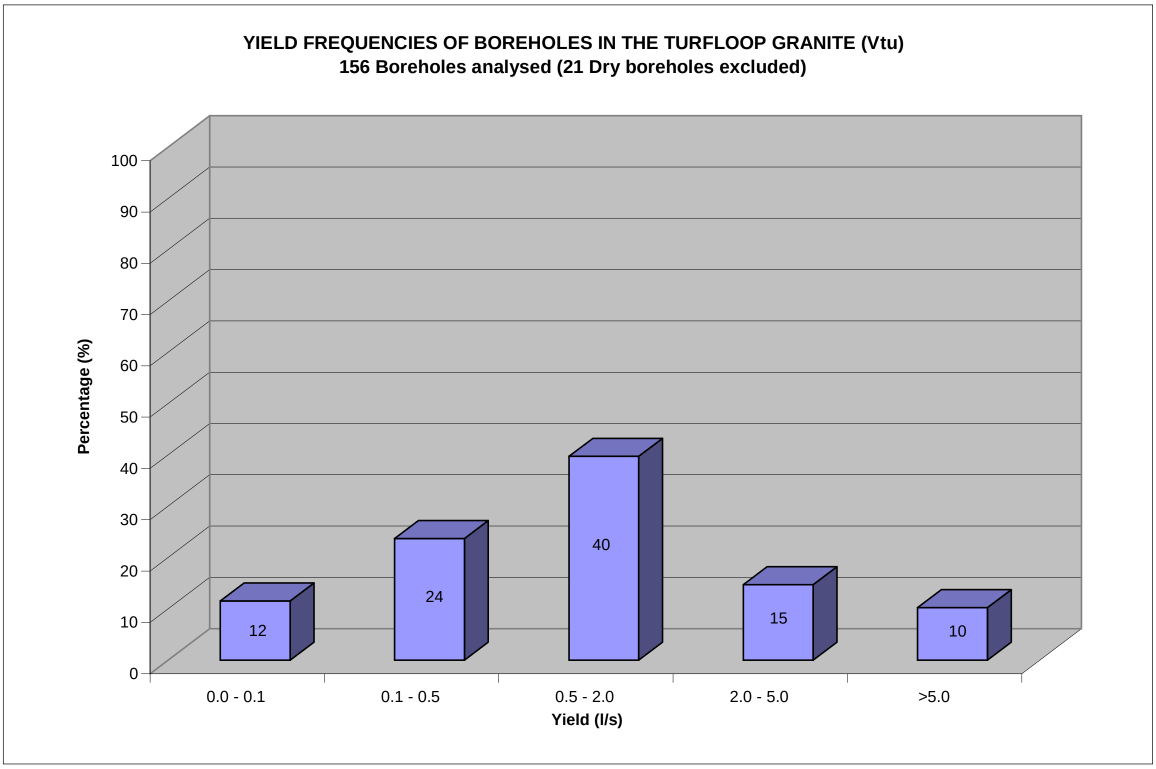

Figure 102: Yield frequency for the intergranular and fractured aquifers of the Turfloop Granite (Vtu).

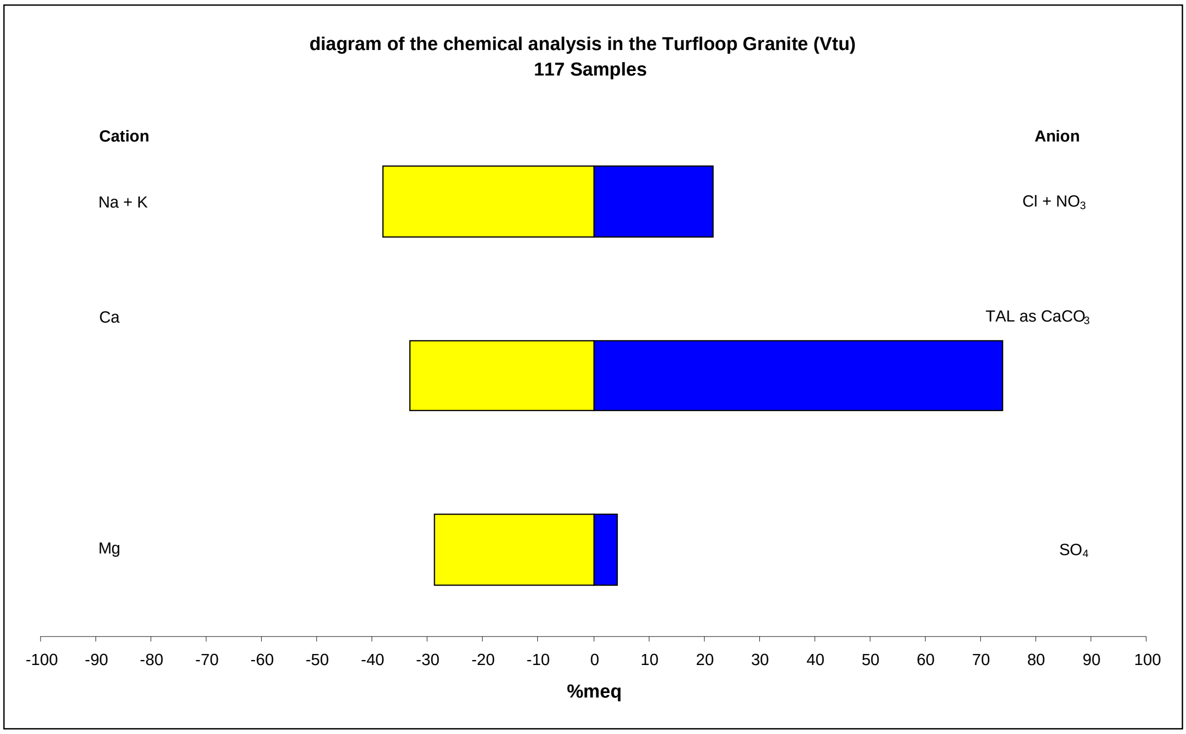

Figure 103: Stiff diagram representing chemical analysis of the Turfloop Granite (Vtu)

7.2.3.14 UNNAMED VAALIAN ROCKS (Vz)

This unit occurs near Haenertsburg in the eastern sector of the map sheet and consists of a leucocratic, whitish, medium-to coarse grained granite. The mineral biotite occurs as a very minor constituent of the granite. (Explanation booklet, map sheet 2328).

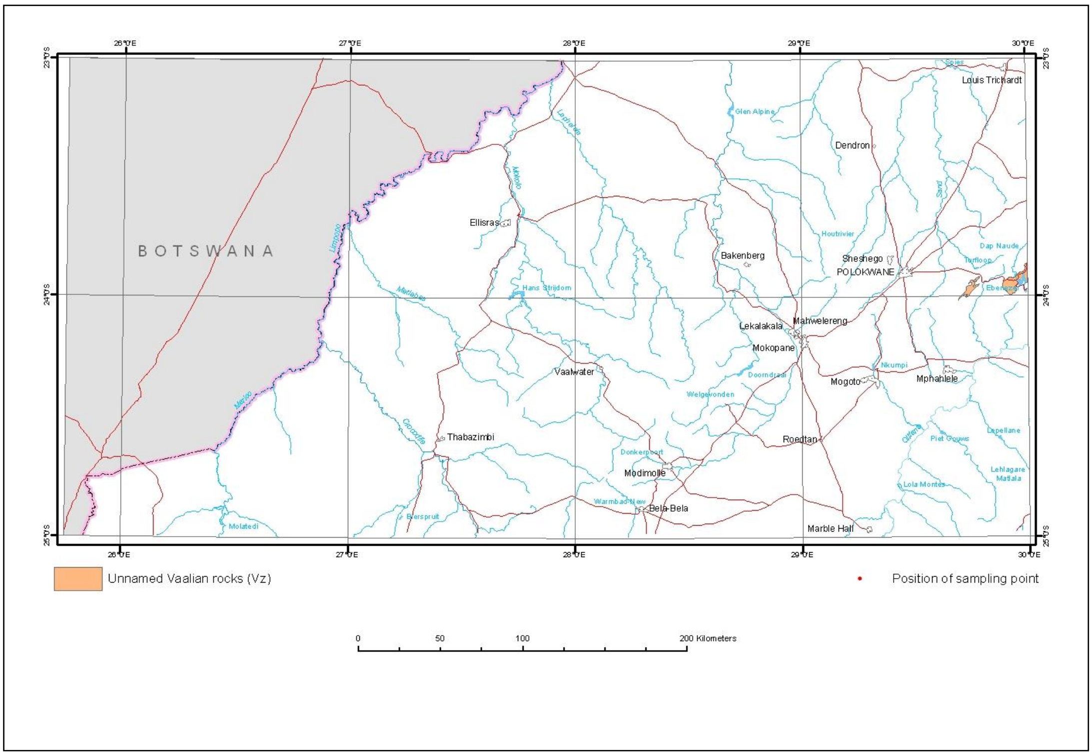

Figure 104: Geographical distribution of the unnamed Vaalian Rocks (Vz) and associated

groundwater sampling points.

Due to insufficient data the yield frequency diagram (Figure 105) does not give a clear indication of the groundwater potential of the unit. The unit is not considered a major aquifer and groundwater is currently predominantly obtained from springs for domestic purposes. Surface water stored in numerous small dams erected along the valleys is utilized for gardens and small irrigation schemes. The rainfall in this area is adequate to sustain the springs but groundwater use from boreholes is expected to increase due to the increasing development of small holdings especially in the Haenertsburg area. The Boyne Shear zone (not indicated on the map) in the western part of the unit is the most important lineament within the unit that can be targeted for groundwater development. Other lineaments are predominantly diabase dykes trending northeast. Groundwater targets in this area will be possible deep sediment accumulation and weathering along the valleys; the transitional zones between weathered basins and fresh bedrock; and the contact/metamorphism zone along diabase intrusions. The latter is expected to give varying success as the contact zone between diabase and the host rock can be fussed together with no visible fracturing as can be seen in the same formation just outside the map area at Debegeni falls. The unweathered, unfractured nature of the bedrock; small unfractured criss crossing pegmatite veins cut by movement and folding; mylonite and the shallow sheet like fractures most probably related to stress relief can be observed here.

No chemical analysis was available to give an indication of the nature of the groundwater of the area. It is likely that the groundwater will be of a very good quality. Members of a religious group collect water from open streams in the area near Haenertsburg and sell it next to the main road through out the year.

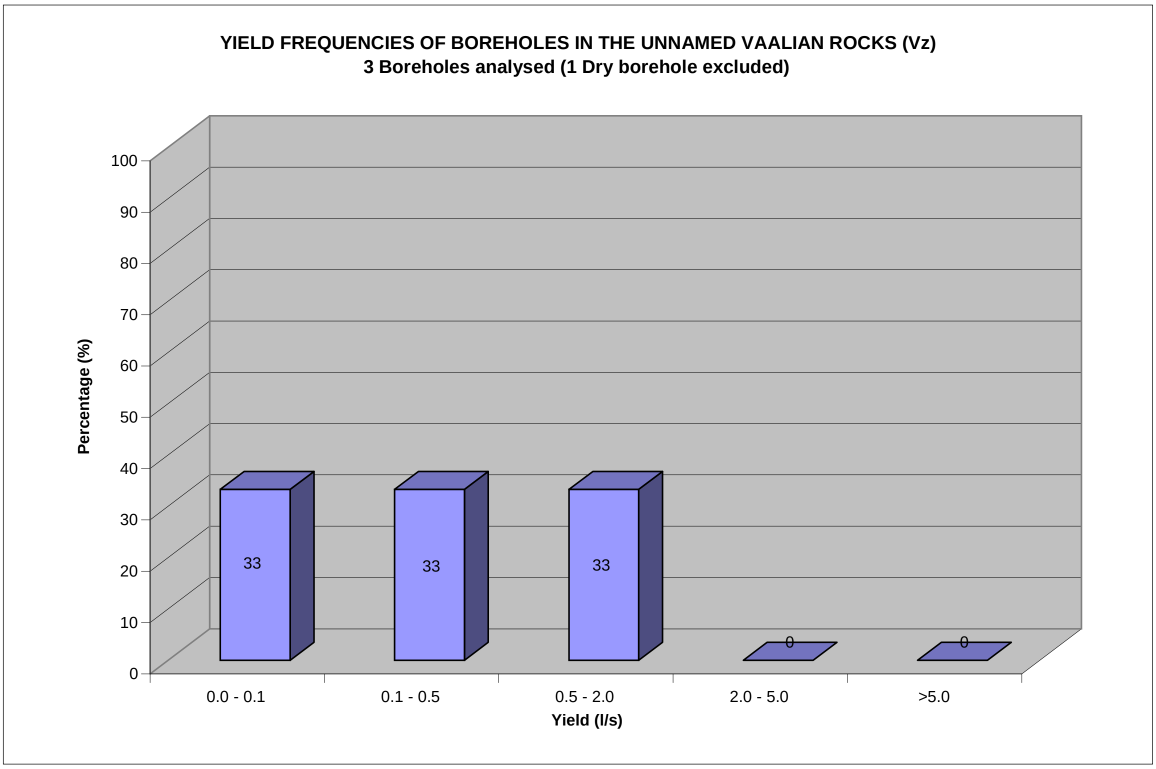

Figure 105 : Yield frequency for the intergranular and fractured aquifers of the unnamed Vaalian Rocks (Vz).

7.2.3.15 MATLALA GRANITE (Rat)

The Matlala Granite which is intrusive in the Hout River Gneiss is located more or less 45km northwest of Polokwane. It occurs as a roughly circular outcrop covering an area of approximately 300km^2 (Figure 106). The outcrop coincides with rugged mountainous terrain which rises some 600m above the surrounding planes. The Matlala Granite ranges in colour from light grey through to pink and red and grain size from fine to coarse porphyritic (Brandl, 1986). Van Wyk (1977) recognized eight varieties with the most widespread one being a grey and pink, fine-grained biotitic rock of granodioritic composition. The contact relationship of the Matlala Granite with the surrounding host rock was investigated during a research project conducted by DWA (Du Toit, 2001). Supported by drilling and geochemical data this study suggests that the Matlala batholith in fact consist of three separate intrusions. The three intrusions shown as one intrusion on the published geological map (sheet 2328) have locally been named by Du Toit (2001) as the Matlala Granite (occupying the largest area), the Tibane Granite located immediately north of the Matlala outcrop and Chloe Granite (dyke-like feature) located northeast of the former respectively. In this document the three granites are, however, grouped together and discussed as the Matlala Granite.

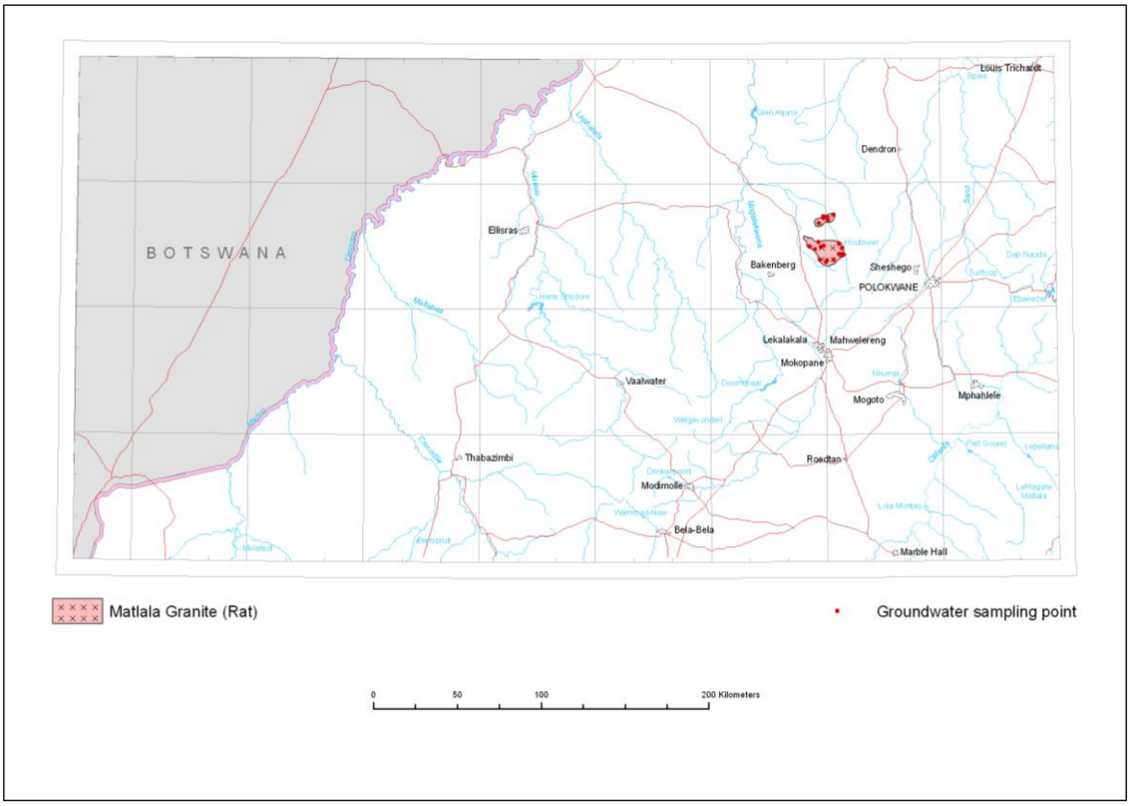

Figure 106:Geographical distribution of the Matlala Granite (Rat) and the associated groundwater sampling points.

As in the case of the Moletsi Granite, drilling results suggests the Matlala Granite to have the characteristics of a weathered and fractured semi-confined to confined aquifer. It also varies in saturated thickness from 1-70m (confirmed by drilling) along the different geophysical traverses surveyed across the contact. Well fractured remnant roof sections appear to be the most important host of the aquifer in the area, whereas the contact between the granite and the host rock (Hout River Gneiss) itself has been indicated by drilling as poor targets for groundwater exploration. Water is mostly intercepted in the transitional zone between the weathered and solid rock. Diabase dyke contacts were also find to be potential targets but due to limited storage may not be sustainable during periods of low recharge.

The yield frequency diagram (Figure 107) indicates that 62% of the boreholes used in the analysis yield <2ℓ/s and 26% >5ℓ/s. The higher yields are related to remnant roof sections of the host rock that is highly fractured.

Chemical data is represented as a stiff diagram (Figure 108). The water exhibits a sodium-bicarbonate-chloride water type with elevated magnesium concentrations. Magnesium concentrations vary between 4.9 to 221mg/l with 17% exceeding the maximum allowed limit (Mg >100mg/l). EC values vary between 21.5 and 596mS/m with a harmonic mean of 125mS/m. 13% of the analysis have EC values exceeding the maximum allowed limit (EC >370mS/m) for domestic use. Fluoride concentrations vary between 0.3 to 4.3mg/l with 50% of the boreholes exceeding the maximum allowed limit (F >1.5mg/l). Nitrate and nitrite (reported as N) concentrations vary between 0.02 to 38.8mg/l with 17% exceeding the maximum allowed limit (N >20mg/l). Sodium concentrations vary between 21.2 to 696mg/l with 27% exceeding the maximum allowed limit (Na > 400mg/l).

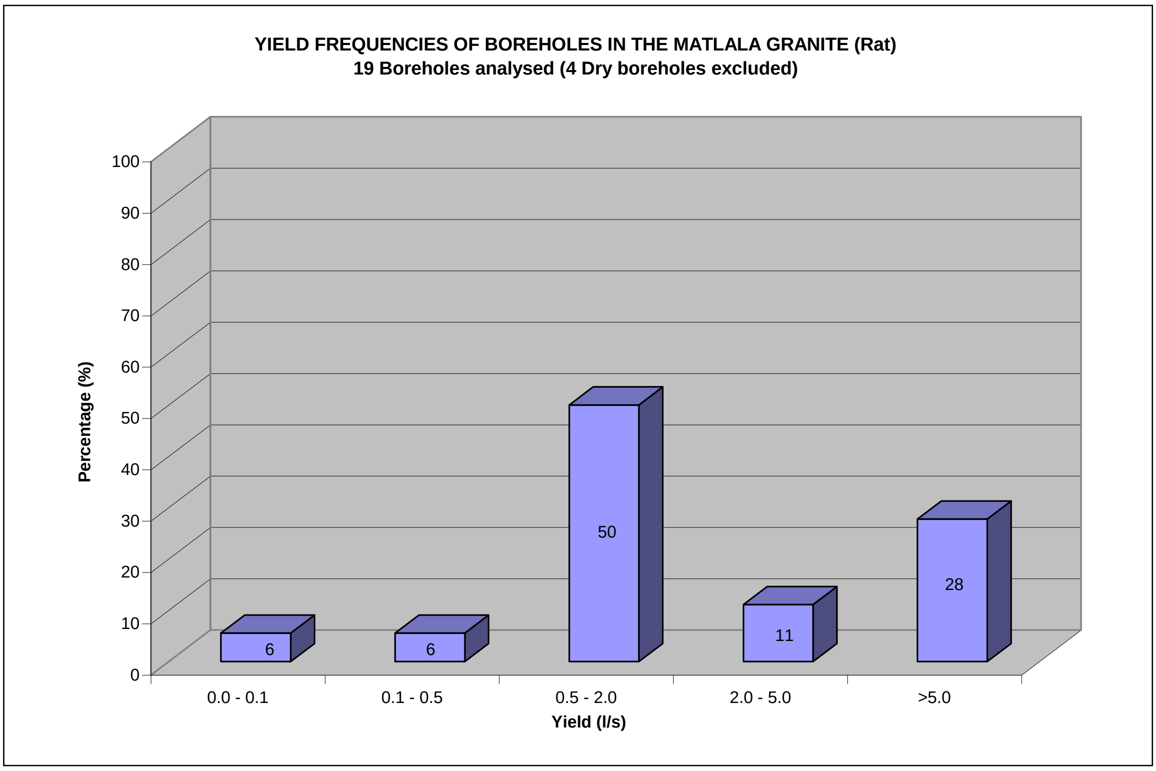

Figure 107:Yield frequency for the intergranular and fractured aquifers of the Matlala Granite (Rat)

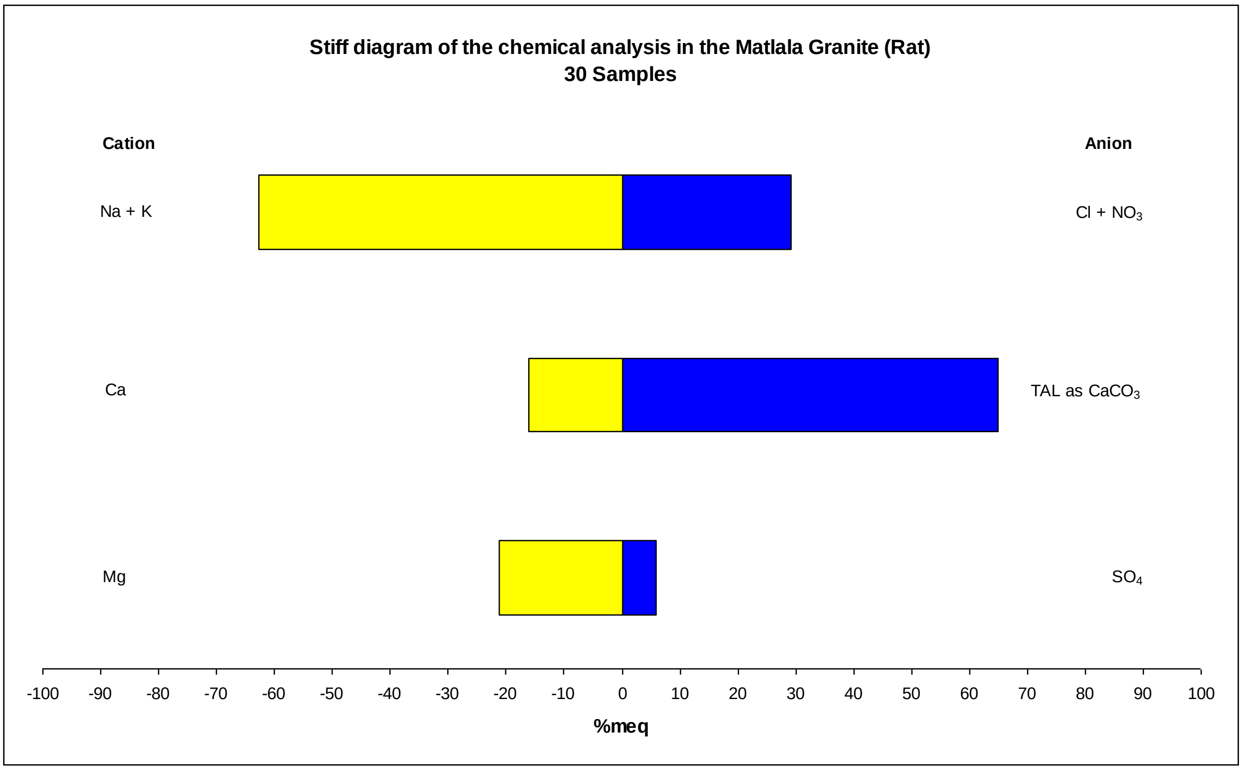

Figure 108: Stiff diagram representing chemical analysis of the Matlala Granite (Rat)

7.2.3.16 GABORONE GRANITE (Rga)

The Gaborone Granite occurs southeast and west of Derdepoort (Figure 109) and consists of various types of granite and associated quartz porphyry and quartz felsite. This unit covers approximately 0.6% of the map sheet area. 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 66% of the successful boreholes yields less than 0.5ℓ/s, 23% yields between 0.5 and 2ℓ/s and only 2% yields more than 5ℓ/s (Figure 110). The depth of weathering could be insignificant for groundwater exploration as fresh bedrock outcrop dominates as scattered hills. The depth to groundwater level varies between 20 and 40m.

The water is mostly used for domestic purposes and livestock watering. Chemical data distribution is poor and only one sample was available for assessment (Figure 111). Although it is not a valid classification, the analysis shows the water to be a calsium-magnesium-bicarbonate type.

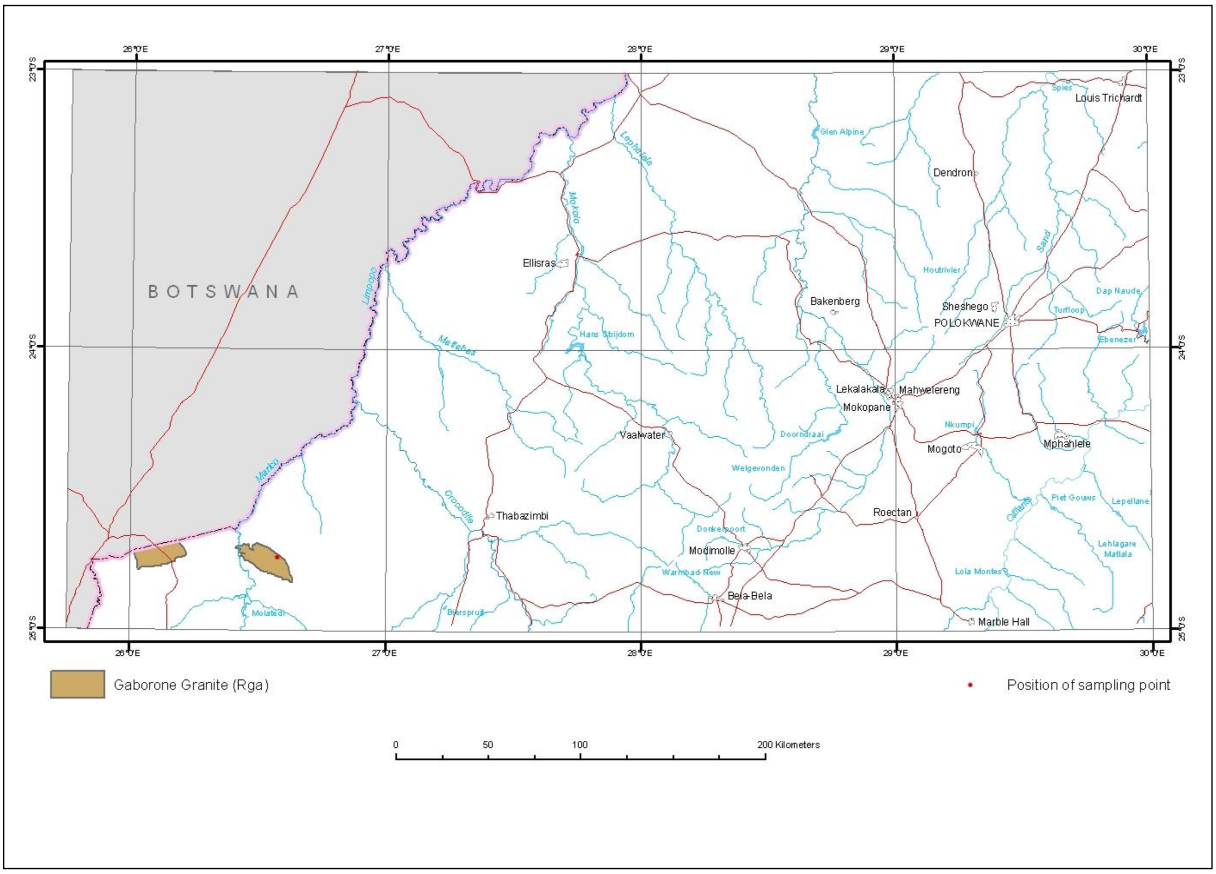

Figure 109: Geographical distribution of the Gaborone Granite (Rga) and associated groundwater sampling points.

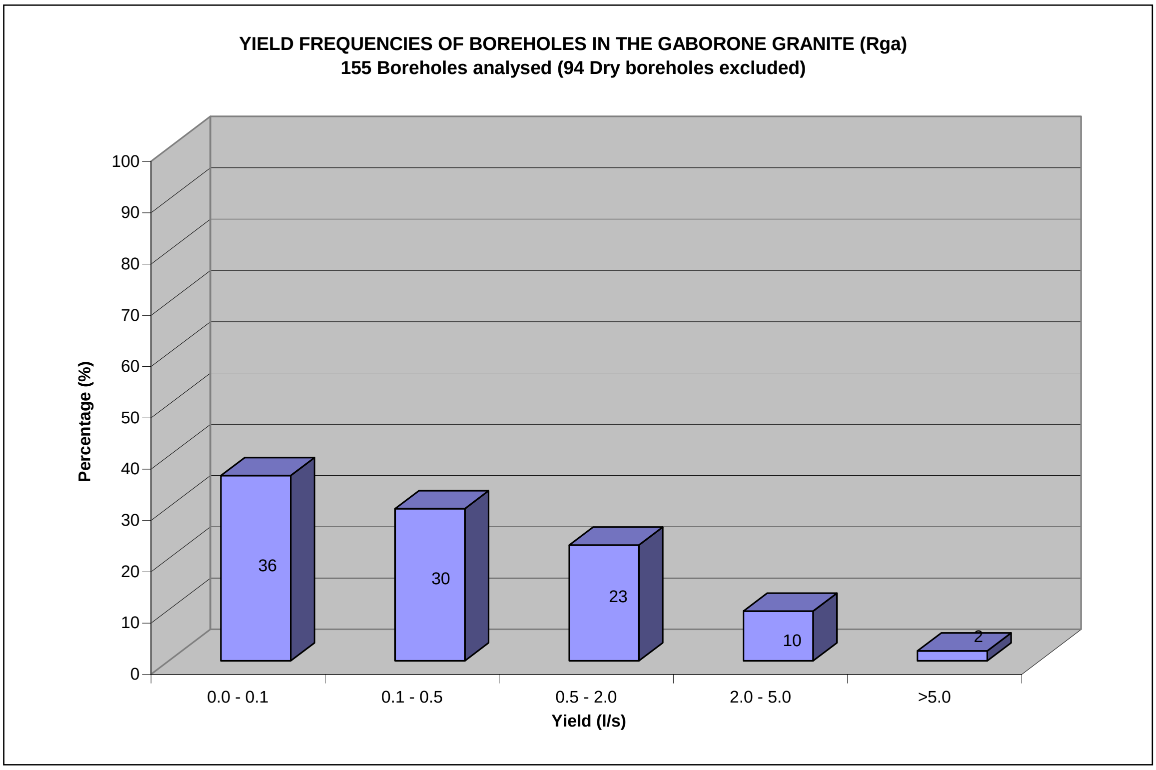

Figure 110:Yield frequency for the intergranular and fractured aquifers of the Gaborone Granite (Rga)

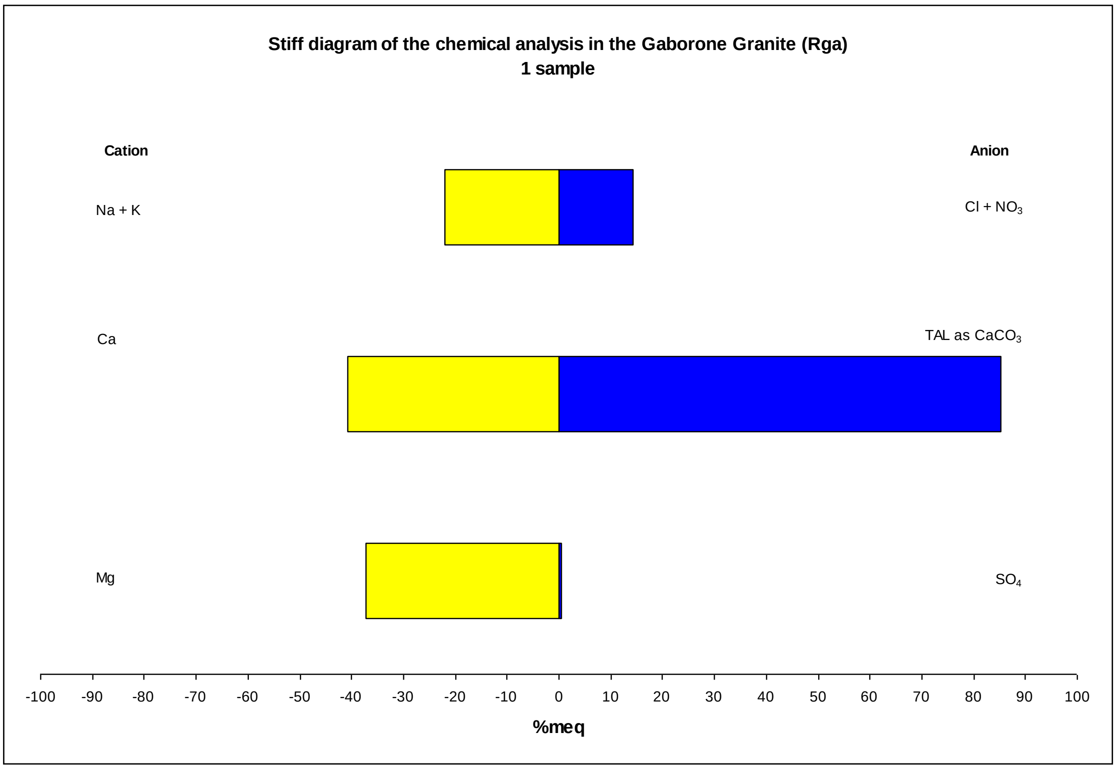

Figure 111:Stiff diagram representing chemical analysis of the Gaborone Granite (Rga)

7.2.3.17 UTRECHT GRANITE (Rut)

The Utrecht Granite which forms a circular stock-like body approximately 55km west of Polokwane is a fine-grained, pink biotitic rock of granodioritic composition. It covers an area of about 25km^2. It can be described as a weathered and fractured semi-confined to confined granitic aquifer. Indications are that it has a low potential for groundwater exploration. No remnant roof sections were found to be present, although numerous gneiss inclusions have been intercepted during drilling. Drilling revealed the contact between the Utrecht Granite and its host rock to be very poor targets for groundwater development. In the few successful boreholes drilled in the granite, water was mostly intercepted in fractures and transitional zones between weathered and solid granite (Du Toit, 2001).

The yield distribution diagram (Figure 113) supports the poor potential for successful groundwater development with 88% of the successful boreholes yielding less than 2ℓ/s. 7 groundwater samples were available for analysis and the results may differ if more information was available. Fluoride concentrations vary from 0.26 to 2.37mg/l with 14% of the boreholes exceeding the maximum allowed limit (F >1.5mg/l). Nitrate and nitrite (reported as N) concentrations vary between 0.05 to 39.9mg/l with 28% exceeding the maximum allowed limit (N >20mg/l). Figure 114 shows the dominant anions/ cations present. The water exhibits a sodium-bicarbonate-chloride nature.

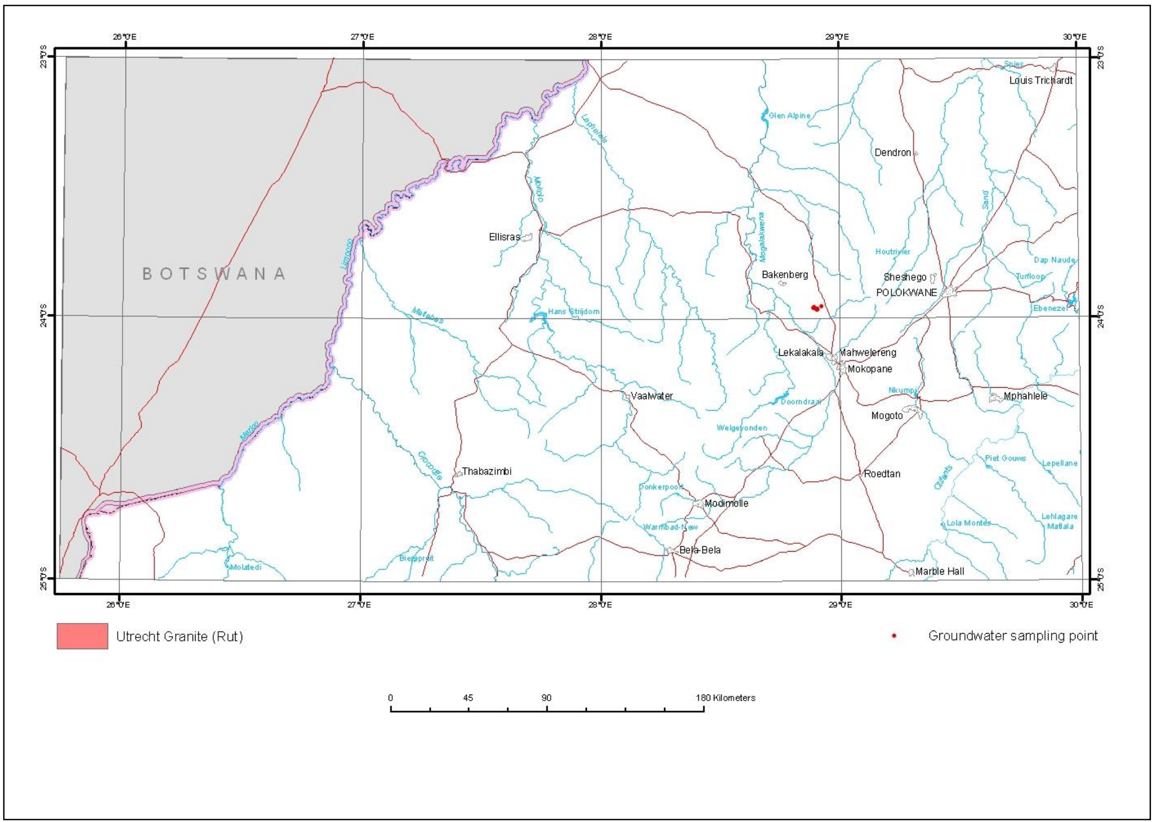

Figure 112:Geographical distribution of the Utrecht Granite (Rut) and associated groundwater sampling points.

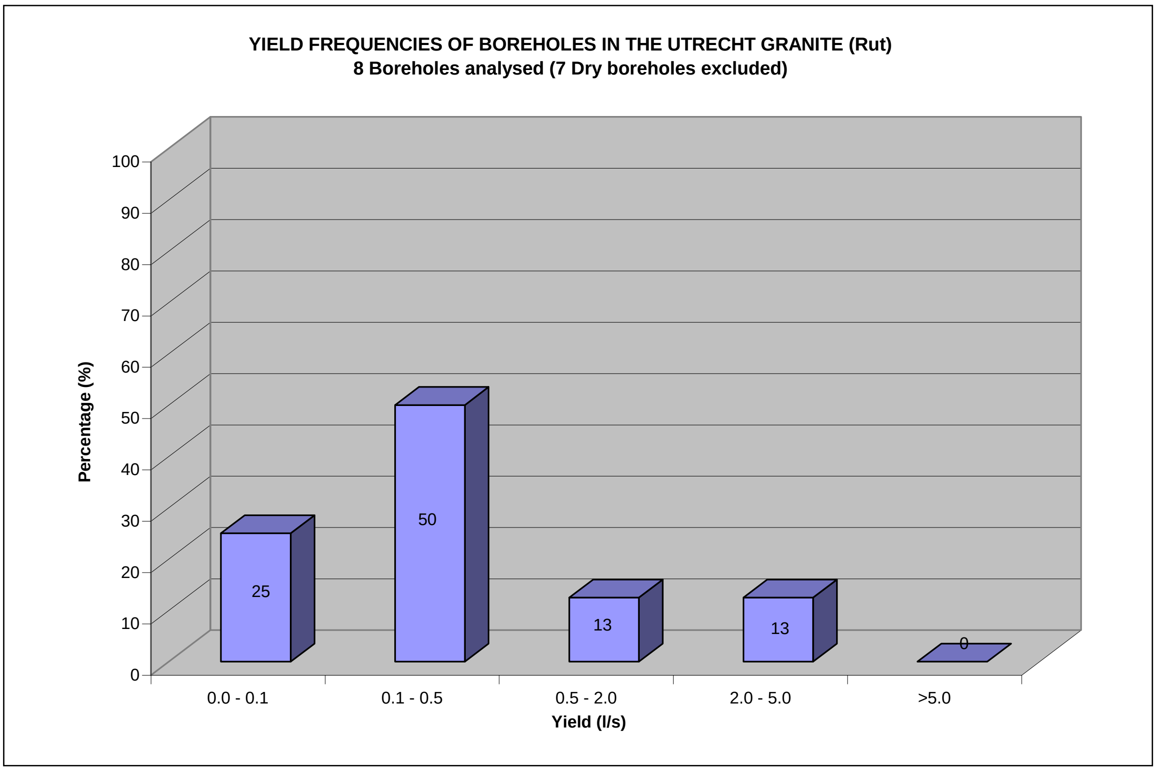

Figure 113: Yield frequency for the intergranular and fractured aquifers of the Utrecht Granite (Rut)

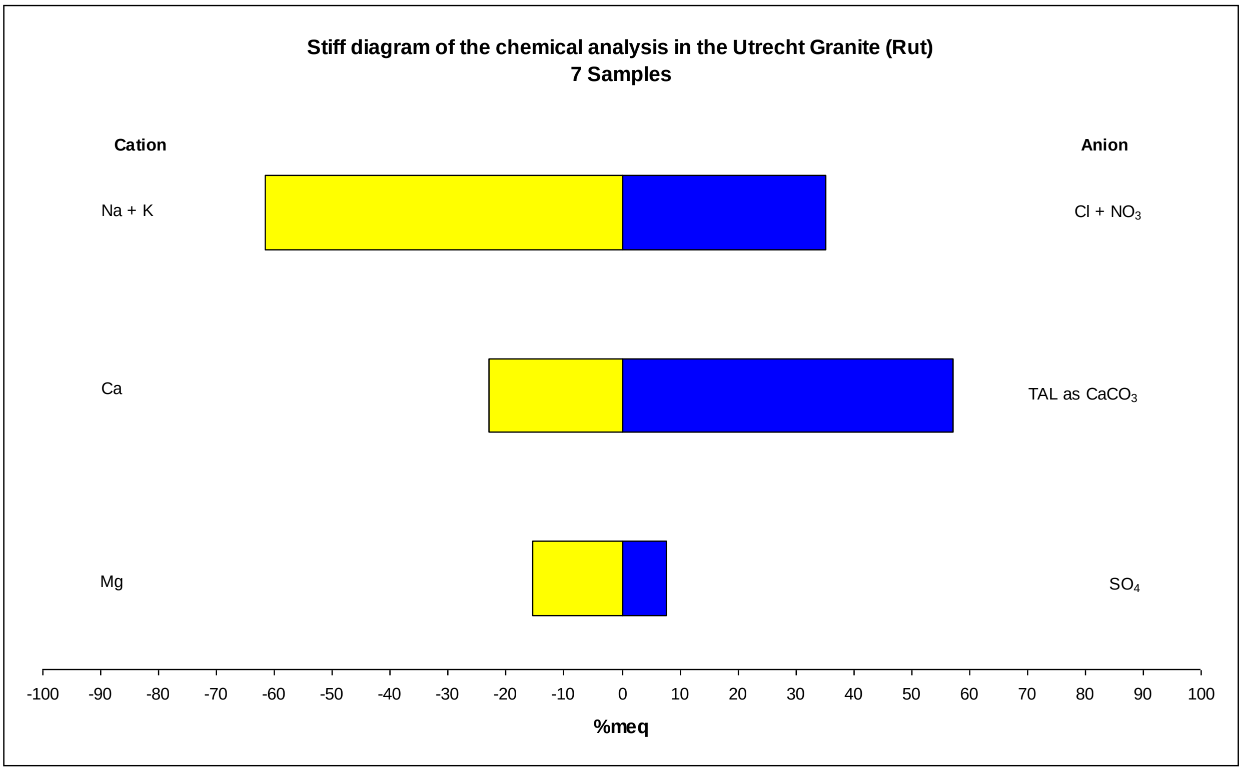

Figure 114:Stiff diagram representing chemical analysis of the Utrecht Granite (Rut)

7.2.3.18 UITLOOP GRANITE (Rui)

Two occurrences of the Uitloop Granite appear on the map sheet namely north and northeast of Mokopane (Potgietersrus). It contains minerals such as quartz, orthoclase, microcline-perthite, sodic plagioclase and biotite. The rock has an adamellitic composition, is medium to coarse grained and mainly reddish in colour. It covers approximately 0.2% of the map area. The yield frequency diagram does not give a good overview of the groundwater potential as only 5 boreholes have been used in the analysis with all yielding less than 0.5ℓ/s. Various northeast orientated lineaments transect this unit and further drilling is needed to investigate the groundwater potential. In general, the occurrence of groundwater in this granite is not expected to be different from that of the other granites on the map sheet. No chemical data was available to determine the nature of the groundwater chemistry for this unit.

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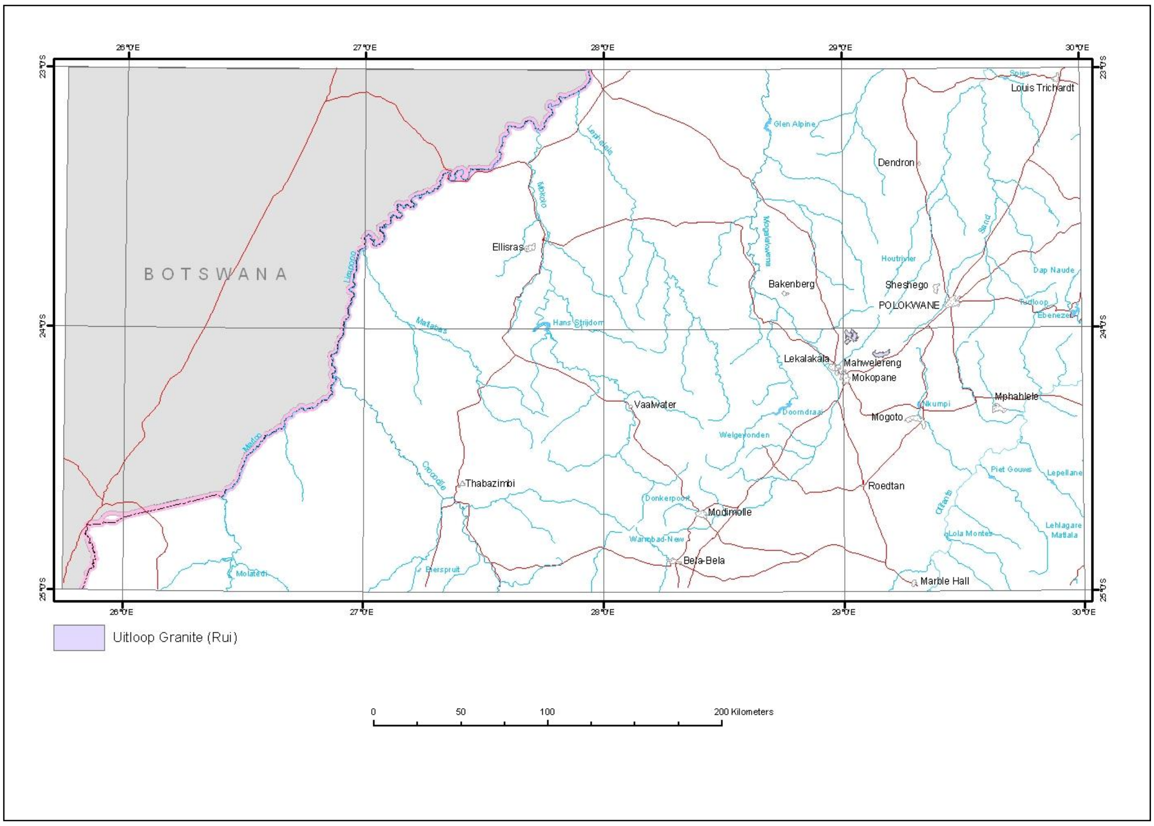

Figure 115: Geographical distribution of the Uitloop Granite (Rui)

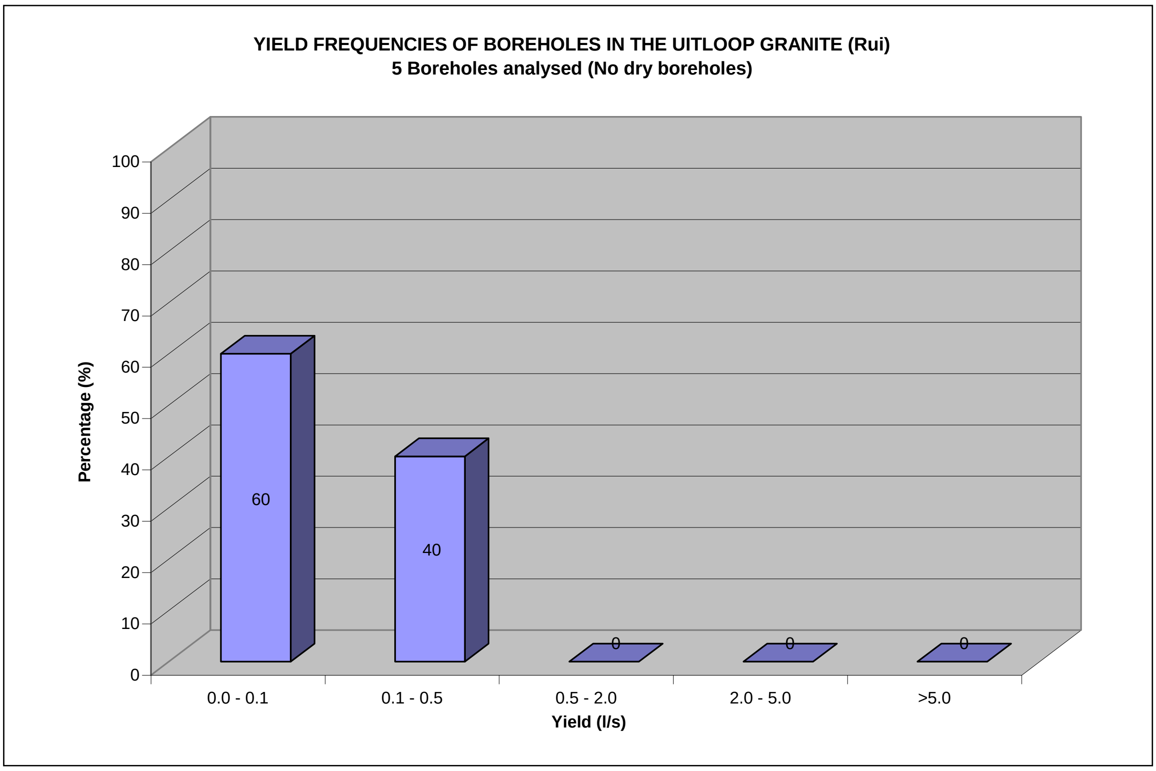

Figure 116:Yield frequency of the intergranular and fractured aquifers of the Uitloop Granite (Rui)

7.2.3.19 LUNSKLIP GRANITE (Rlu)

The Lunsklip Granite occurs northeast of Mokopane (Potgietersrus) and southwest of Polokwane. The latter is medium to coarse grained, pink and pinkish grey in colour and its main constituents are quartz, orthoclase, microcline-perthite, sodic plagioclase, hornblende and biotite. The composition of the granite varies between adamellitic and granodioritic. In places there is a knife-sharp contact with the country rock. It underlies approximately 0.9% of the map sheet area.

From the yield frequency diagram, (Figure 117) indications are that the Lunsklip Granite has a low groundwater development potential with 73% of the successful boreholes yielding less than 0.5ℓ/s and only 5% yielding between 0.5 to 2ℓ/s. This unit is most suitable as a resource for domestic and livestock watering.

Figure 118 shows the dominant anions and cations present. 28 groundwater samples were available for analysis. Fluoride concentrations vary from 0.13 to 9.23mg/l with 64% of the boreholes exceeding the maximum allowed limit (F >1.5mg/l). Nitrate and nitrite (reported as N) concentrations vary from 0.02 to 11.1mg/l with 93% within the ideal to acceptable range (N <10mg/l). Figure 119 shows the dominant anions and cations present. The groundwater exhibits a sodium-calcium-bicarbonate character.

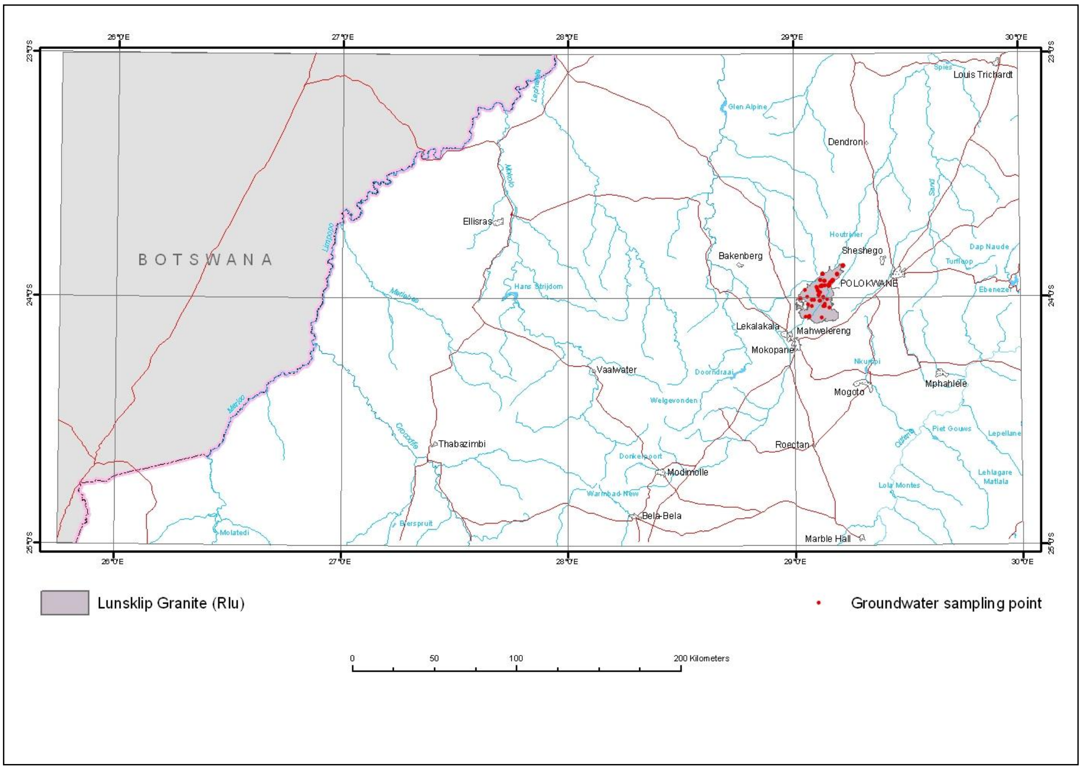

Figure 117: Geographical distribution of the Lunsklip Granite (Rlu) and associated groundwater sampling points.

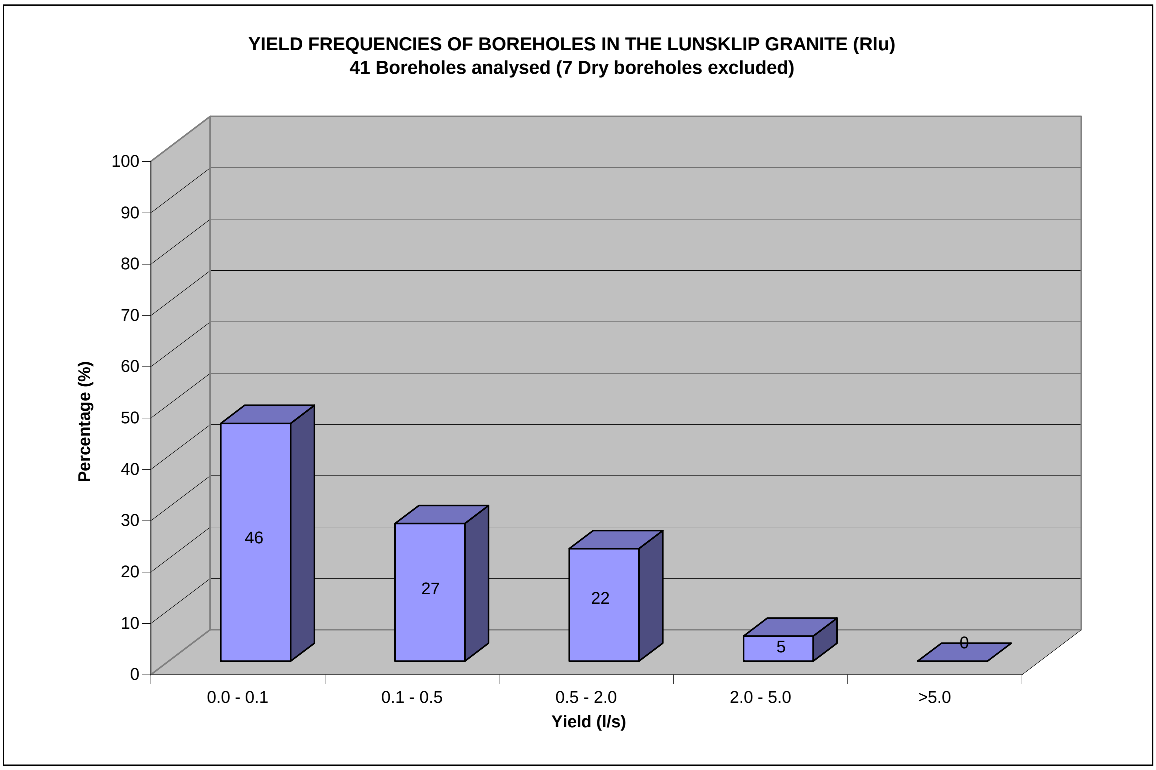

Figure 118: Yield frequency for the intergranular and fractured aquifers of the Lunsklip Granite (Rlu)

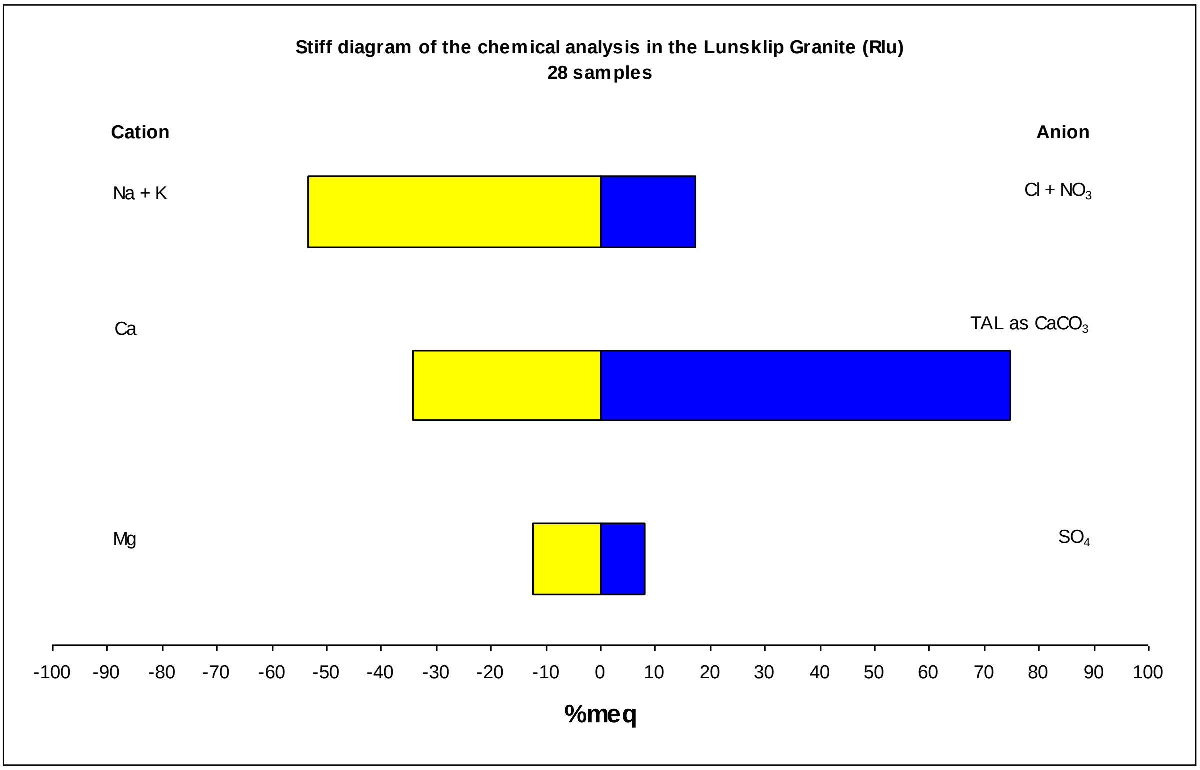

Figure 119: Stiff diagram representing chemical analysis of the Lunsklip Granite (Rlu)

7.2.3.20 MOLETSI GRANITE (Rmo)

This batholith intrusion occurs northwest of Polokwane (Pietersburg) as a single cluster on the map sheet (Figure 120). This biotite rich granite weathers typically into huge oval boulders and consists of two varieties, a pink to grey coarse-grained granite which is rimmed by the second described as a grey to pink, medium-grained porphyritic rock. It contains inclusions of banded gneiss and leucocratic granite. Garnets may occasionally be present.

Plate 13: Xenoliths of gneiss occurring in outcrops of the Moletsi Granite. Studies of the groundwater potential of the Moletsi and other large granite intrusions (Batholiths) revealed that weathered and/or fractured remnant gneissic roof sections are good targets for groundwater development and can occasionally produce yields of >40ℓ/s. These high yields relate to tensional fractures, which developed in the roof during the emplacement of the magma (Photograph: WH du Toit).

Based on the drilling results of a research project conducted by DWA on the Moletsi Granite, (Du Toit 2001), it can be described as a weathered and fractured semi confined to confined aquifer. It varies in saturated thickness from 1 to 70m (confirmed by drilling) along the different traverses that were surveyed. The weathering and fracturing is of a secondary nature as it only formed after the intrusion of the granite. Well fractured remnant roof sections appear to be the most important host of the aquifer in the area, where as the contact between the granite and the host rock (Hout River Gneiss) itself has been indicated by the drilling as poor targets for groundwater exploration. Groundwater is mostly intercepted in the transitional zone between the weathered and solid granite. Drilling has further shown that diabase intrusions, especially their contact zones with the host rock may also be targeted for successful boreholes. However, these contact zones generally have limited storage and may not be sustainable if not managed properly.

The yield frequency diagram (Figure 121) indicates that 42% of the successful boreholes yield less than 2ℓ/s, 44% yield between 2-5ℓ/s and 15% yield above 5ℓ/s. Most of the high yielding boreholes are related to remnant roof sections of the host rock.

(Figure 122) shows the dominant anions and cations present. The water has a sodium-bicarbonate-chloride character. 28 groundwater samples were available for analysis. 96% of the EC values are within acceptable water quality for domestic use. The values vary between 37.2 and 156mS/m with a harmonic mean of 72.6mS/m. Fluoride concentrations vary from 0.3 to 3.7mg/l with 39% of the boreholes exceeding the maximum allowed limit (F >1.5mg/l). Nitrate and nitrite (reported as N) concentrations vary between 0.02 and 50.7mg/l with 82% within the ideal to acceptable range (N <10mg/l) with only 7% exceeding the maximum allowed limit (N >20mg/l).

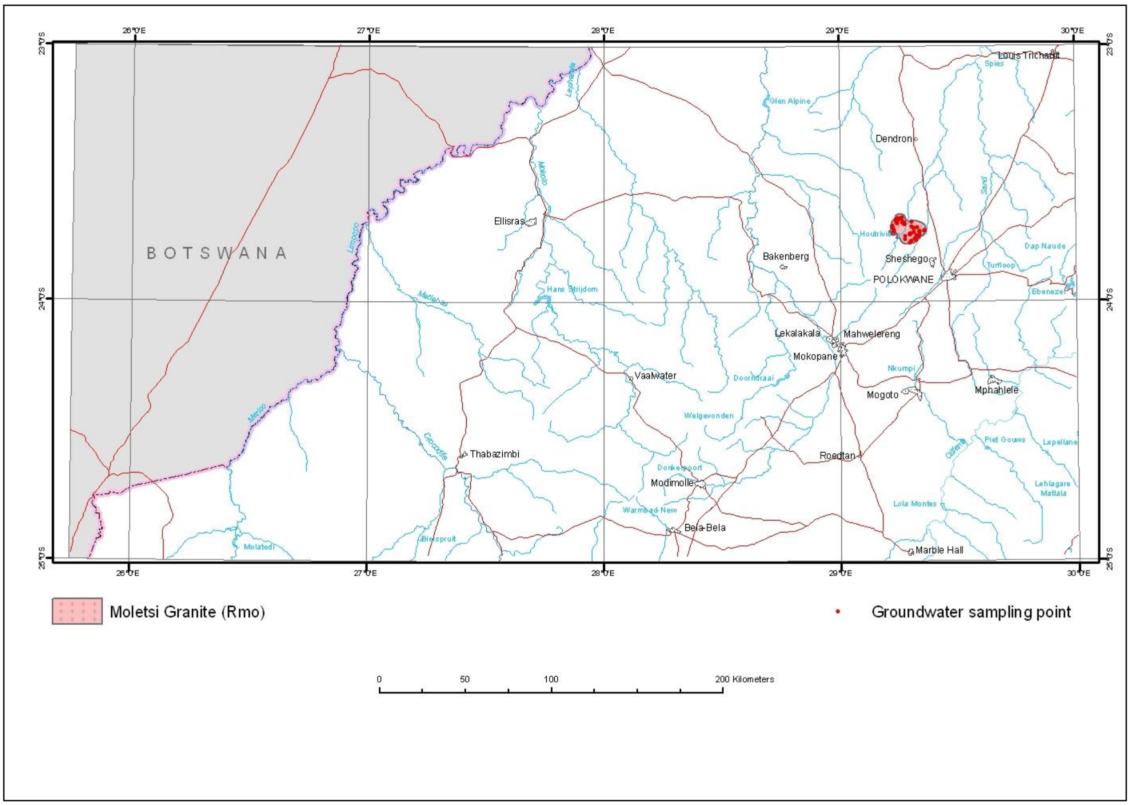

Figure 120: Geographical distribution of the Moletsi Granite (Rmo) and associated groundwater sampling points.

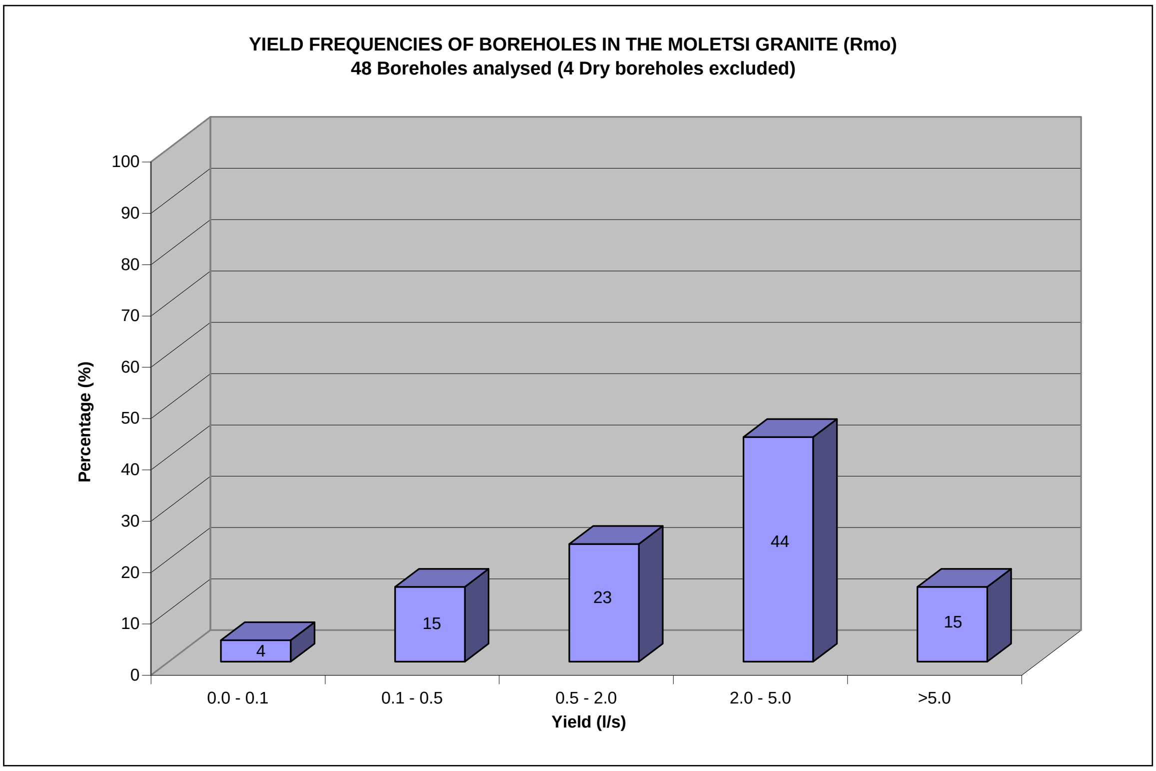

Figure 121 : Yield frequency for the intergranular and fractured aquifers of the Moletsi Granite (Rmo)

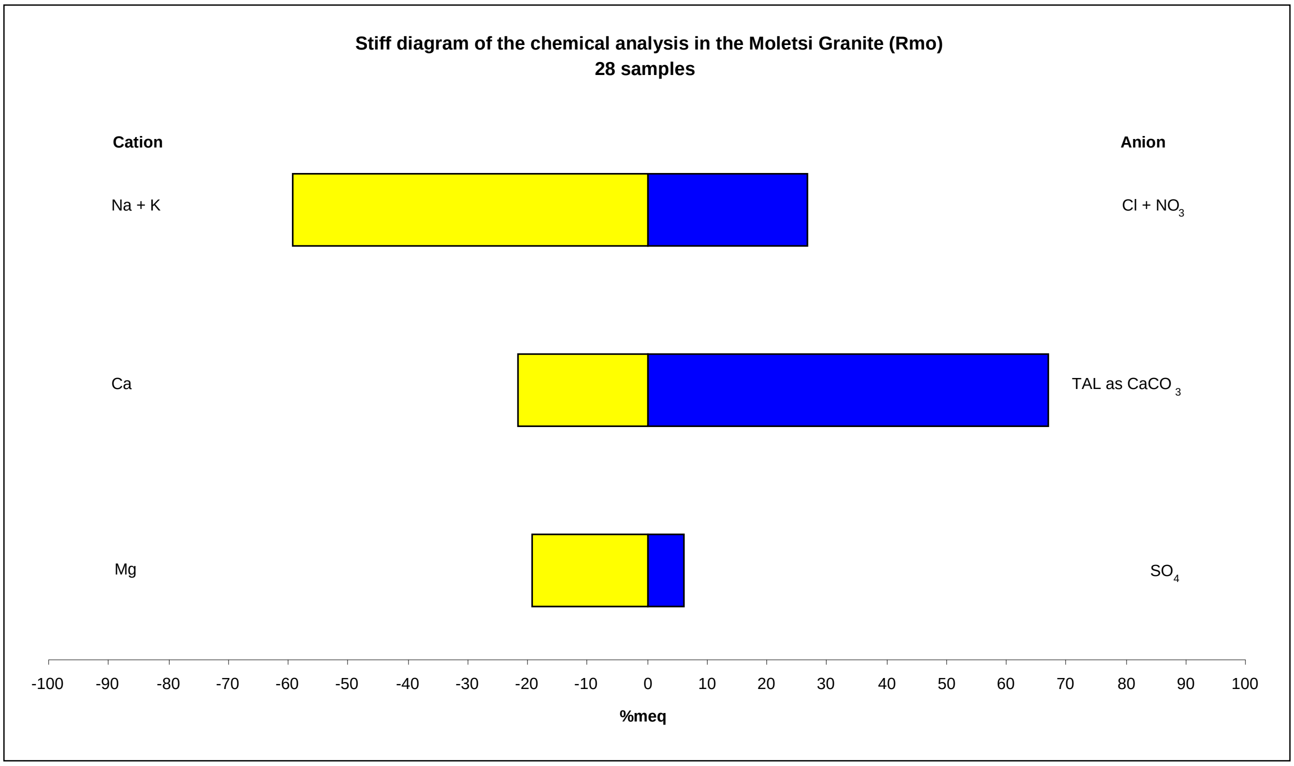

Figure 122: Stiff diagram representing chemical analysis of the Moletsi Granite (Rmo)

7.2.3.21 MATOK GRANITE (Rma)

The Matok Granite occurs in the north-western sector of the map sheet, more or less halfway between Polokwane and Louis Trichardt along the N1 north. It is a major batholithic intrusion and includes several smaller stocks north of the Rhenosterkoppies. It is characterized by the presence of a mafic and a younger granitic phase. The mafic phase itself can be divided into an older enderbitic and a younger charno-enderbitic phase. Both are confined mainly to the northern edge of the batholith. The enderbite is typically fine grained and dark coloured whereas the charno-enderbite is paler and coarser-grained. Mineralogical both types are similar and are composed of plagioclase and biotite with subordinate augite, hypersthene, orthoclase and quartz. They differ only in pyroxene content, which is less in the charno-enderbite phase. It covers approximately 0.8% of the map sheet.

The yield frequency diagram (Figure 124) gives an indication of the expected yield of the boreholes. 71% of the successful boreholes yield less than 2ℓ/s, and 3% yields more than 5ℓ/s. Available information indicates that yields more than 5ℓ/s relates to a major northeast trending fault.

21 groundwater samples were available for analysis. No EC values exceed the maximum allowable limit (EC >370mS/m) although the average is high with values varying between 104.5 and 296mS/m with a harmonic mean of 188.4mS/m. Fluoride concentrations vary from 0.5 to 4.2mg/l with 62% of the boreholes exceeding the maximum allowed limit (F >1.5mg/l). Nitrate and nitrite (reported as N) concentrations vary between 0.9 and 58.4mg/l with only 7% exceeding the maximum allowed limit (N >20mg/l). Figure 125 shows the broad classification according to anions and cations. Groundwater in this unit has a sodium-chloride-bicarbonate character.

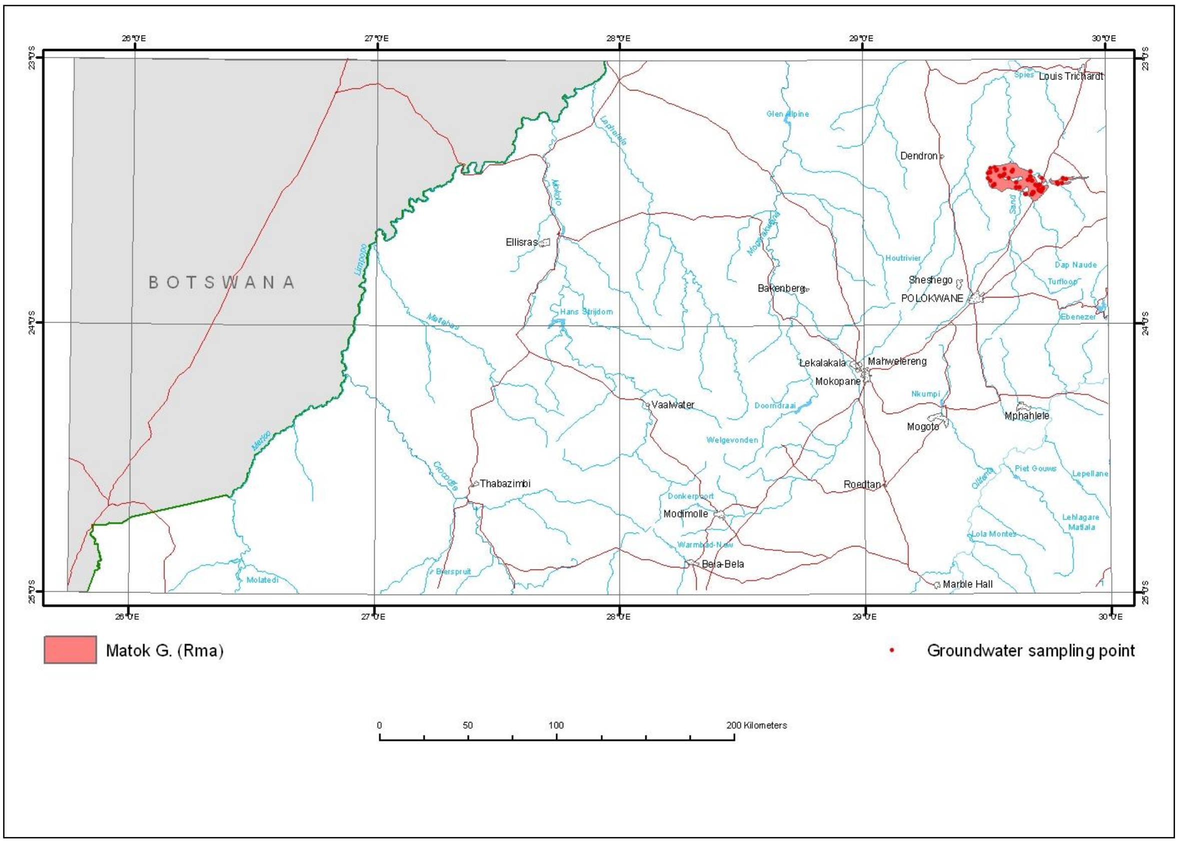

Figure 123: Geographical distribution of the Matok Granite (Rma) and associated groundwater sampling points.

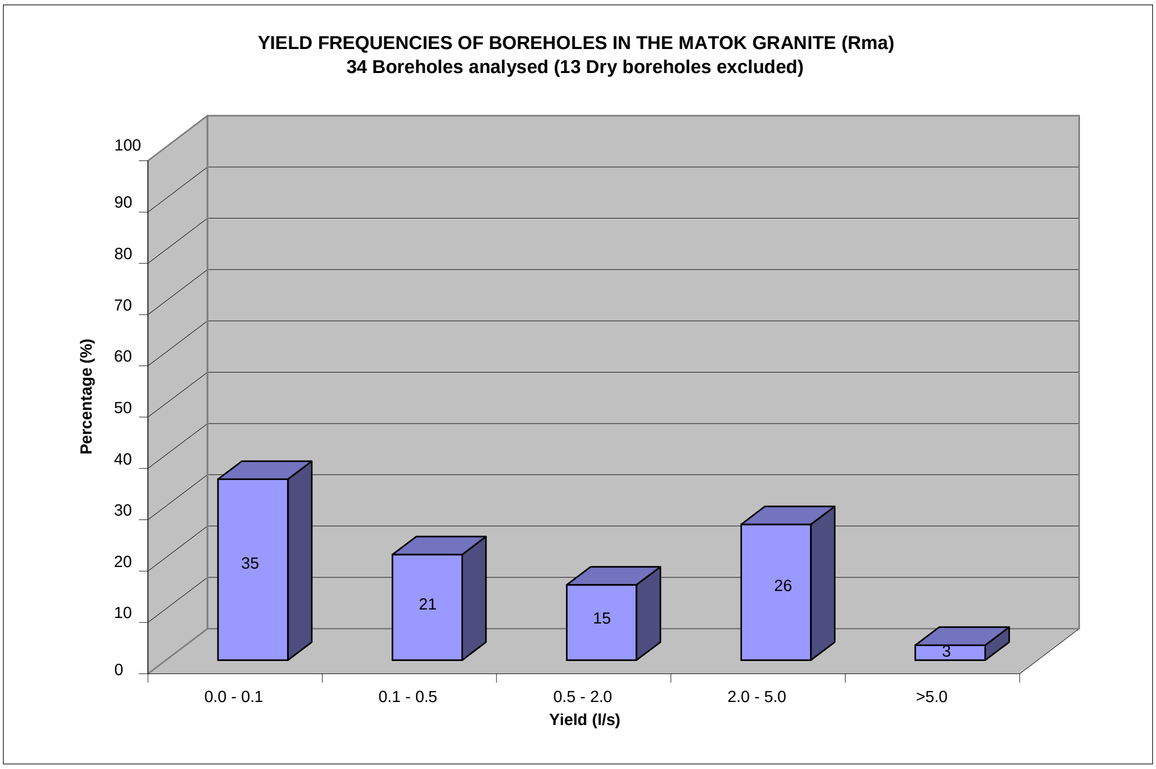

Figure 124: Yield frequency for the intergranular and fractured aquifers of the Matok Granite (Rma).

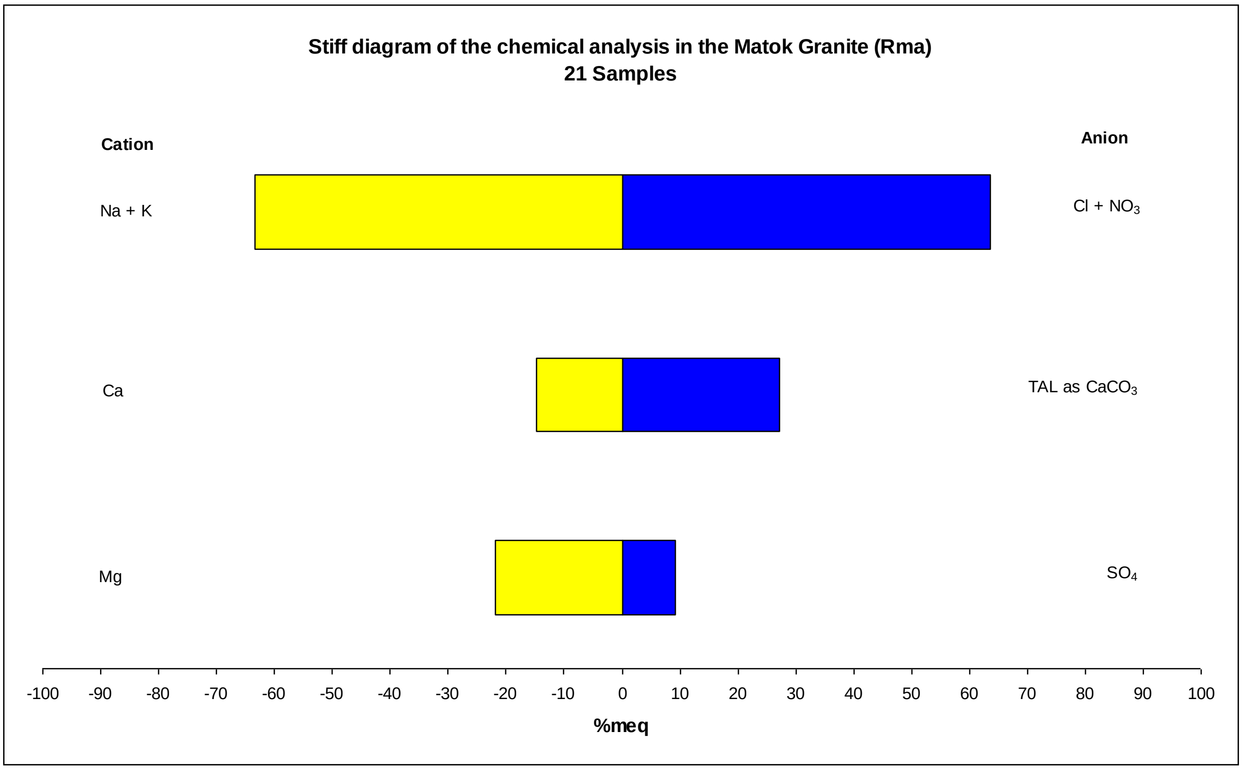

Figure 125: Stiff diagram representing chemical analysis of the Matok Granite (Rat)

7.2.3.22 HUGOMOND GRANITE (Rhu)

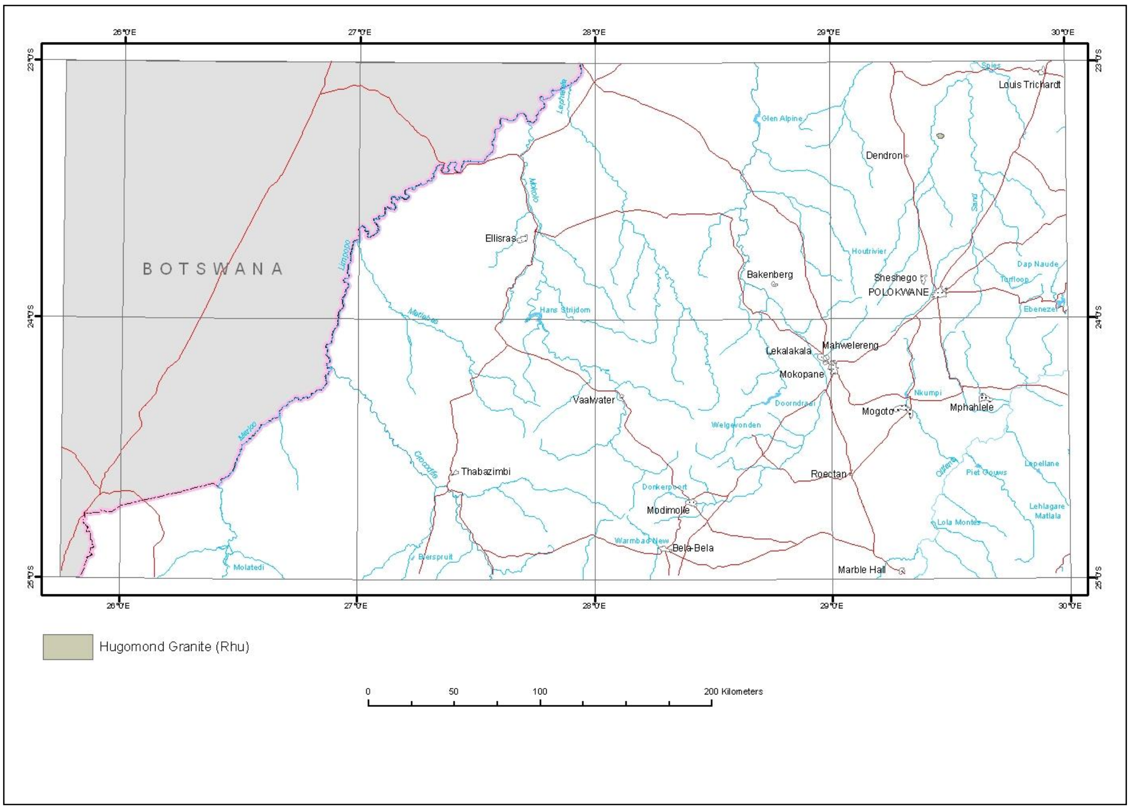

Figure 126: Geographical distribution of the Hugomond Granite (Rhu).

The Hugomond Granite is a coarse-grained, sometimes porphyritic, grey biotitic rock which occurs as a number of low barren ridges east-northeast of Dendron. It is cut by tourmaline-bearing pegmatitic veins having indistinct contacts. It covers approximately 0.02% of the map sheet area. There is no yield or water chemistry data available for this unit but it is expected to be similar to that of other granite intrusions on the map sheet.

7.2.3.23 GEYSER GRANITE (Rge)

The Geyser Granite which occurs northeast and east of Mokopane (Potgietersrus) is described as a homogeneous biotite granite-gneiss intruded by leucocratic granite and pegmatite (Figure 127). Xenoliths of the Pietersburg Group are a common feature within this unit with the northeast trending Ysterberg fault as the most prominent lineament transacting the unit. Smaller northeast trending faults and fracture zones are common within this unit. These can be targeted for groundwater development.

Although the data is limited within this unit the yield frequency distribution gives a good indication of the groundwater potential. 17% of the successful boreholes yield less than 0.1ℓ/s, 66% yield between 0.1 and 2ℓ/s and 6% yield more than 5ℓ/s (Figure 128).

No groundwater chemistry data is available for this granite.

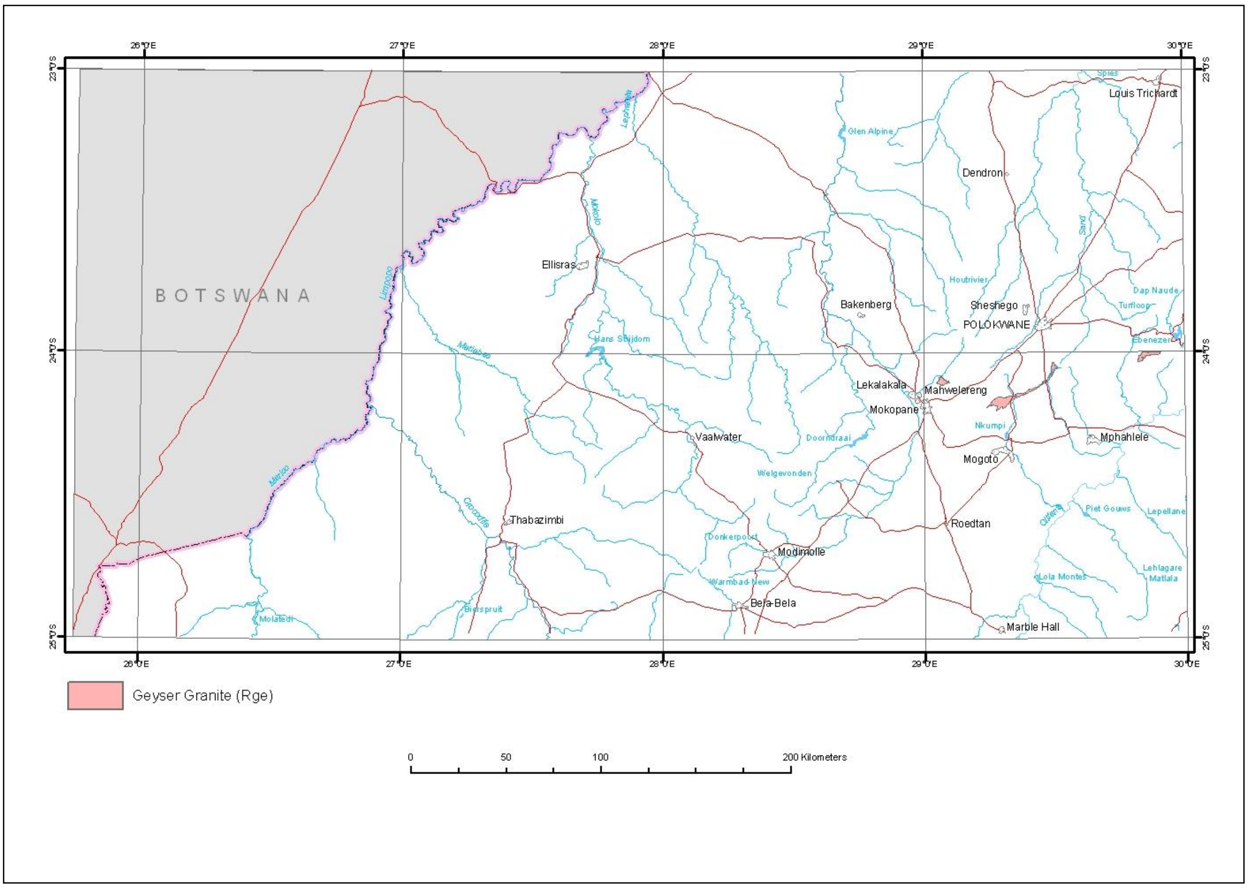

Figure 127: Geographical distribution of the Geyser Granite (Rge)

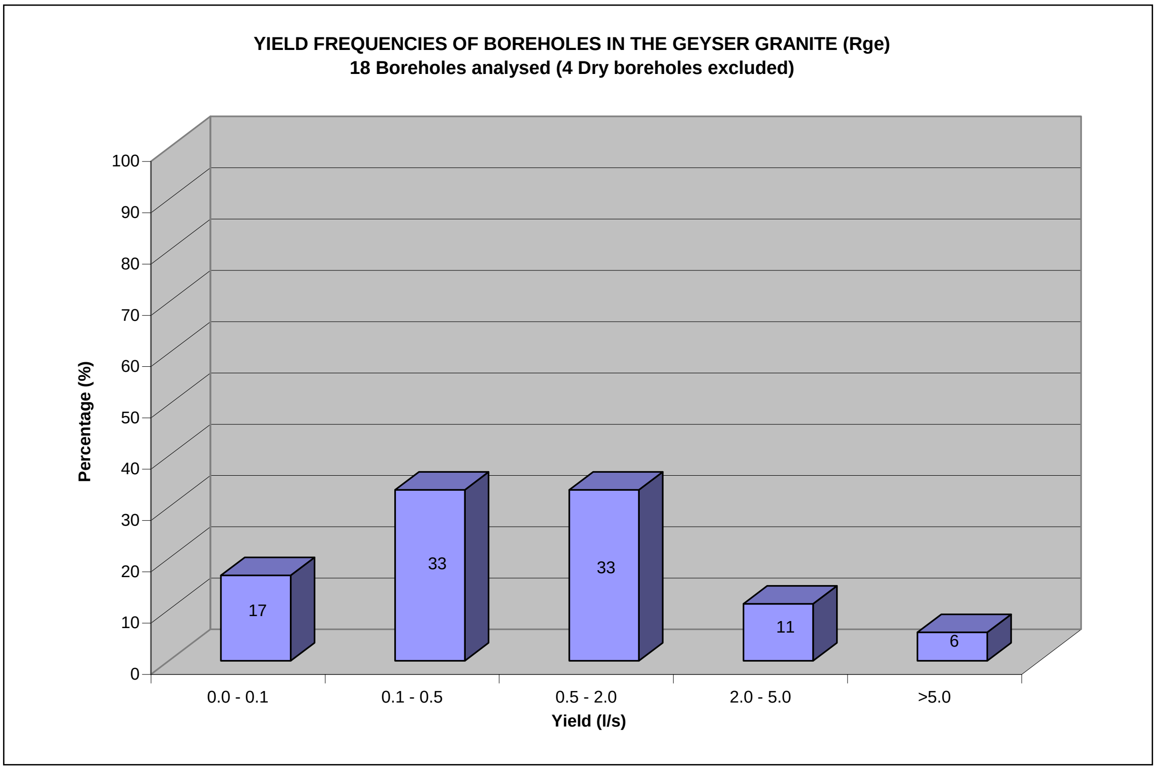

Figure 128: Yield frequency for the intergranular and fractured aquifers of the Geyser Granite (Rge)

7.2.3.24 PLATBERG GROUP (Rp) (Mostly lavas)

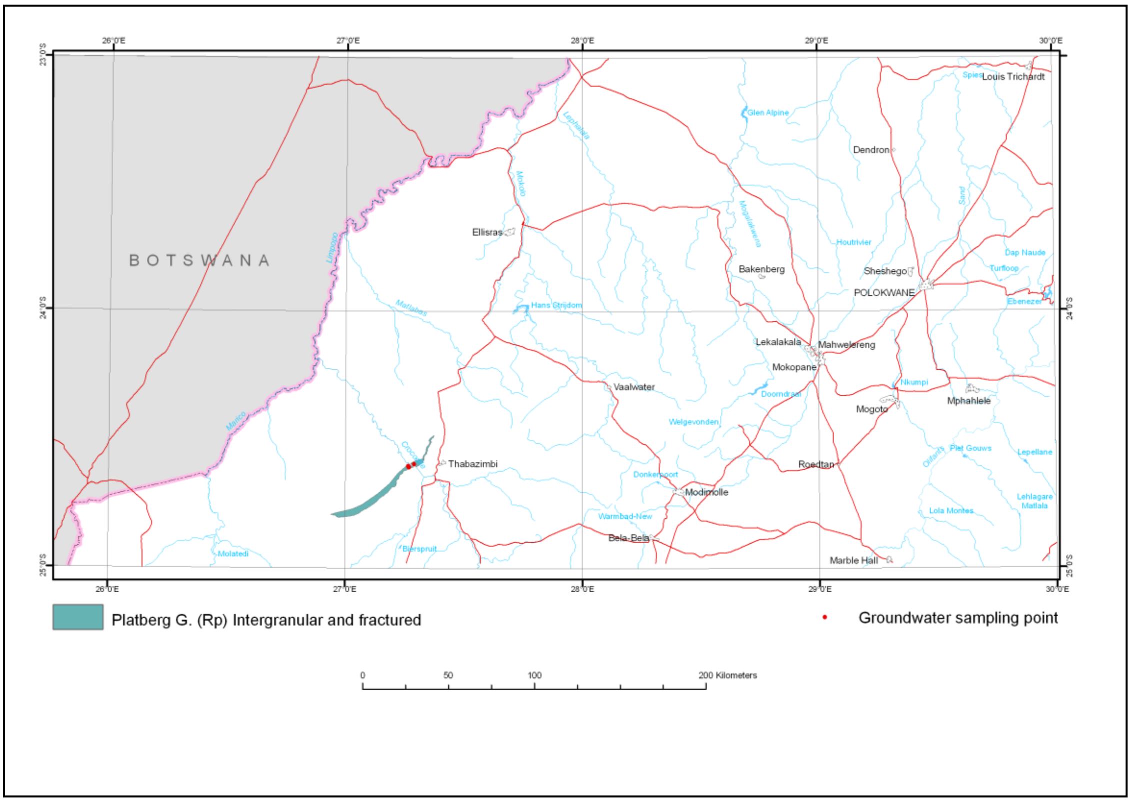

Figure 129: Geographical distribution of the Platberg Group (Rp) (mostly lavas) and associated groundwater sampling points.

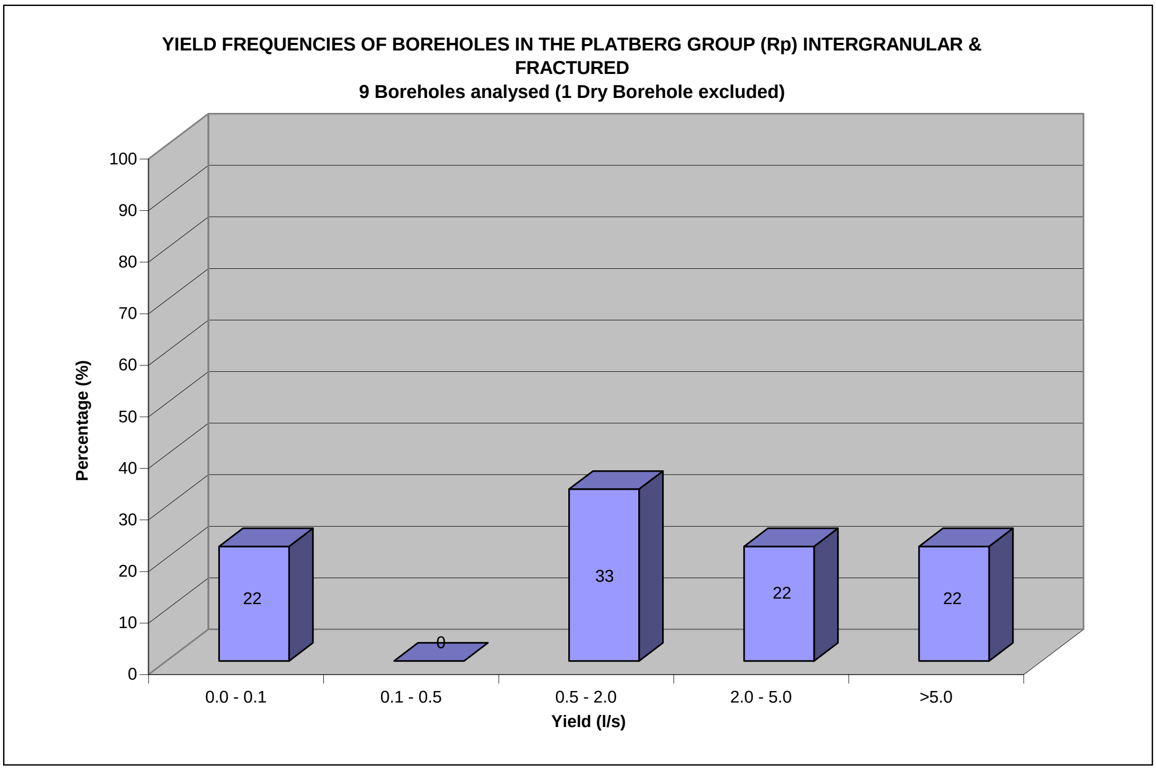

Figure 130:Yield frequency of the intergranular and fractured aquifers of the Platberg Group (Rp) (mostly lavas).

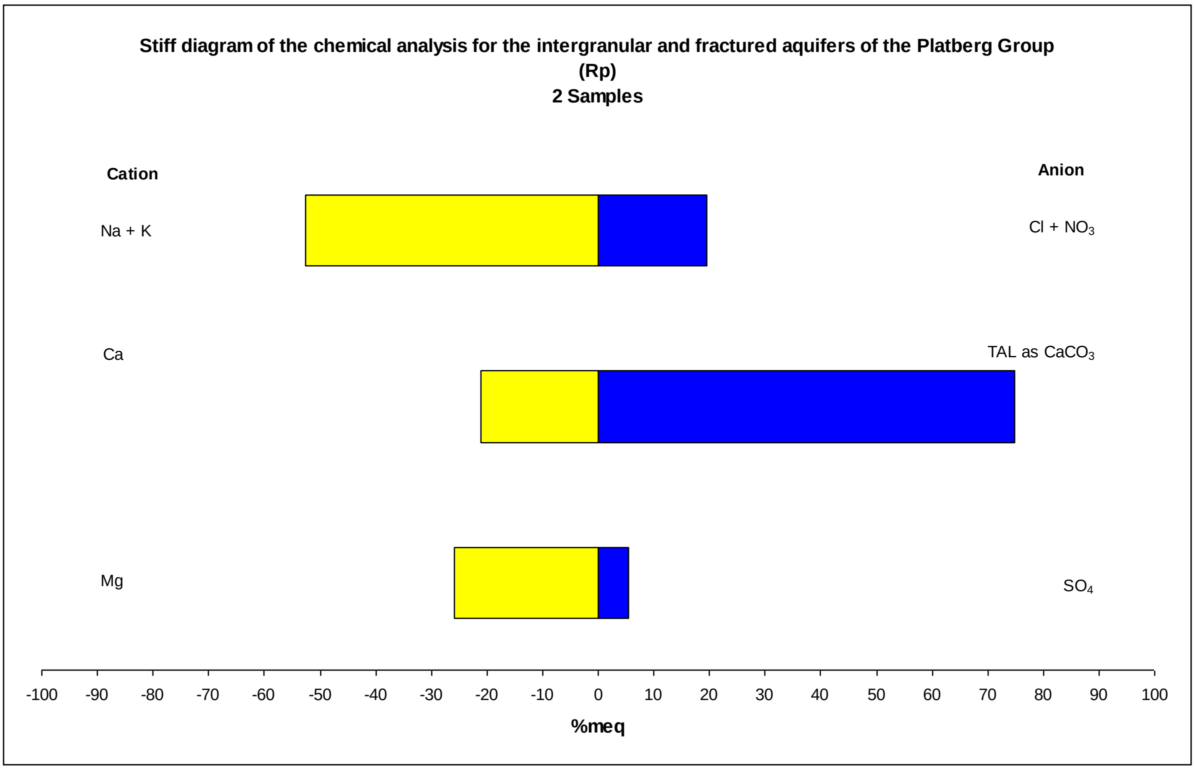

Figure 131:Stiff diagram representing chemical analysis of the intergranular and fractured aquifers in the Platberg Group (Rp) (mostly lavas)

This unit of the Platberg Group occurs as intergranular and fractured aquifers and comprises green to grey amygdaloidal lavas. It occurs as a single cluster west of Thabazimbi. According to the fourth addition of the 1:1000 000 South African geological map sheet the unit has been re-grouped under the Transvaal Super Group as the Buffelsfontein Group but for the purpose of the 1:500 000 Polokwane Hydrogeological map and explanation brochure, it is maintained as part of the Platberg Group.

The apparent good potential of this intergranular and fractured aquifer unit (22% of the boreholes yield more than 5ℓ/s) as shown by the frequency diagram (Figure 130) might be closely linked to various east and northeast trending faults transecting the unit. 33% of the boreholes yield between 0.5 and 2ℓ/s and 22% between 2 and 5ℓ/s.

The fractured and intergranular unit does not show the same elevated nitrate and nitrite (reported as N) concentrations that were found in the fractured unit (Chapter 5.2.1.16). From the two samples available for assessment of this unit, the groundwater is shown to have a sodium-bicarbonate character but due to the limited data it should be considered with caution.

7.2.3.25 KANYE FORMATION (Rka)

This volcanic and associated sediments unit extends from Botswana into the south-western part of the map sheet (Figure 132). It is mapped as acid lava (quartz porphyry, felsite and rhyolite) agglomerate, tuff with interbedded quartzite, grit, conglomerate, breccia and shale. Although limited yield data is available, the yield frequency diagram (Figure 133) provides a reasonable indication of expected groundwater potential which is regarded as low as 50% of the boreholes yield less than 0.1ℓ/s, 30% yields between 0.1 and 2ℓ/s and the remaining 20% yields >2ℓ/s. Various south to southeast trending fault zones extending into the dolomitic rock of the Chuniespoort Group transect the area. Proper groundwater investigations need to be done as the groundwater potential in the vicinity of these fault zones can be much higher than the unit as a whole. Only three chemical analyses were available for analysis. The stiff diagram (Figure 134) represents the major cations and anions present in the groundwater found in this unit. The water exhibit a magnesium-calcium-sodium-bicarbonate water character. The water quality is good with EC values ranging from 79.2 to 95.8mS/m and a arithmetic mean of 85mS/m falling just within the acceptable domestic quality range (70 < EC < 150mS/m).

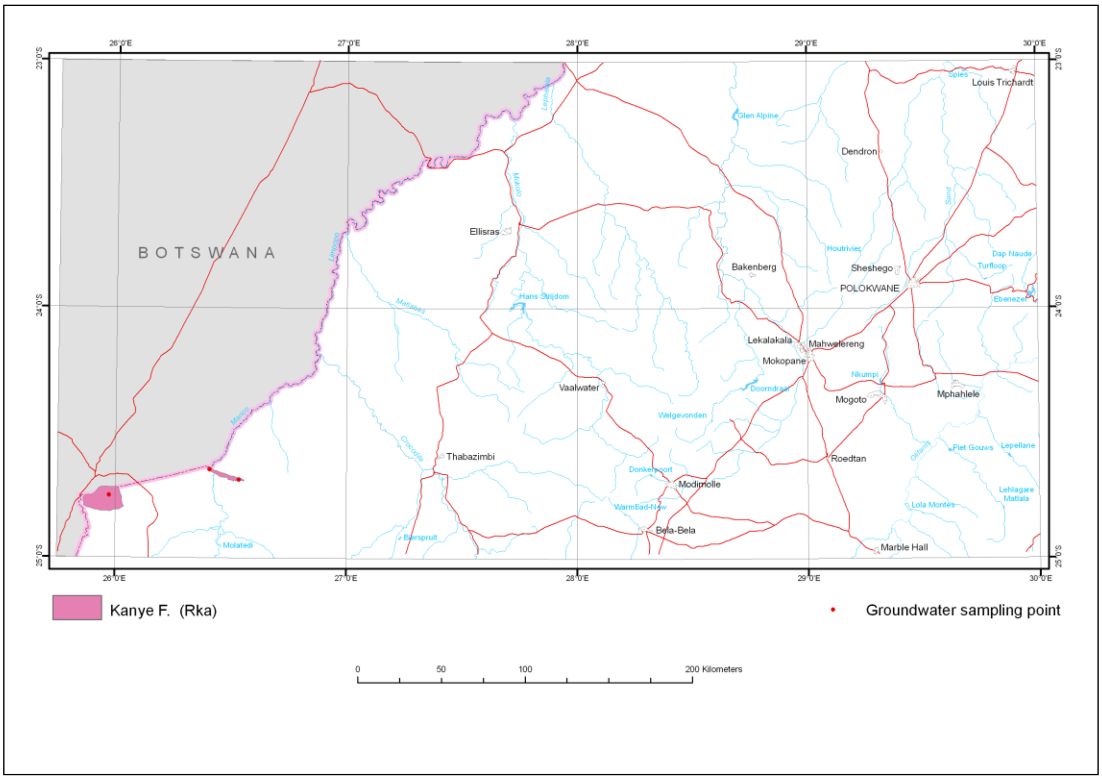

Figure 132: Geographical distribution of the Kanye Formation (Rka) and the associated groundwater sampling points.

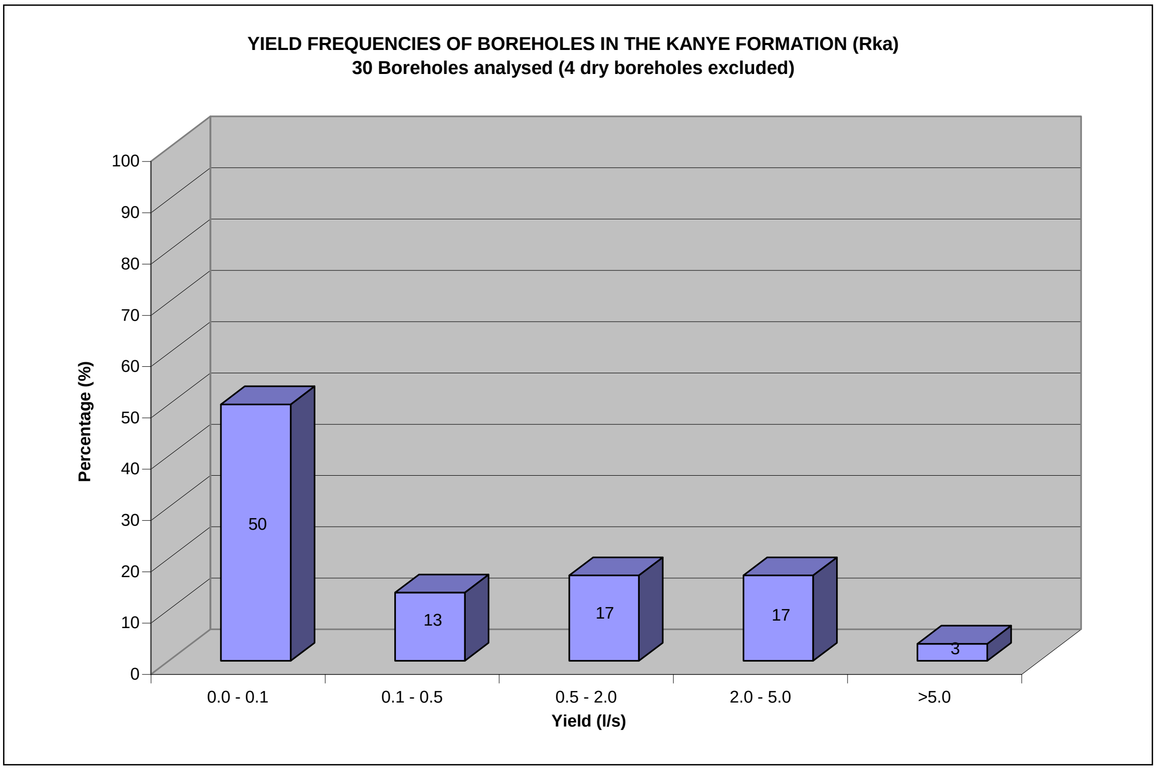

Figure 133: Yield frequency for the intergranular and fractured aquifers of the Kanye Formation (Rka)

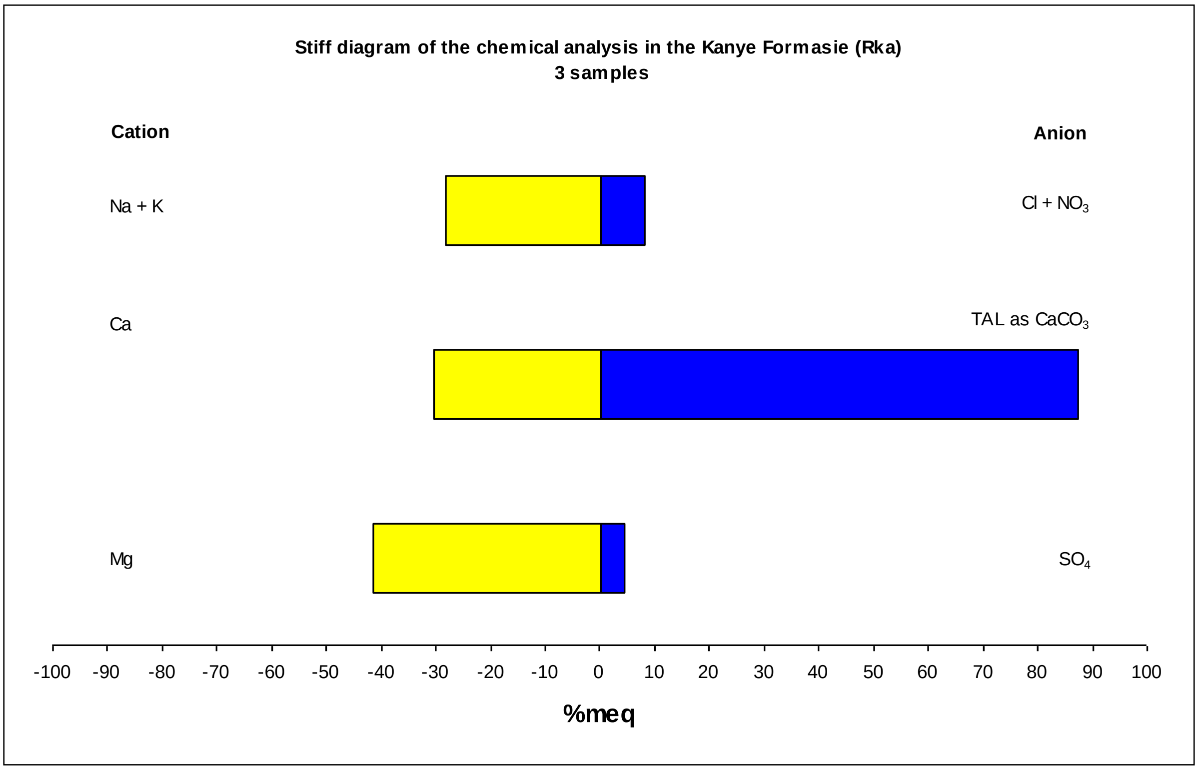

Figure 134: Stiff diagram representing chemical analysis of the Kanye Formation (Rka)

7.2.3.26 KLIPRIVIERSBERG GROUP (Rk)

The Klipriviersberg Group occurs in the south-western sector of the map sheet near Derdepoort and consists of andesitic lava with acid lava and quartzite (Figure 135). It covers approximately 0.7% of the total map area. The geological unit was originally defined by Winter (1965) that divided the Klipriviersberg Group into six formations based mainly on information from borehole logs from work done in the Westonaria, Bothaville and Welkom areas. As a fundamental stratigraphic unit it is not included in either the Witwatersrand or Ventersdorp Super Groups.

Limited data is available for analysis. Water occurs mainly in fault zones, lava flow contacts and contact zones with the surrounding gneiss and sedimentary rocks. The groundwater potential is generally low mainly due to the low permeability of the weathered rock. Yields thus rarely exceed 2ℓ/s. The depth to water level varies between 30-60m. Figure 136 which displays the borehole yield frequency indicates that 85% of the yields are <2ℓ/s of which 67% are less than 0.5ℓ/s.

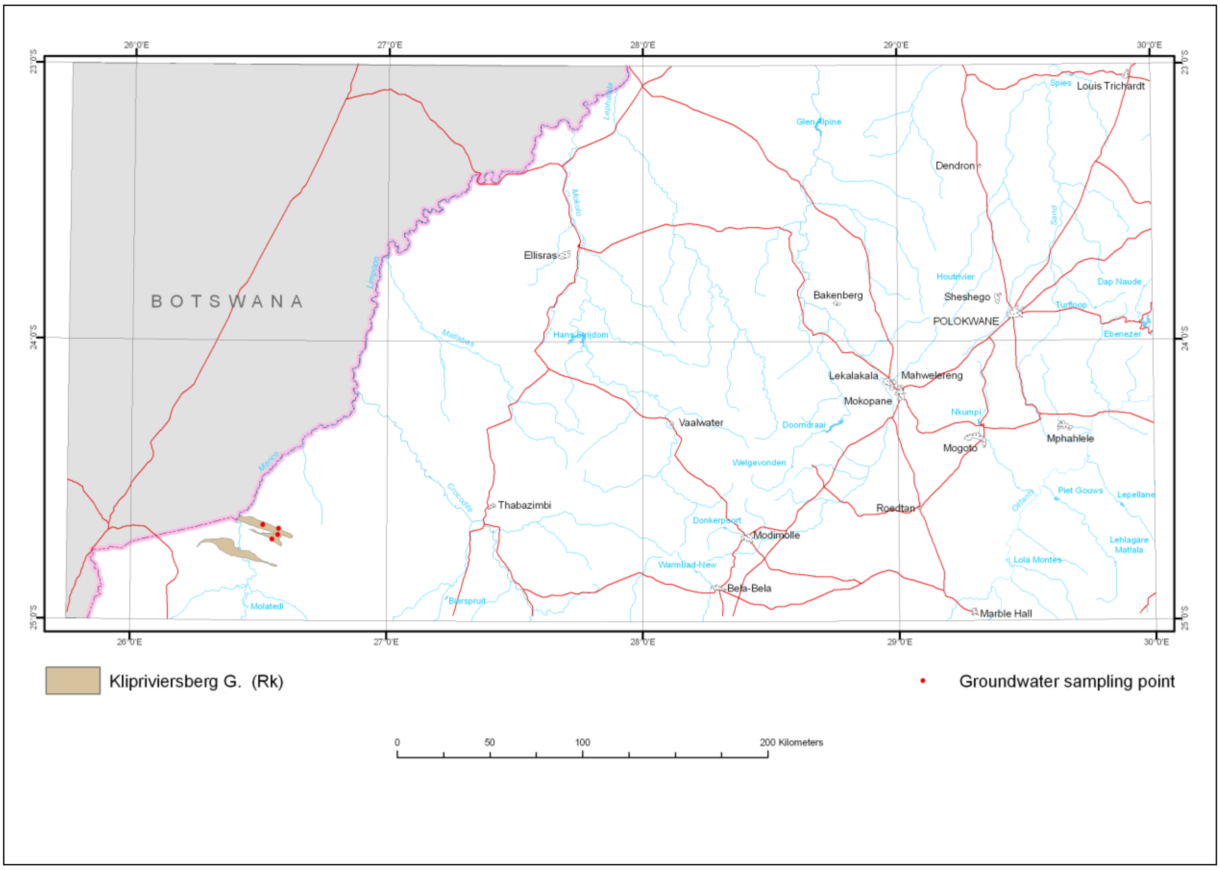

Figure 135: Geographical distribution of the Klipriviersberg Group (Rk) and the associated groundwater sampling points.

Figure 137 shows the broad classification according to anions and cations. The stiff diagram representing the chemical analysis of three boreholes displays a sodium-calcium-chloride-bicarbonate water character. Two of the samples have EC values falling into the ideal to acceptable water quality range for domestic supplies with the third (178mS/m) just into the maximum allowed range (150 < EC <370mS/m). One of the boreholes has a fluoride concentration of 2.4mg/l thus falling in the unacceptable range (F >1.5mg/l). The remaining two samples are within the ideal water quality limit (F <0.7mg/l).

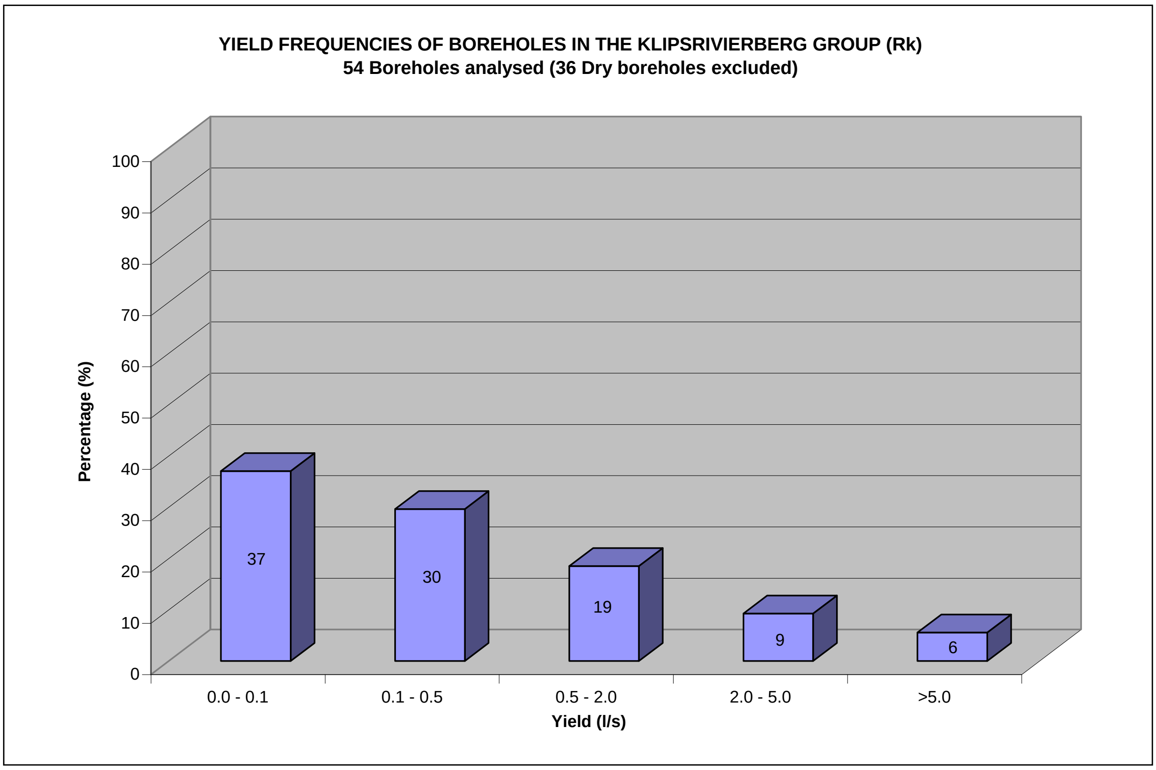

Figure 136: Yield frequency for the intergranular and fractured aquifers of the Kliprivliersberg Group (Rk)

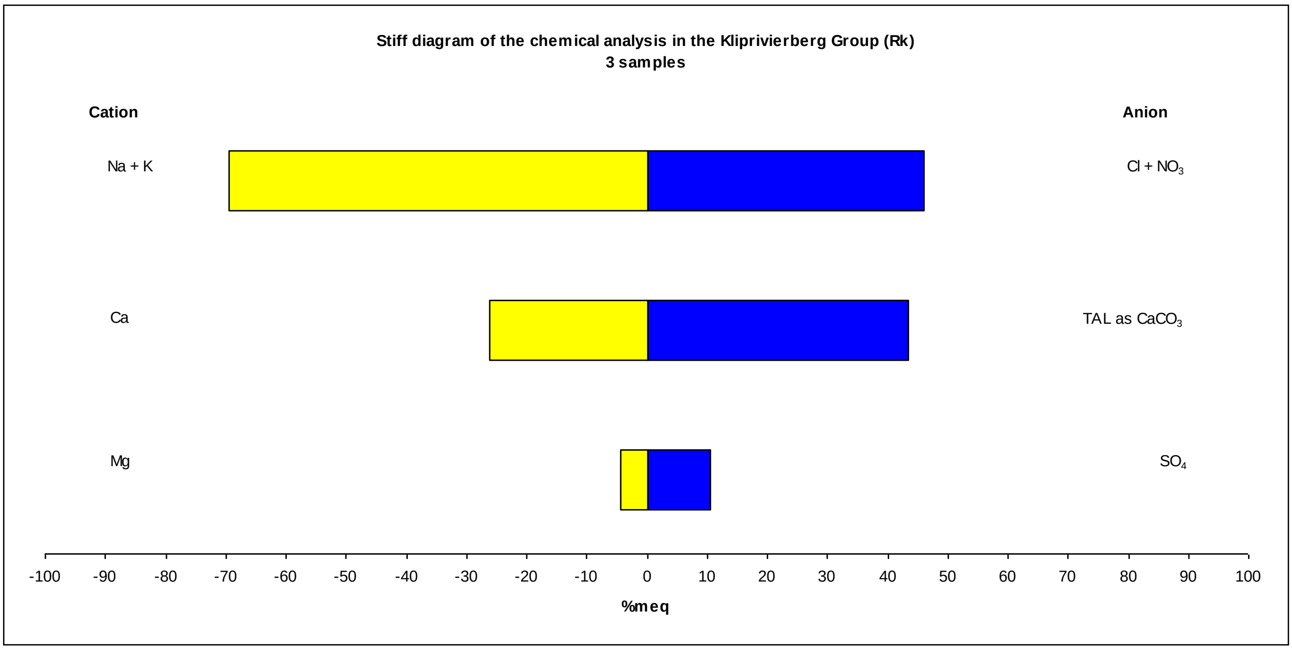

Figure 137: Stiff diagram representing chemical analysis of the Kliprivliersberg Group (Rk)

7.2.3.27 HOUT RIVER GNEISS (Rho)

The Hout River Gneiss is mostly exposed in ephemeral streams throughout its occurrence in the Polokwane (Pietersburg) area in the south up to the Soutpansberg in the north. A wide variety of granitoid rocks have been grouped under this unit. It includes leucocratic migmatite and gneiss, grey and pink hornblende-biotite gneiss, grey biotite gneiss and pegmatitic rocks. Inclusions of rocks belonging to the Bandelierskop Complex occur as highly deformed keels within the gneiss. Various granites and numerous diabase dykes intruded into the unit. The dykes are predominantly trending northwest and northeast. This unit covers approximately 13.2% of the total map sheet and is an important groundwater resource for rural villages, highly populated areas such as Polokwane and Louis Trichardt and agriculture purposes including irrigation and livestock watering. The area is generally flat and covered by sandy soils.

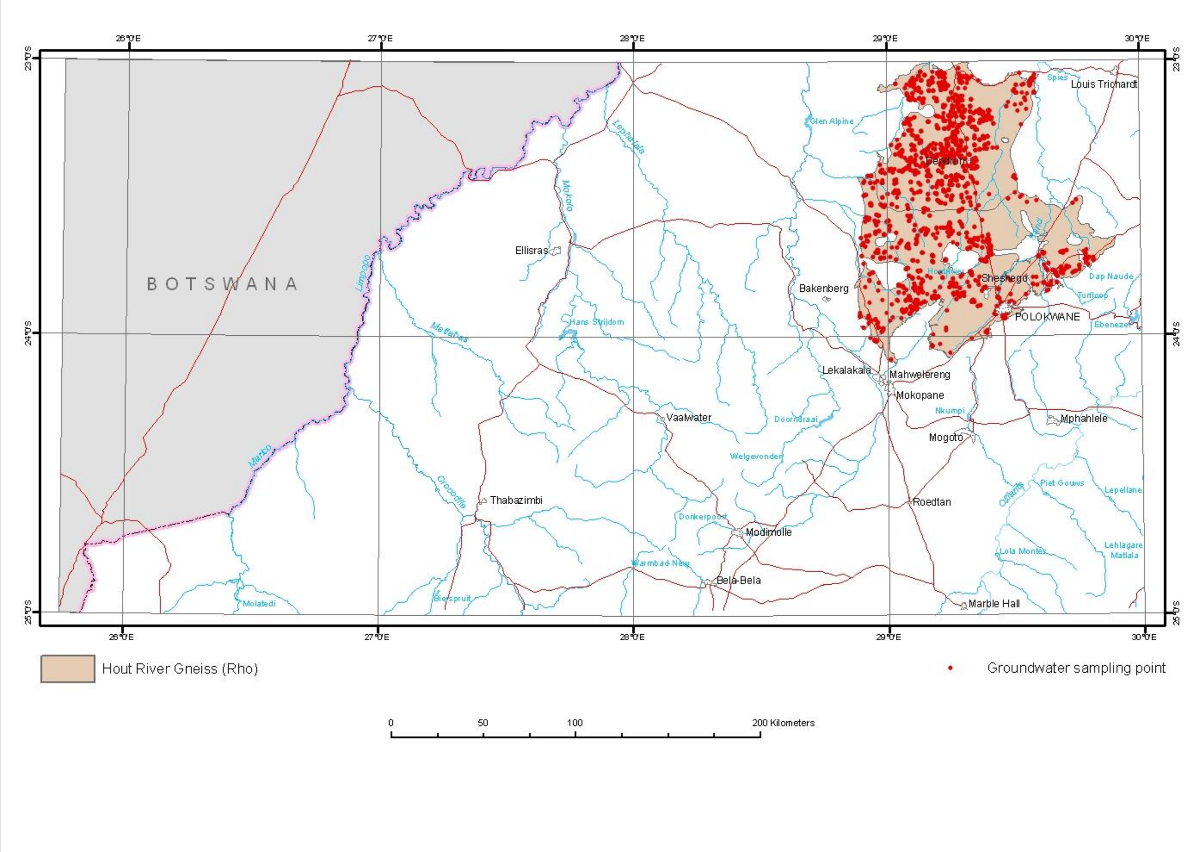

Figure 138: Geographical distribution of the Hout River Gneiss (Rho) and associated groundwater sampling points

The groundwater potential of the gneisses is generally good with 20% (Figure 139) of the boreholes yielding between 2 and 5ℓ/s and 54% yielding >5ℓ/s. High yielding boreholes such as in the Dendron area appear to be related to the occurrence of pegmatites in the area whose origin, composition and its relation to the occurrence of groundwater is not yet known. Drilling in the Louis Trichardt area revealed that the presence of these pegmatites could make a considerable difference in the yield over very short distances. Water is also obtained in deep basins of weathering as well as in the transitional zone between weathered and solid gneiss. Depths of weathering in excess of 40m are not uncommon which enlarges the storage capacity for groundwater.

Over-utilization of groundwater resources in the Dendron/Vivo area depleted the groundwater to such an extent that the present groundwater level is already below the average depth of weathered basins in places. This prompted irrigation farmers to drill deeper and abstract water from deeper seated fractures and pegmatites. Many of the fractures intercepted with depth are thought to be related to off-loading. Water occurs also in fault and shear zones and also to a lesser extent along diabase dyke contacts. Some of the wider dykes in the area are sometimes more fractured, fissured or decomposed than the surrounding host rock and act as the preferred pathways for groundwater. As the wider dykes cooled slower than the narrow ones they are coarser grained and therefore more susceptible to weathering and fracturing (Du Toit, 1986). The depth to groundwater level is generally between 10 and 30m but in high abstraction areas such as Bandelierskop and Dendron it can be in excess of 60m. Approximately 10km west of Dendron at Wurthsdorp excessive local abstraction for rural water supply created a cone of depression extending several kilometres with a depth up to 85mbgl.

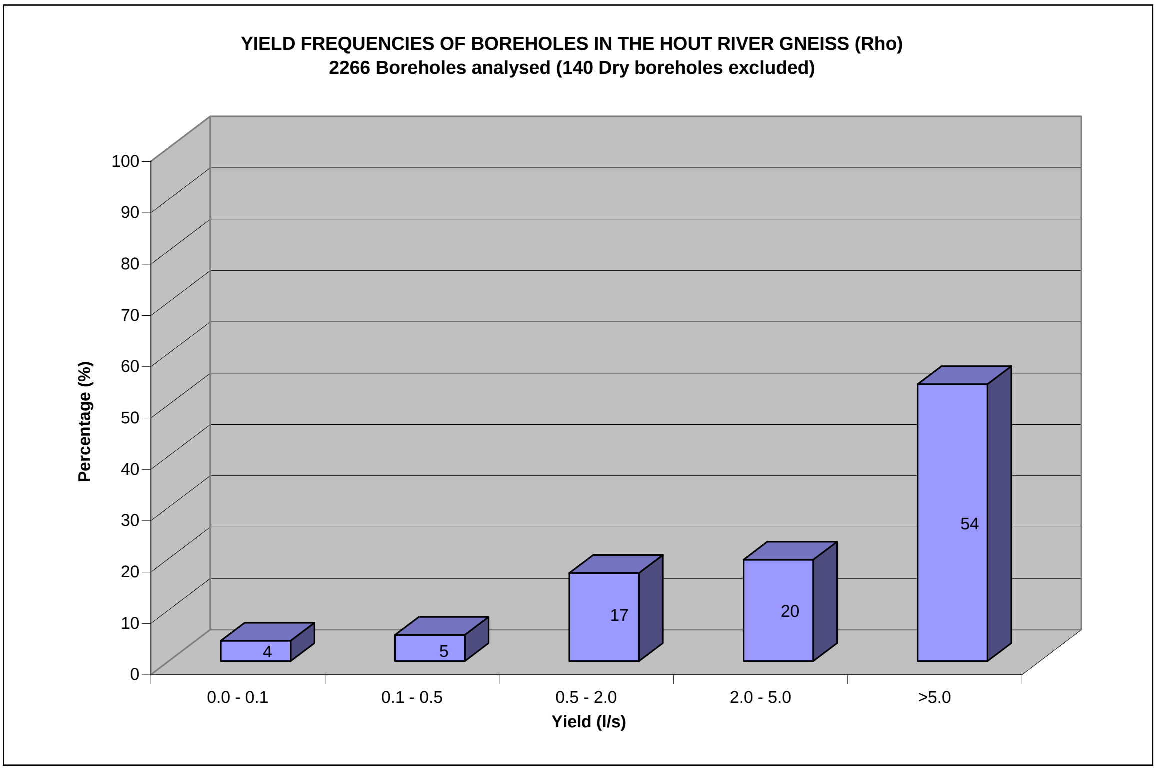

Figure 139: Yield frequency for the intergranular and fractured aquifers of the Hout River Gneiss (Rho).

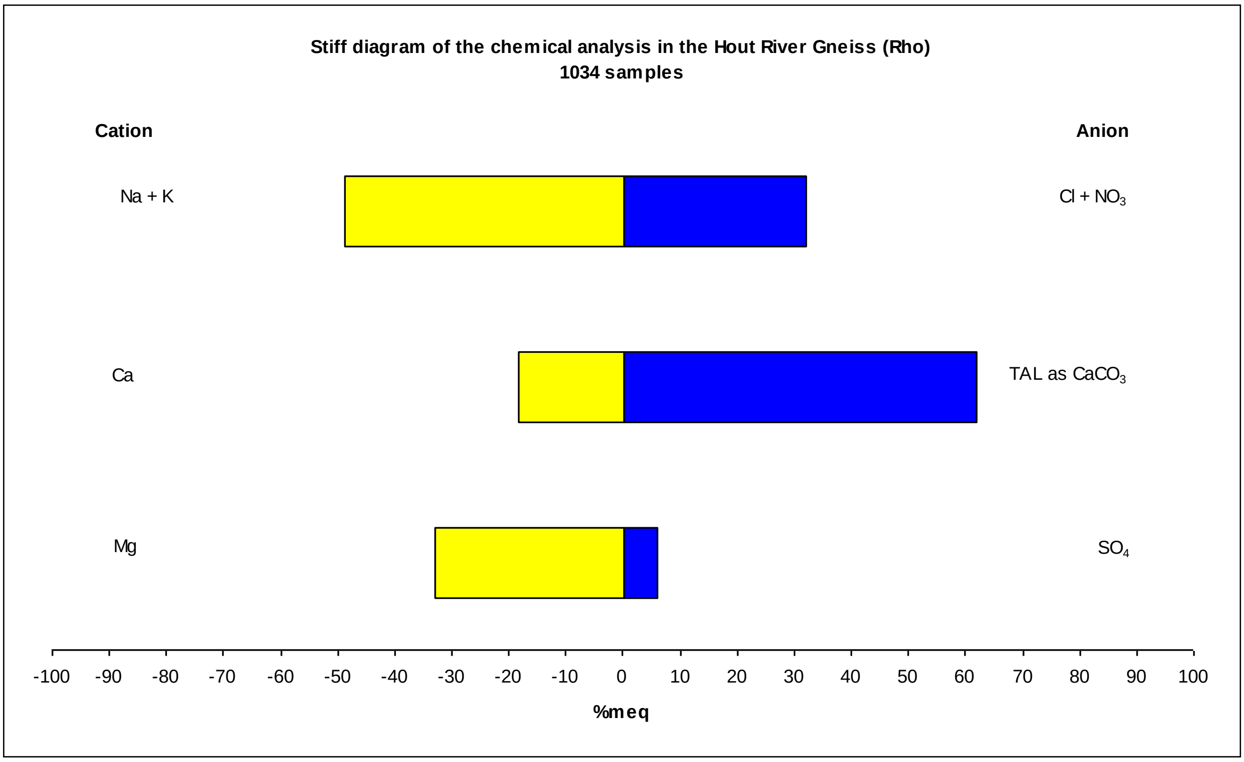

Figure 140: Stiff diagram representing chemical analysis of the Hout River Gneiss (Rho).

The quality of the water is generally good with a harmonic mean of the 104mS/m for the EC of the unit. The EC values varies between 8.2 and 534mS/m with 74% of the samples with values varying between the ideal quality and the acceptable limit for domestic use (EC <150mS/m).Only 1% falls in the unacceptable (EC >370mS/m) category. Fluoride concentrations are not a concern as it varies from 0.05 to 4.1mg/l with only 3% of the boreholes exceeding the maximum allowed limit (F >1.5mg/l). Nitrate and nitrite (reported as N) concentrations vary between 0.02 and 156mg/l with only 5% exceeding the maximum allowed limit (N >20mg/l). Figure 140 shows the broad classification according to anions and cations. Groundwater in this unit has a sodium-magnesium- bicarbonate-chloride character.

7.2.3.28 MODIPE COMPLEX (Zmo)

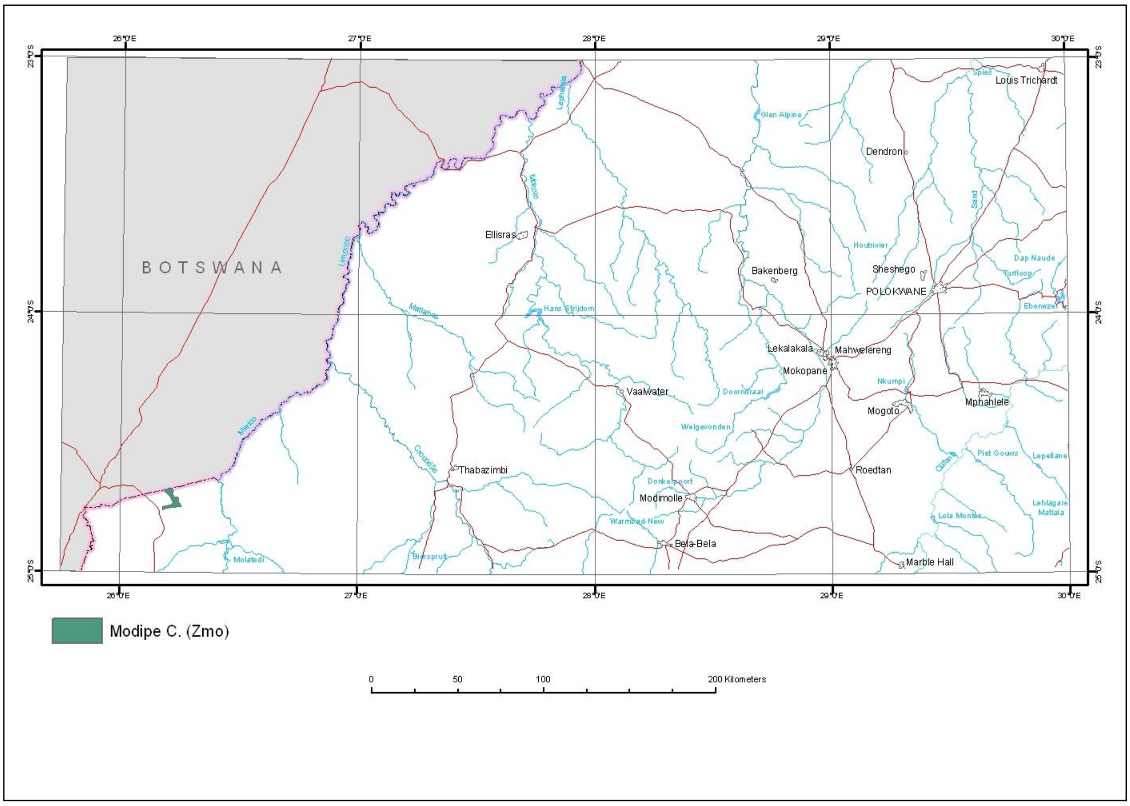

Figure 141: Geographical distribution of the Modipe Complex (Zmo)

This unit covers a small area in the south-western corner of the map sheet extending over the border into Botswana (Figure 141). It consists of gabbros associated with norites, hyperites, pyroxenites, wehrlites, dunites, serpentinites, magnetitites and anorthosites (SACS, handbook 8). Limited outcrop occurs as the area is mostly covered by quaternary sands and soils. Groundwater information regarding quality and yield is inadequate for a comprehensive assessment of the groundwater development potential of this unit.

7.2.3.29 MESSINA SUITE (Zbm)

This unit comprises principally metapyroxenite and serpentinite which are considered to be intrusive into the Beit Bridge Complex. A small occurrence in the northern part of the map sheet is shown in Figure 142. Only one borehole is known to occur in this unit and is it therefore not possible to perform a valid assessment of expected yield and chemistry. It does, however, show the water to exhibit a magnesium-calsium-sodium-bicarbonate-chloride character.

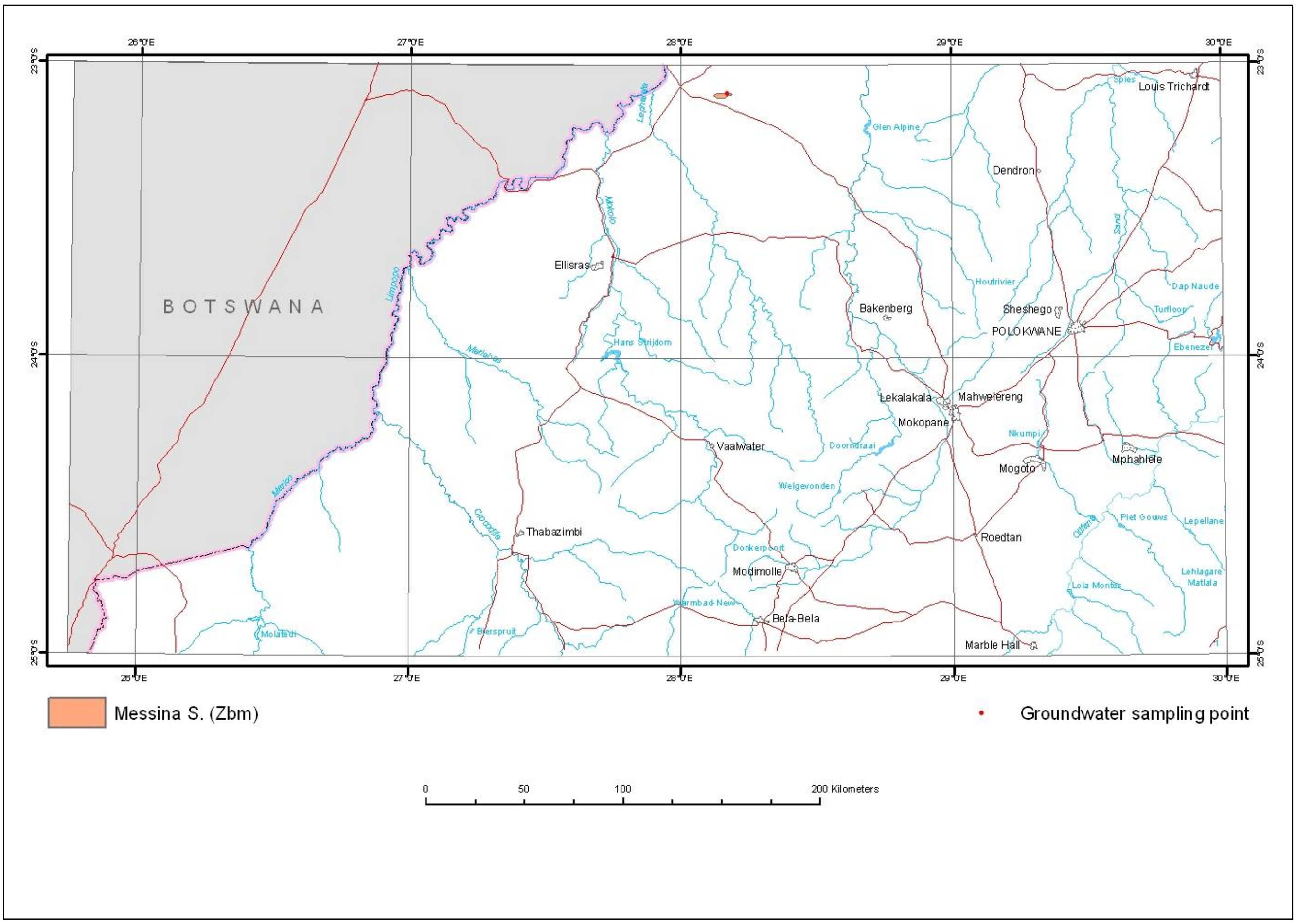

Figure 142: Geographical distribution of the Messina Suite (Zbm) and associated groundwater sampling points.

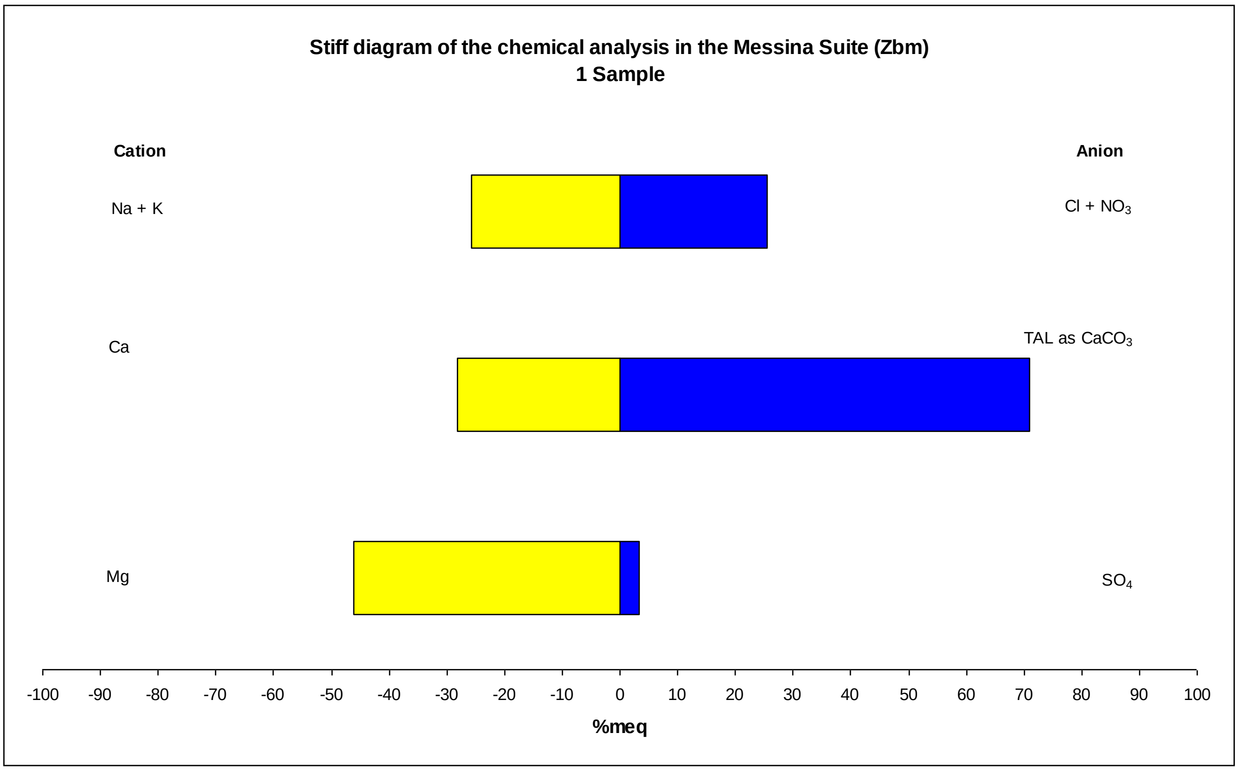

Figure 143:Stiff diagram representing chemical analysis of the Messina Suite (Zbm)

7.2.3.30 GOUDPLAATS GNEISS (Zgo)

The Goudplaats Gneiss which covers the north-eastern part of the map sheet (Figure 144) consists of gneiss, layered gneiss, migmatite and accompanying leuco-granite. Due to extended sandy soil cover, outcrop is mostly visible in ephemeral stream beds. The gneiss can be large unfoliated masses or can exhibit alternating bands of melanocratic and leucocratic material. This unit is believed to have formed the basement to the Bandelierskop Complex and the Pietersburg Group. It has been intruded by various granites and numerous diabase and dolerite dykes with a predominantly northeast to southwest orientation.

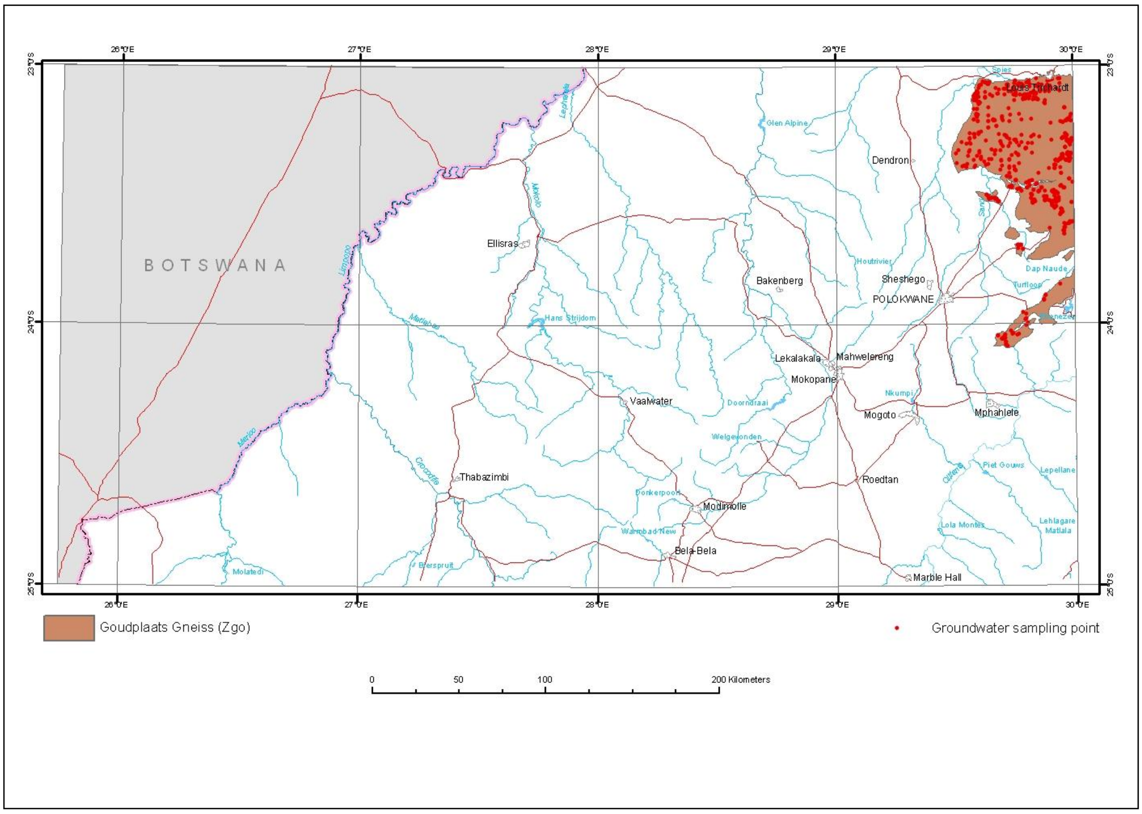

Figure 144: Geographical distribution of the Goudplaats Gneiss (Zgo) and associated groundwater sampling points.

The groundwater potential of the Goudplaats Gneiss is moderate but not as good as that of the Hout River Gneiss. The depth to groundwater level is generally situated between 10-30mbgl. It is widely used for domestic and agricultural purposes and is in some rural areas the only source of supply to communities.

The yield frequency distribution diagram in Figure 145 gives a very good indication of the expected groundwater potential. 59% of the successful boreholes are yielding less than 2 ℓ/s, 25% between 2 and 5ℓ/s and 15% yields more than 5ℓ/s. Geophysical methods have been successfully employed in the search for groundwater within this unit. Groundwater targets usually include deep weathering and fracturing, faults, pegmatite zones and secondary fracturing associated with dyke intrusions. The success rate increase in areas where the gneiss exhibits foliation and pegmatitisation.

The quality of the water is generally good with a harmonic mean of the 84.9mS/m for the EC of the unit. The EC values varies from 12.46 to 480mS/m with 70% of the samples with values varying between ideal water quality and the acceptable limit for domestic use (EC <150mS/m). Only 1% falls in the unacceptable (EC >370mS/m) category. Fluoride concentrations are not a concern as it varies between 0.05 and 6mg/l with only 3% of the boreholes exceeding the maximum allowed limit (F >1.5mg/l). Nitrate and nitrite (reported as N) concentrations vary from 0.02 to 116.8mg/l with 11% exceeding the maximum allowed limit (N >20mg/l). This is more than double than that of the Hout River Gneiss (5%) but it could be attributed to a greater number of rural villages. Figure 146 shows the dominant anions and cations present. The groundwater displays a sodium-magnesium-bicarbonate character.

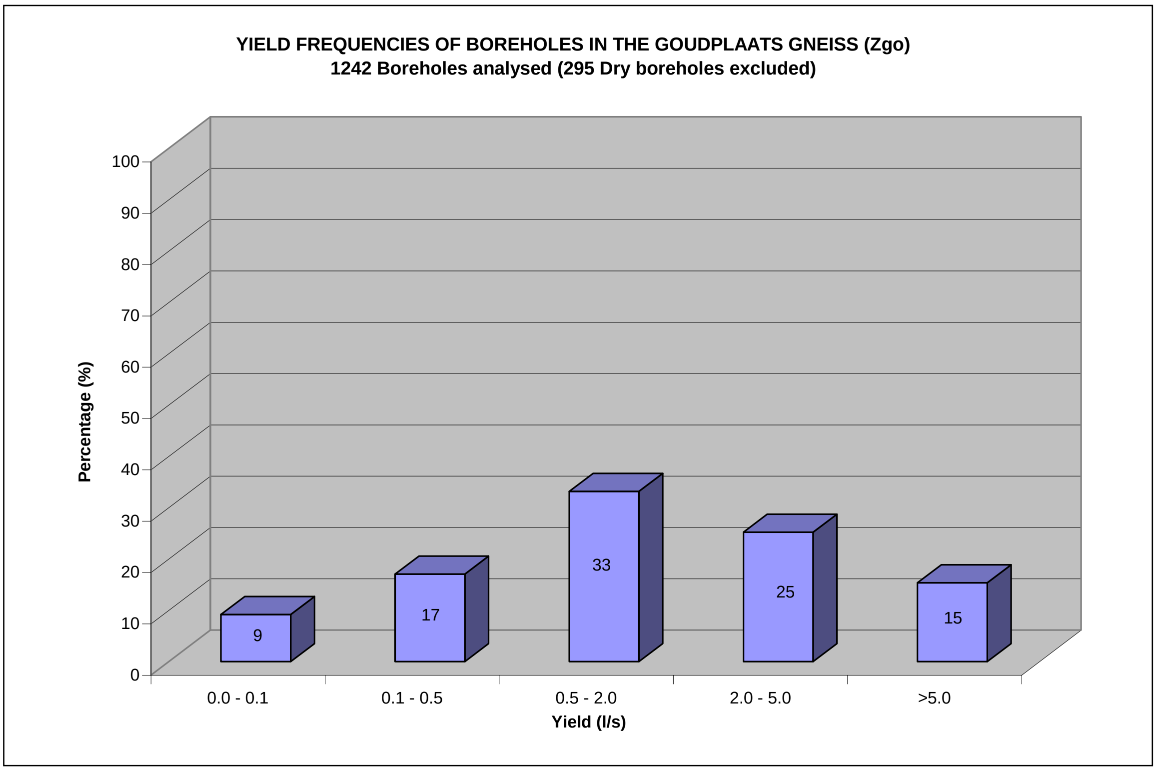

Figure 145: Yield frequency for the intergranular and fractured aquifers of the Goudplaats Gneiss (Zgo)

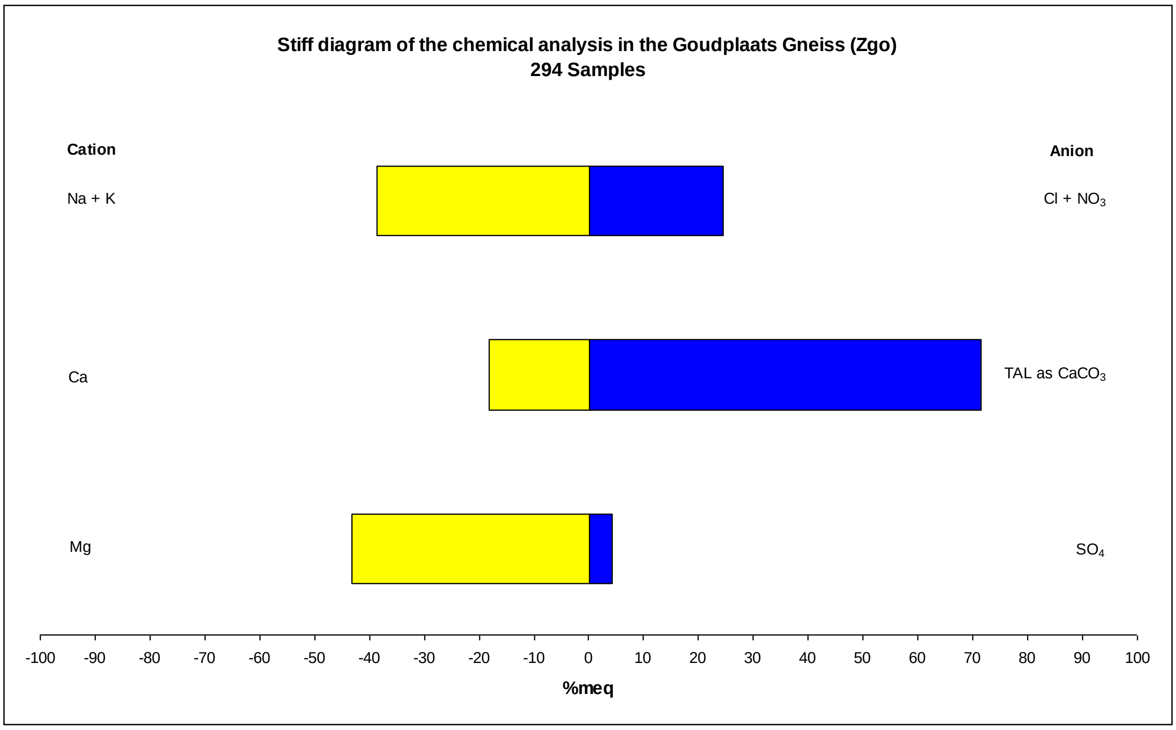

Figure 146:Stiff diagram representing chemical analysis of the Goudplaats Gneiss (Zgo)

7.2.3.31 THE BEIT BRIDGE COMPLEX (Z)

The Complex is part of the central zone of the Limpopo Mobile Belt and is a succession of metasedimentary and metavolcanic rocks. Although parts of the Complex is covered by quaternary sediments as indicated on the 1:250 000 geological map sheets 2328 and 2326, the quaternary sediments does not have aquifer characteristics and were ignored.

The unit has been divided into three Groups viz. Mount Dowe, Malala Drift and Gumbu. Together they underlay approximately 5% of the total map area (Figure 147). The rocks were originally deposited in a shallow basin and subsequently deformed by folding in various phases and were ultimately intruded by rocks of the Messina Suite and by the Bulai Gneiss, during which period they underwent various phases of metamorphism.

Groundwater occurs mainly in faults and associated shear zones as well as fractured contact zones between mafic and acidic rocks and dyke contacts. The Complex has in general a low groundwater potential. High yielding boreholes occurring in the Tom Bourke/Baltimore area are related to geological lineaments. Due to the low and erratic rainfall (350-450mm/a) in this area together with periodical droughts and the dense vegetation in places, recharge events are very irregular. This together with abstraction contributed significantly to the generally deep water levels (30-60m) occurring in the area.

The water is mainly used for livestock watering and domestic purposes although limited irrigation is practised in the Tom Bourke/Baltimore area.

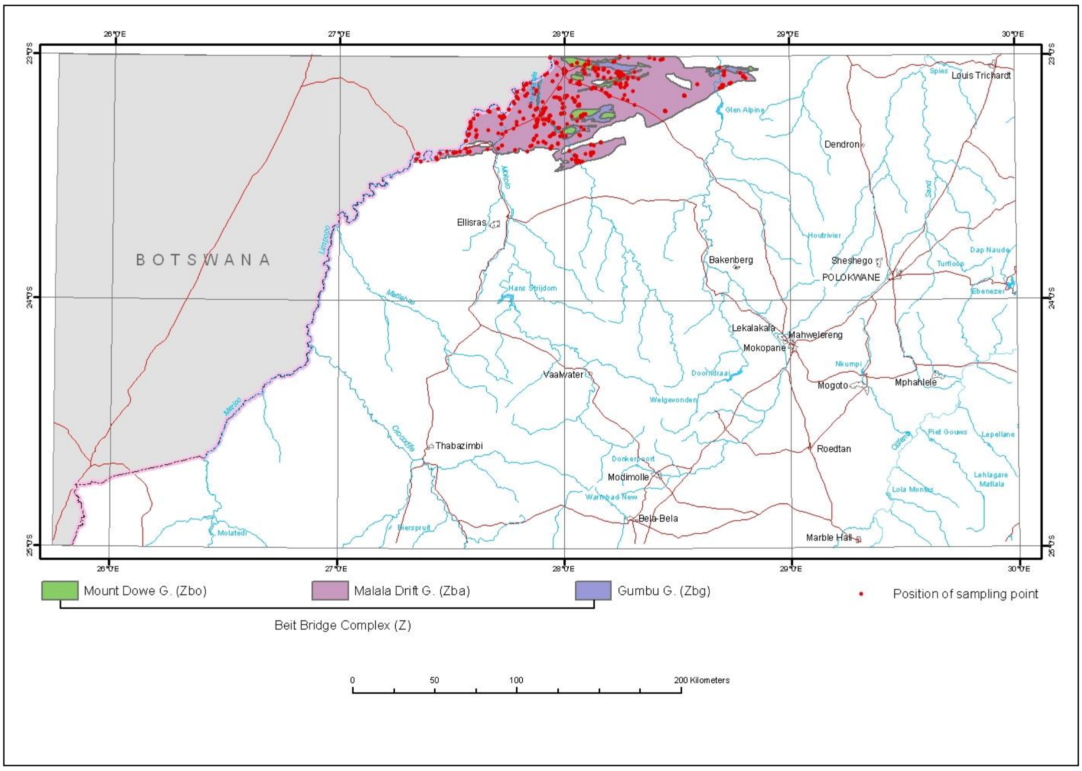

Figure 147: Geographical distribution of the Beit Bridge Complex (Z) and associated groundwater sampling points

7.2.3.31.1 GUMBU GROUP (Zbg)

Marble together with associated calc-silicate rocks constitutes the bulk of this Group, apparently at the top of the Beit Bridge Complex. Minor intercalations include amphibolite, metaquartzite and garnetiferous leucocratic gneiss. Outcrop of this unit usually forms positive topographic features, often covered by surface limestone that consists of a fine grained matrix with host rock fragments of various sizes. The Group occurs as scattered isolated outcrops along the 23º latitude (Figure 148).

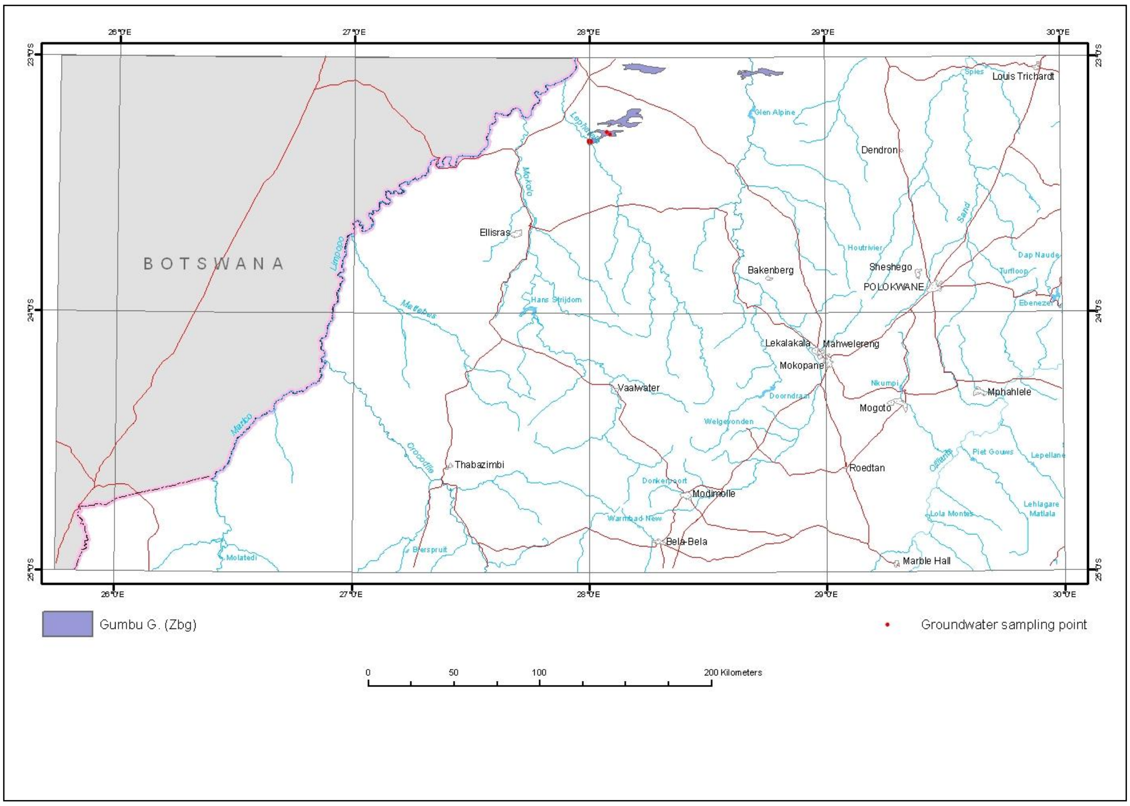

Figure 148: Geographical distribution of the Gumbu Group (Zbg) and associated groundwater sampling points.

The yield frequency diagram (Figure 149) shows that 90% of the successful boreholes yield less than 2ℓ/s. Figure 150 shows the dominant anions and cations presented as a stiff diagram compiled from the nine available chemical records. The water displays a sodium-bicarbonate-chloride character. 100% of the samples are within the ideal quality regarding EC values; (harmonic mean 90mS/m).

Only one groundwater sample with a nitrate (N) concentration of 84mg/l falls outside the maximum allowed limit (N >20mg/l). Generally the water is within an ideal to acceptable domestic quality.

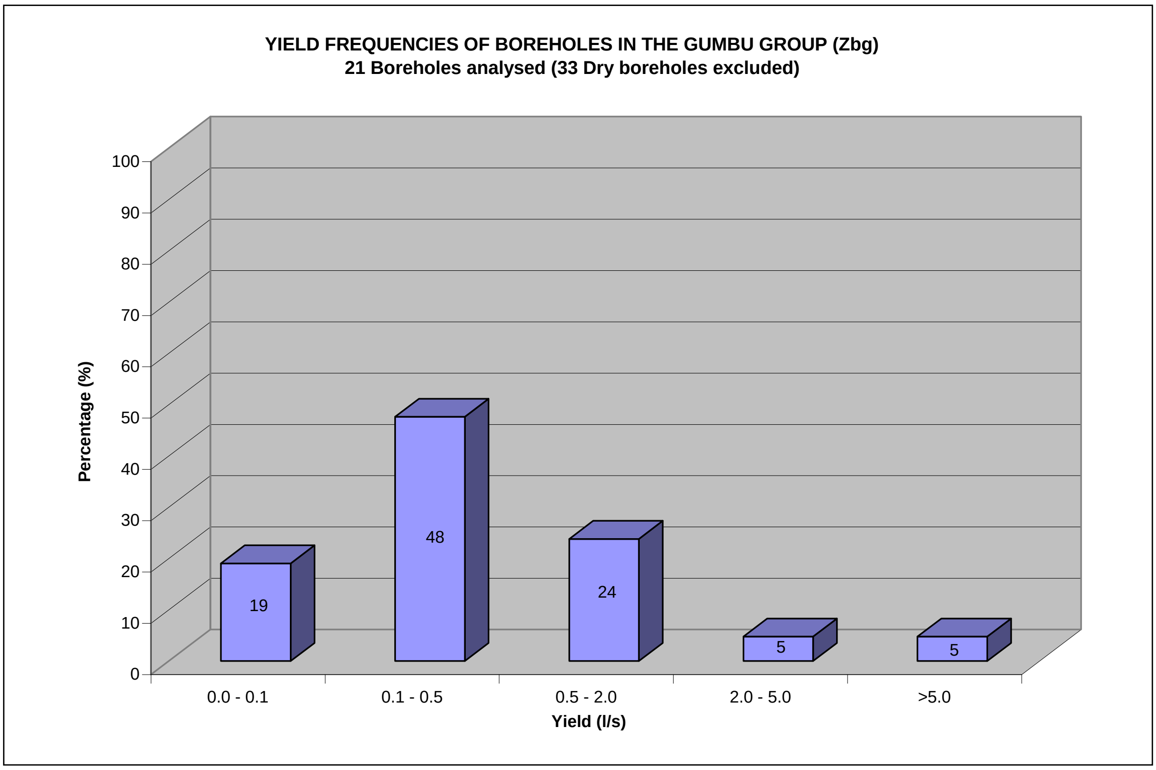

Figure 149: Yield frequency for the intergranular and fractured aquifers of the Gumbu Group (Zbg)

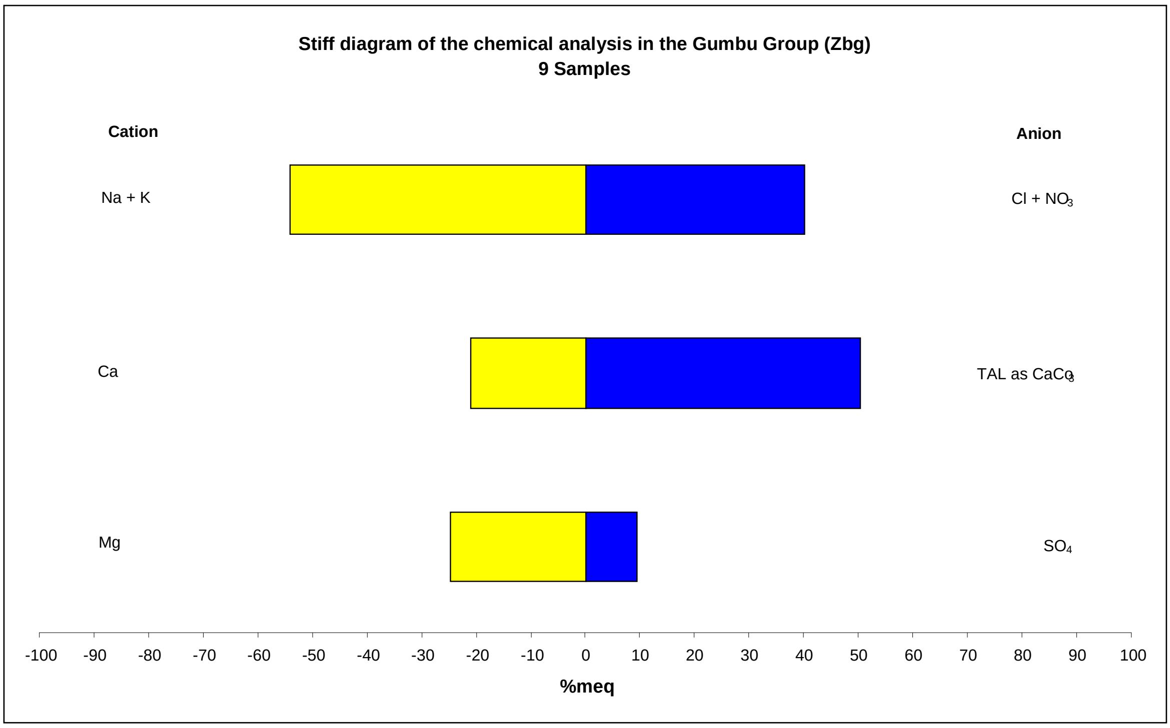

Figure 150:Stiff diagram representing chemical analysis of the Gumbu Group (Zbg)

7.2.3.31.2 MALALA DRIFT (Zba)

The Malala Drift Group which covers the biggest area of the three groups included under the Beit Bridge Complex comprises mainly garnetiferous, leucocratic gneiss, amphibolite with mafic granulite and metapelite. Occurrences are found in the Tom Bourke/Marnitz and Dwaalboom/Makoppa areas (Figure 151).

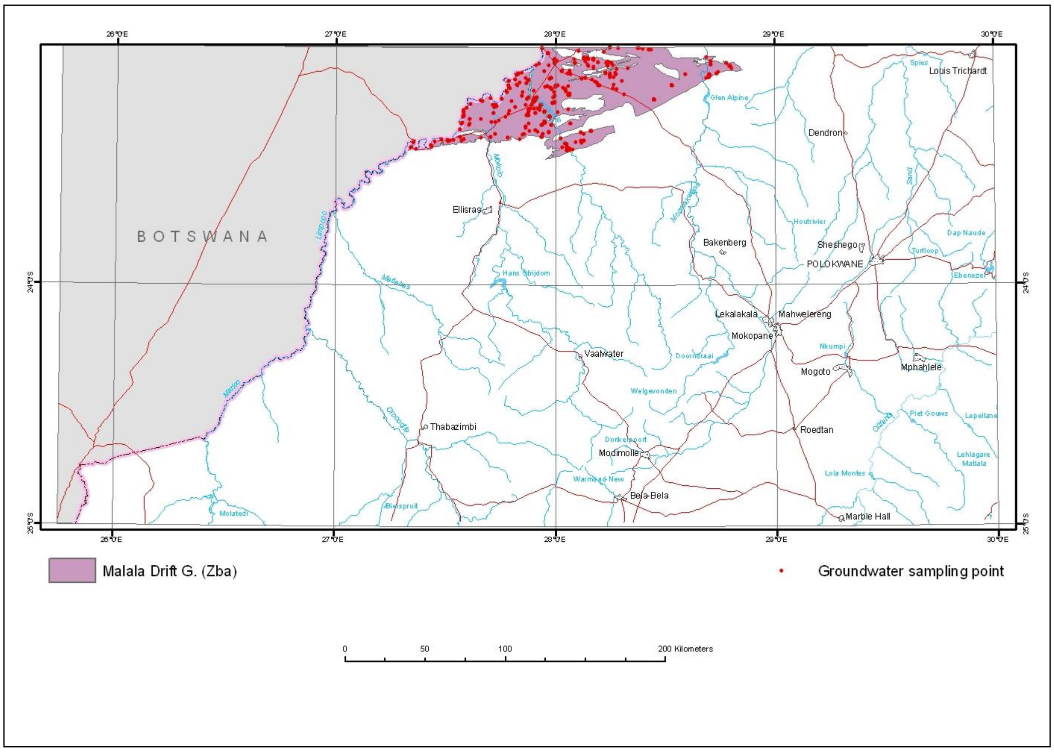

Figure 151: Geographical distribution of the Malala Drift Group (Zba) and associated groundwater sampling points.

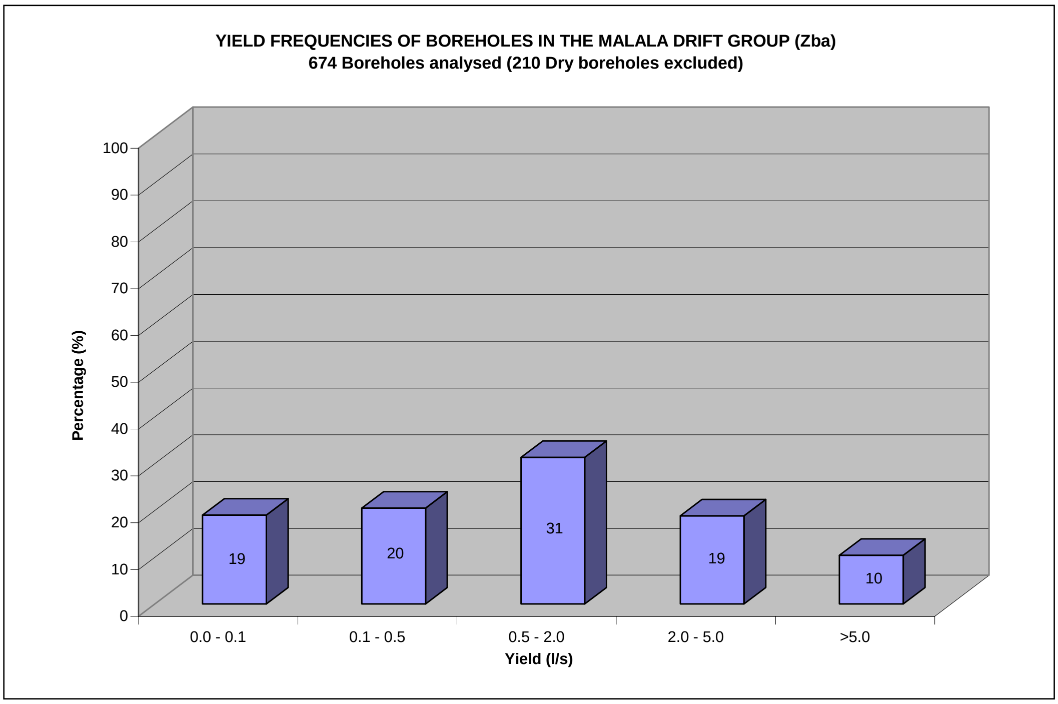

Figure 152: Yield frequency for the intergranular and fractured aquifers of the Malala Drift Group (Zba)

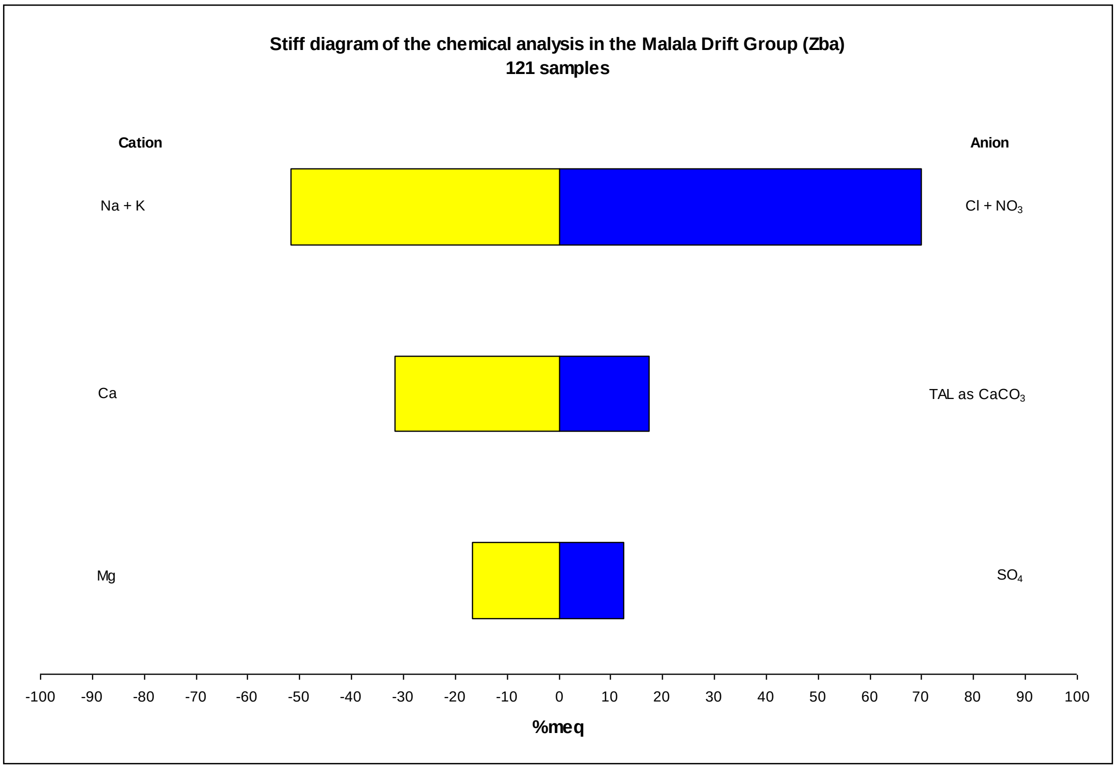

Figure 153:Stiff diagram representing chemical analysis of the Malala Drift Group (Zba)

The yield frequency diagram (Figure 152) indicates that 70% of the successful boreholes yield less than 2ℓ/s.

The stiff diagram (Figure 153) shows the broad classification according to anions and cations. The water exhibits a sodium-calcium-chloride water type. In 50% of the sampled boreholes chloride values exceed the maximum allowable concentrations (Cl >600mg/l). In 21% of the sampled boreholes, the concentration of sodium falls outside the maximum allowed limit (Na >400mg/l). Nitrate and nitrite concentrations (reported as N) are exceeding the maximum allowed limit in 21% of the samples (N >20mg/l). The water quality is moderate with EC values ranging from 10.6 to 1140mS/m and the harmonic mean calculated as 161mS/m. This is more than the acceptable limit (EC <150mS/m) for domestic use, but less than the maximum allowable limit (EC <370mS/m). 22% of the sampled boreholes used in the analyses, exceeds the maximum allowable Fluoride concentration of 1.5mg/l.

Considering the above it can be stated that 50% of the water needs to be treated before use for domestic supplies

7.2.3.31.3 MOUNT DOWE GROUP (Zbo)

This Group, probably at the base of the Beit Bridge Complex, consists of metaquartzite and magnetite quartzite with minor intercalations of garnetiferous leuco-gneiss, amphibolite and mafic granulite. It occurs as isolated outcrops close to the Botswana border more or less along the 28º longitude (Figure 154). The yield frequency diagram (Figure 155) shows that 94% of the successful boreholes yield less than 2ℓ/s.

The water quality is good with EC values ranging from 82 to 247mS/m and the harmonic mean calculated as 111mS/m. Fluoride concentrations are not a major concern as it varies between 0.37 and 3.49mg/l with only one (8%) of the boreholes exceeding the maximum allowed limit (F >1.5mg/l). Nitrate and nitrite (reported as N) concentrations vary from 0.01 to 29.8mg/l with the same borehole exceeding the maximum allowed limit (N >20mg/l). Overall the water is ideal for domestic use. The groundwater exhibits a sodium-magnesium-bicarbonate-chloride character.

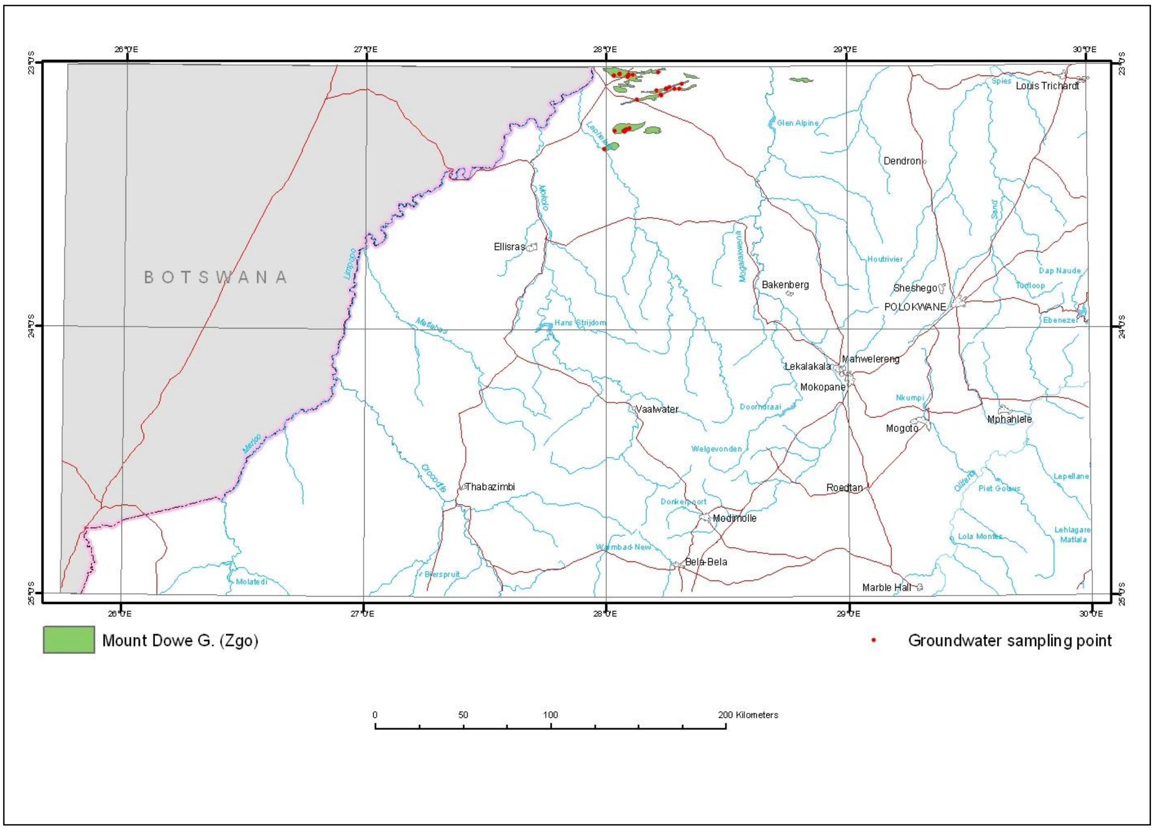

Figure 154: Geographical distribution of the Mount Dowe Group (Zbo) and associated groundwater sampling points.

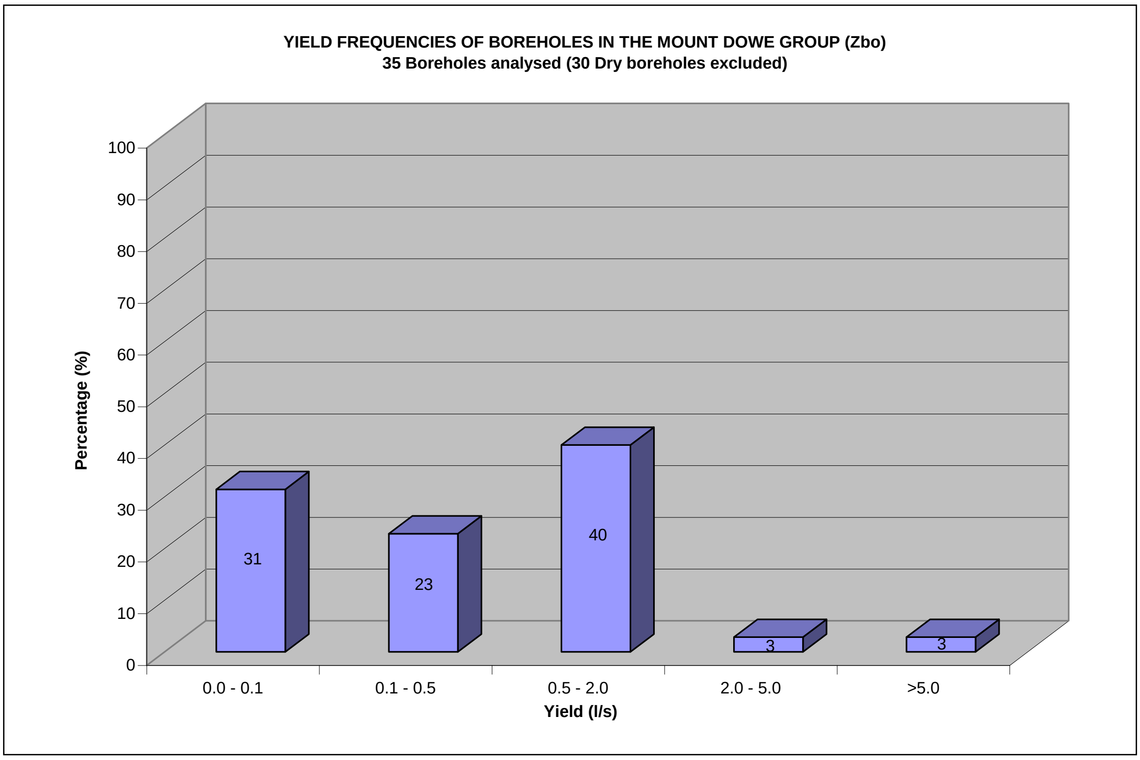

Figure 155: Yield frequency for the intergranular and fractured aquifers of the Mount Dowe Group (Zbo)

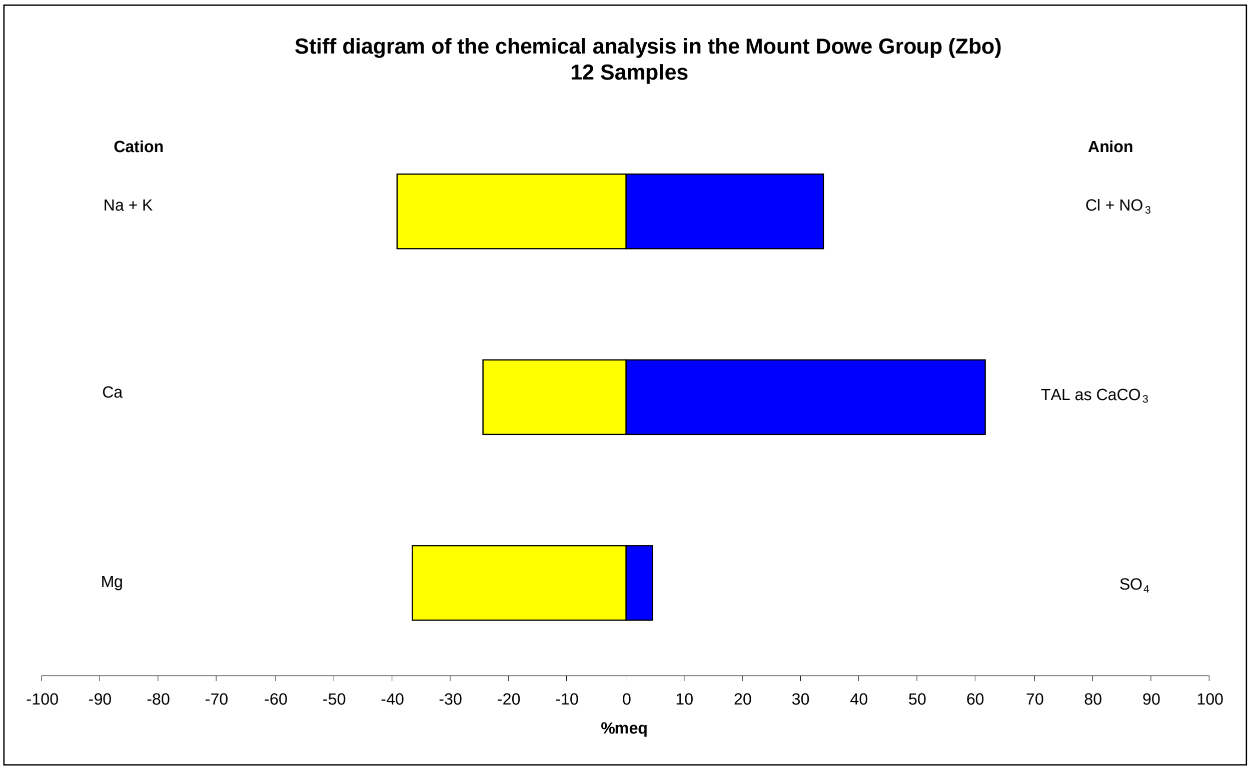

Figure 156:Stiff diagram representing chemical analysis of the Mount Dowe Group (Zbo)

7.2.3.32 BANDELIERKOP COMPLEX (Zga)

This unit occurs mainly as numerous small scattered clusters within the Goudplaats and Hout River Gneisses in an area bounded more or less in the west by longitude 29º,(near Bochum) and in the east by longitude 30º, (map boundary). The southern boundary is latitude 23.5º (Matok) and the northern boundary latitude 23.13º, (Louis Trichardt). Due to their number and size they have mostly been incorporated into the above mentioned gneisses and are therefore not indicated on the map. A small occurrence within the Matok Granite could not be incorporated and is thus depicted separately as representing the Bandelierskop Complex (Figure 157).

The numerous xenoliths constitute a typical greenstone belt succession of metasedimentary and metavolcanic rocks subdivided into ultramafic, mafic and pelitic rock units. The complex is part of the southern marginal zone of the Limpopo Mobile Belt and the rocks have been subjected to granulite-facies metamorphism: these rocks now occurring as highly deformed keels surrounded by the Goudplaats and Hout River Gneisses (Explanatory booklet 2328).

Due to the lack of borehole information a yield frequency and chemical stiff diagram could not be compiled.

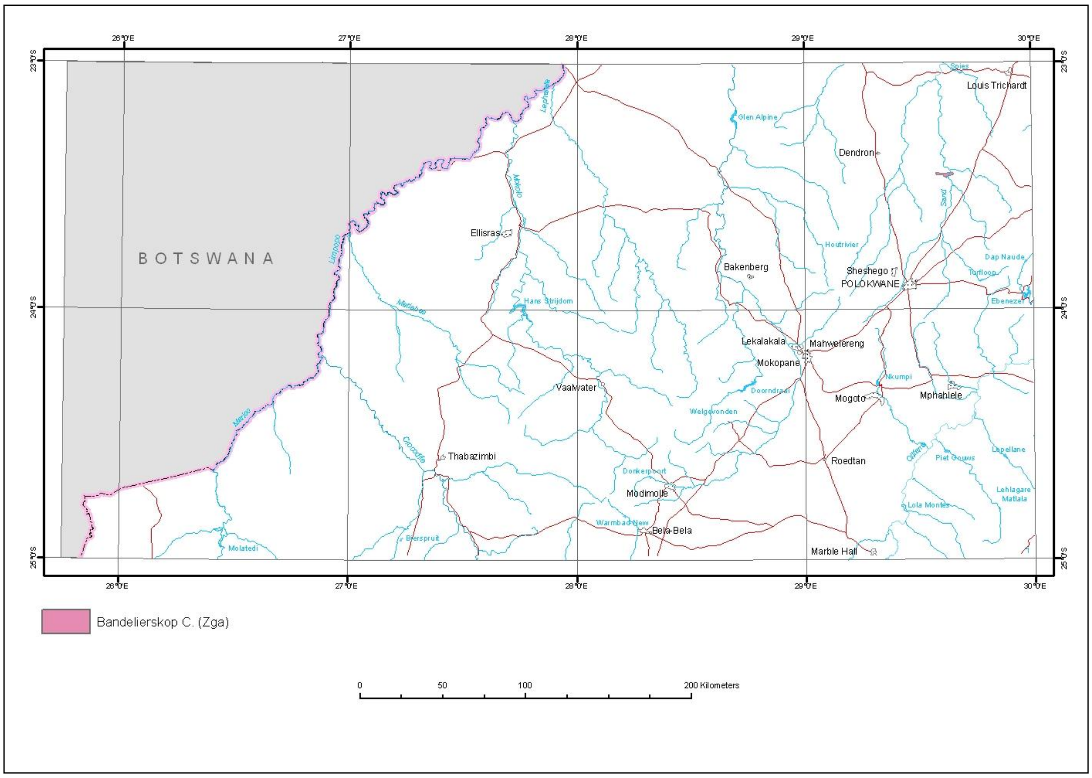

Figure 157: Geographical distribution of the Bandelierskop Complex (Zga)

7.2.3.33 PIETERSBURG GROUP (Zp)

This Group, which is a typical Archaean greenstone belt, is found exposed from near Mokopane (Potgietersrus) up to northeast of Polokwane (Pietersburg) (Figure 158) forming a series of well-defined ridges, including the well-known Mount Marè (not indicated on the map).

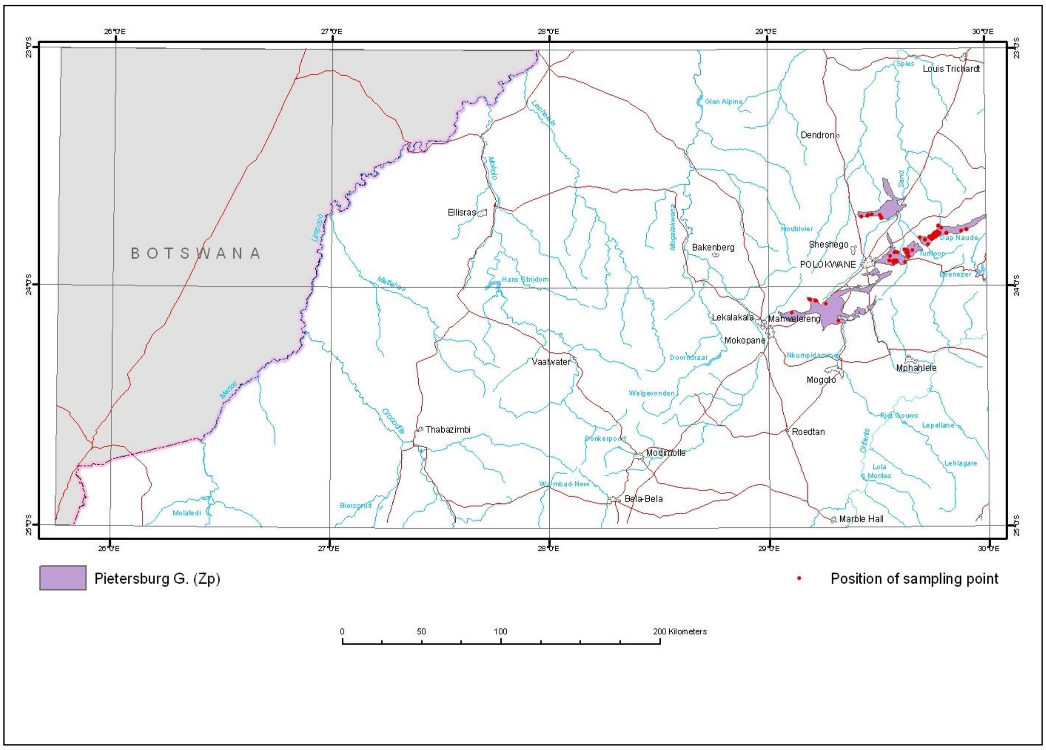

Figure 158: Geographical distribution of the Pietersburg Group (Zp) and associated groundwater sampling points.

Six formations (not shown on the map) were distinguished within the Group of which only the **Mothiba** (ultramafic metavolcanics, Talc-chloride and amphibole-chloride schist, talc schist and serpentinite and amphibolite with thinly interbedded banded ironstone and ferruginous quartzite), **Eersteling** (scattered xenoliths of amphibolite), and **Sandrivierspoort Formations** (mafic metavolcanic rock and intercalated magnetite quartzite, minor metaquartzite, quartz-sericite schist and calc-silicate rocks) are of some importance in terms of groundwater. It underlay approximately 1.0% of the map sheet.

Groundwater occurs mainly in faults and associated shear zones (i.e. Ysterberg shear fault), lithological contacts, dyke contacts and fractured lavas, quartzite and schist. The Eersteling and Sandrivierspoort Formations have in general a low groundwater potential although some strong boreholes, related to the fractured Sandrivierspoort and Hout River Gneiss contact, have been reported. Deep weathering of between 18 and 48m is found in the Mothiba Formation. However, a very low permeability, possibly due to excessive clay produced through the weathering processes, renders its basins of weathering extremely poor aquifers. Water is exclusively obtained in fissures and fractures below the weathering zone. Fissures and fractures in the Pietersburg Group originate mainly from folding, faulting, assimilation and metamorphism, and intrusion of granitic batholiths, diabase dykes and other tectonic forces. Although the Group possesses limited storage capacity, 63% of borehole yields (Figure 159) in the greenstones are in excess of 2ℓ/s. Over-exploitation can lead to borehole failure as in the case of the Dalmada smallholdings northeast of Polokwane (Pietersburg).

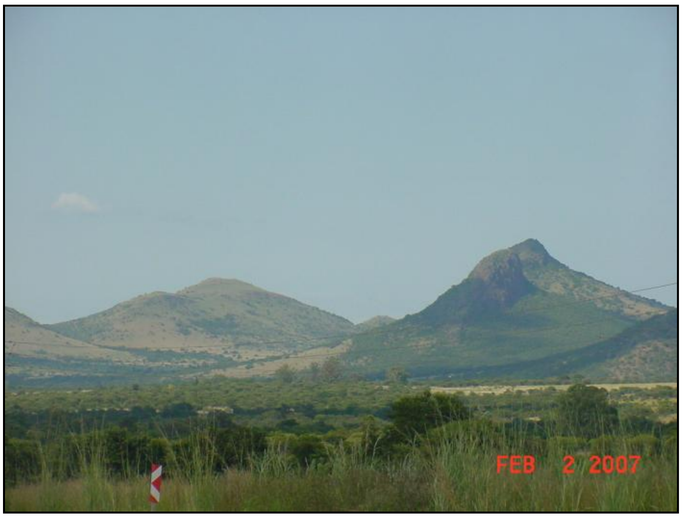

Plate 14: View of Ysterberg on the right looking south comprising banded ironstone of the Pietersburg Group and sediments of the Transvaal Sequence making up the mountain on the left with the Ysterberg fault running along the valley between them. The Ysterberg fault, which is of pre-Transvaal age, was re-activated on occasions until after deposition of the Transvaal Sequence. It has a lateral displacement of about 9 km (Photograph: WH Du Toit)

According to Bond (1947) the water from this Group is of an alkaline-sodium-carbonate type and in general suitable for most purposes. The stiff diagram (Figure 160) representing the broad classification according to anions and cations shows the groundwater to have a magnesium-calcium-sodium-bicarbonate character. The water quality is **good** with EC values ranging from 27 to 127mS/m. The harmonic mean is calculated as 66.5mS/m making it ideal for human consumption.

In 17% of the sampled boreholes used in the analyses, the concentration of fluoride falls outside the maximum allowed limit (F <1.5mg/l). However, in 78% of the sampled boreholes used in the analyses, the Fluoride values are ideal for human consumption (F <1mg/l). 100% of the sampled boreholes in the analyses fall within the ideal to maximum allowed limit for nitrate and nitrite (presented as N) with N <20mgl/).

Groundwater from this Group is mainly abstracted for stock watering and domestic purposes and to a limited extent for irrigation.

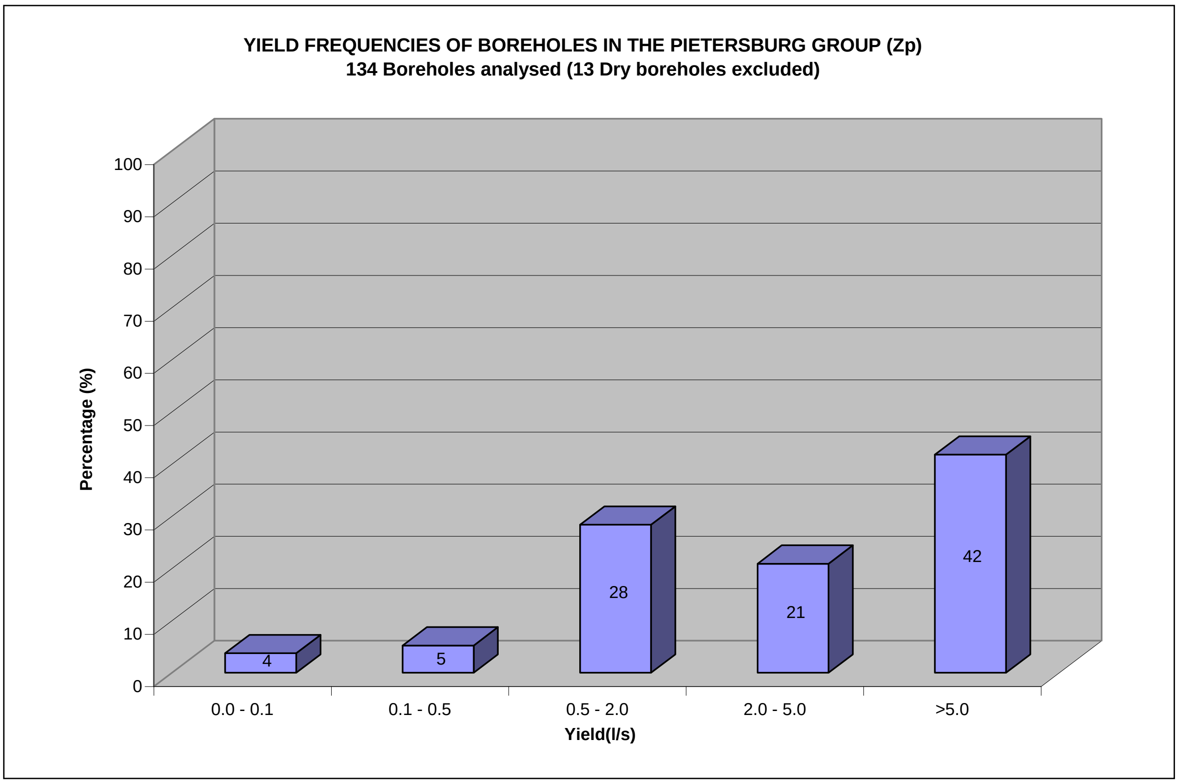

Figure 159: Yield frequency for the intergranular and fractured aquifers of the Pietersburg Group (Zp)

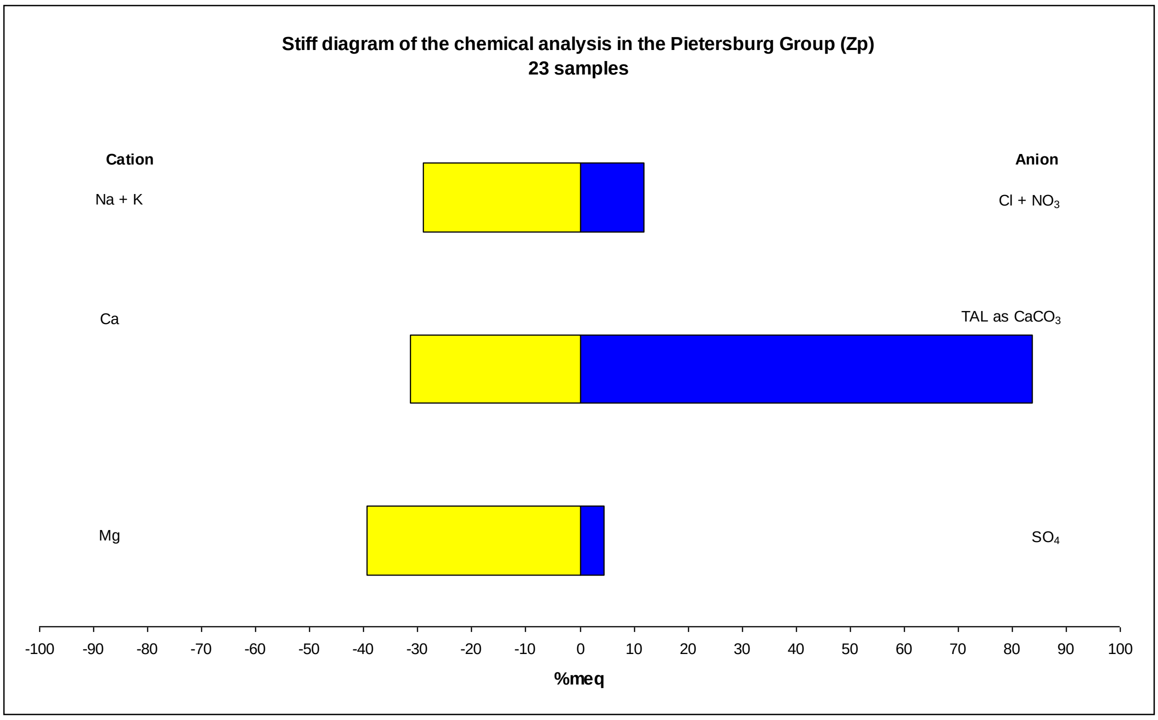

Figure 160:Stiff diagram representing chemical analysis of the Pietersburg Group (Zp)

7.2.3.34 UNNAMED SWAZIAN ROCKS (Zz)

Intrusive in the Swazian stratified rocks is this unnamed granite body of granitic to granodioritic composition. It has a gneissose structure in many places with migmatitic phases developed around inclusions of primitive rock. It occurs west of Thabazimbi (Figure 161) and covers approximately 6.2% of the total map area.

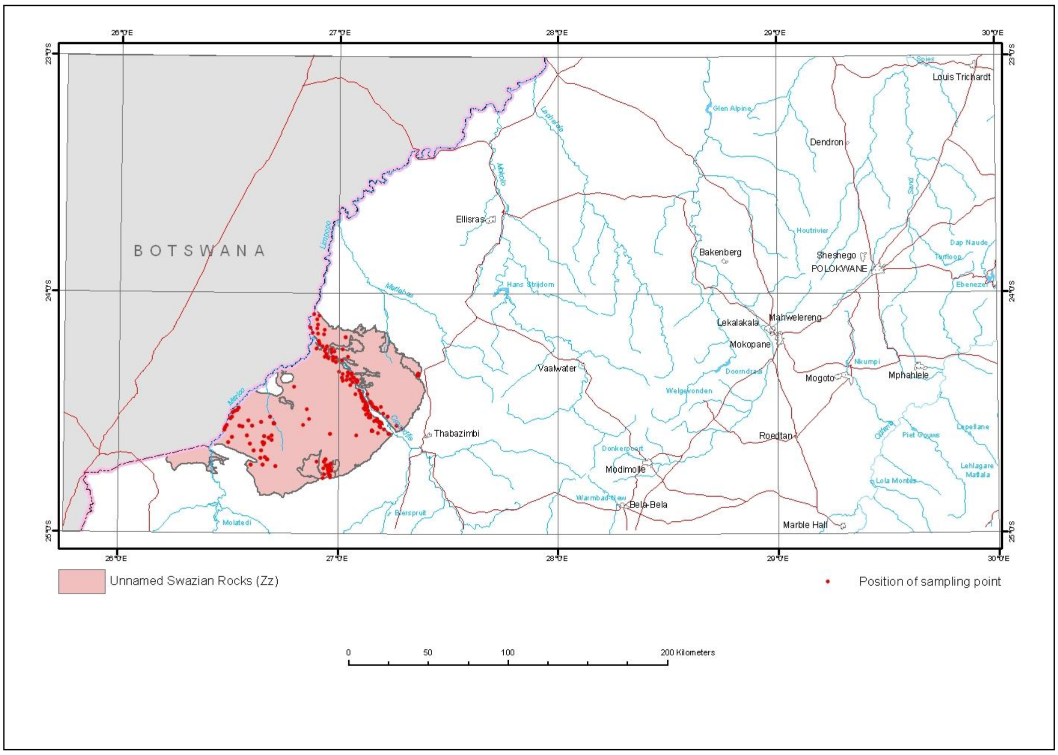

Figure 161: Geographical distribution of the unnamed Swazian Rocks (Zz) and associated groundwater sampling points.

Groundwater occurs in fault and associated shear zones and fractures related to quartz veins, pegmatites and inclusions of primitive rock. Water also occurs to a limited extent along dyke contacts.

The groundwater potential of these granites and gneisses is generally low as approximately 84% of the successful boreholes yield less than 2ℓ/s (Figure 162). Deep drilling (up to 250m) to intercept deeply seated fractures yielded little success. The generally deep water level (30-60mbgl.) in the area is related to the low and irregular rainfall (350-450mm/a) and dense vegetation subsequently resulting in little or no recharge. 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. Groundwater is exclusively used for livestock watering and domestic purposes.

The stiff diagram (Figure 163) shows the broad classification according to anions and cations. The water displays a magnesium-sodium-bicarbonate-chloride character. The water quality is moderate to poor with EC values varying between 45mS/m and 1040mS/m and with a calculated harmonic mean of 133mS/m. 49% of the sampled boreholes used in the analyses have ideal EC values, 6.4% exceeds the maximum allowable EC values of 370mS/m. 20% of the sampled boreholes used in the analyses, exceed the maximum allowable nitrate (N) values of 20mg/l and 16% exceed the maximum allowable fluoride values of 1.5mg/l. Based on the above approximately 80% of the sources within this unit can be used for domestic supplies without any treatment.

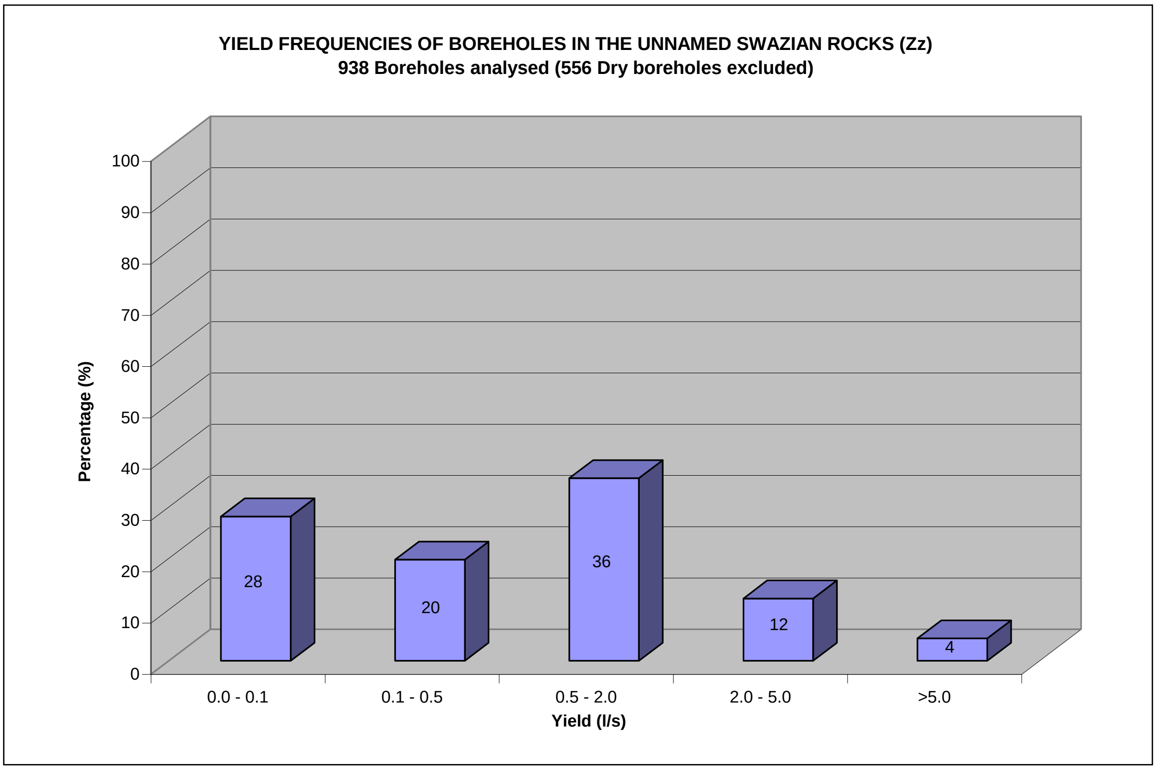

Figure 162: Yield frequency for the intergranular and fractured aquifers of the Unnamed Swazian rocks (Zz)

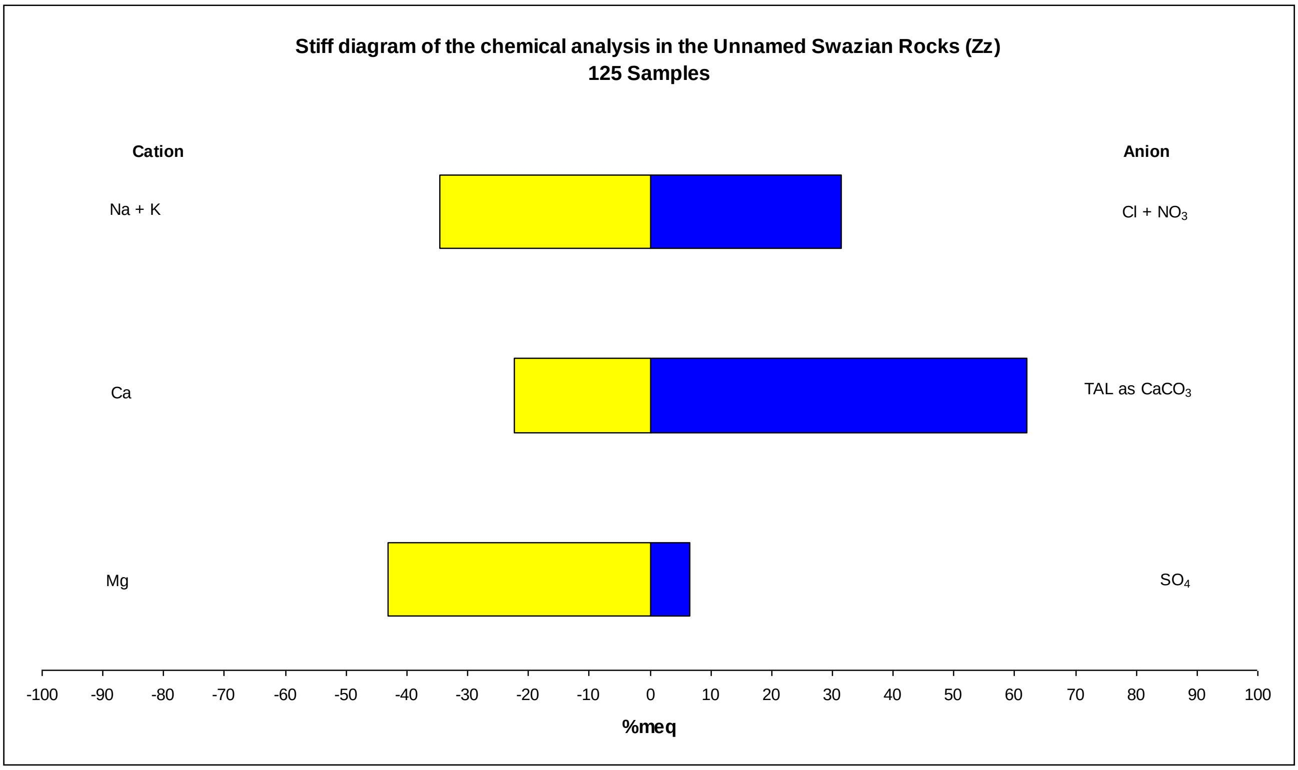

Figure 163:Stiff diagram representing chemical analysis of the Unnamed Swazian Rocks (Zz)

8 SPRINGS AND ARTESIAN BOREHOLES

8.1 Hot Springs

Of the 90 (Kent, 1968) known hot springs in the Republic of South Africa, 9 occurs on the Polokwane hydrogeological map sheet at the following locations:

- 15km north of Marble Hall (unnamed)
- 45km east of Roedtan (unnamed)
- Warmbaths
- Loubad (25km north west of Modimole, (Nylstroom))
- Vischgat (10km south-west of Mookgophong, (Naboomspruit))
- Libertas (10km north-west of Mookgophong, (Naboomspruit))
- Die Oog (10km north-west of Mookgophong, (Naboomspruit))
- Driefontein (10km north of Mookgophong (Naboomspruit))
- Buffelshoek (20km east of Thabazimbi).

In all the above cases heated water rises along fault zones reaching the surface as springs on the topographically lowest points. Deep groundwater circulation related to fault zones is most likely the reason for the occurrence of a number of warm water boreholes in the area. Although not depicted on the map they occur at Stokkiesdraai and Wonderkrater just outside Modimole (Nylstroom) and Mookgophong (Naboomspruit).

Since active volcanic regions are non-existent in South Africa, magmatic water can therefore not play a role with regard to the origin (source) of the hot water, also not as a source of heat (Visser, 1989). The source of the water must therefore be meteoric. According to Kent (1949, 1968), the catchment areas are in the adjoining more elevated terrains, from where rainwater filters along joint and fracture planes and eventually into narrow conduits. Along these conduits the water descends to such depths where the internal heat of the earth causes local convection cells to develop and the water is heated. The descending of cold water and subsequent ascending of heated water is a timeous process. Isotope age determinations conducted at the Warmbaths spring, indicated the age of the water to be in the order of 20 000 years.

8.2 Cold Springs

Several cold springs occur on the map sheet area but are not indicated on the map. Most of the springs, particularly the more perennial ones, occur in the dolomitic rocks e.g. in the Thabazimbi, Mokopane (Potgietersrus) and Wolkberg areas. As discussed in Chapter 7.2.2.1 they are important contributors to base flow in rivers such as the Olifants and Dorps. Seasonal fluctuations or exact flow rates of these springs are not known but the stronger ones are at most only a few litres per second. Springs also occur in the Soutpansberg, Waterberg, and Marble Hall areas. The most important one is the Clouds End spring rising at the foot of the Soutpansberg Mountain near Louis Trichardt. The spring, which still supplies water to the well-known Clouds End Hotel, used to supply water to Louis Trichardt.

Numerous farms in the map sheet area were named after springs that occur on them. However most of these springs dried up when boreholes were drilled and the farms developed.

The cold springs on the map sheet area rise mostly in valleys on the upstream side of dykes, from geological contacts or fault zones or where the water level cuts the topography. In some cases as discussed in Chapter 7.2.3.8 it is due to over-saturation of the water-bearing rock.

8.3 Artesian boreholes

Artesian conditions prevail at only five known areas within the map sheet. Possible explanations to the reasons for this phenomenon are given for each of the areas.

- Werkendam just north of Lephalale (Ellisras).
- Nylsvley between Modimole (Nylstroom) and Mookgophong (Naboomspruit).
- Bela Bela (Warmbaths).
- Eastern part of the northern Springbok Flats.
- Libertas, 10km northwest of Mookgophong (Naboomspruit).

The last three listed are not indicated on the map.

At **Werkendam** impervious Karoo sediments overlie the water-bearing Waterberg sandstones. It is believed that these confined sandstone layers are recharged through fractures and along bedding planes at the higher mountainous areas where it outcrops. Due to the height differences between recharge and abstraction areas, the hydraulic pressure at the point of abstraction is higher than atmospheric pressure resulting in the surface outflow of groundwater where the impervious layer are punctured by drilling. The flow rates vary from more or less 1ℓ/s to a few ℓ/s. Numerous artesian boreholes were recently drilled just south of Lephalale (Ellisras). This water has elevated fluoride concentrations (DWA, 2009).

The artesian boreholes at **Nylsvley** flow under hydrostatic pressure from micro fractures, which are probably recharged from higher altitudes to the north of Nylsvley. The flow rate is at most not more than 0.2ℓ/s.

In the **Bela Bela (Warmbaths)** case it was envisaged that the development of two major east-west trending faults that transects the area, resulted in the formation of numerous minor fractures in the underlying granite. The fractures are aligned sub-parallel to the major fault direction (Verhagen, 1981). An artesian borehole, which is also hot (38°C), is drilled in such a fracture. It is considered that the artesian borehole and the hot spring have the same original source, which is being heated through the same deep convection processes. The water is transmitted along the fracture network and brought to the surface at pressures higher than atmospheric pressure resulting in artesian conditions. The borehole flows at a rate of 2.7ℓ/s. The isotope radiocarbon dating gives a conventional age of 27 000 years for the water flowing from this borehole.

The artesian condition occurring in the eastern part of the **northern Springbok Flats** is discussed in Chapter 7.2.3.4.

The artesian borehole at **Libertas** replaced the original hot spring as water source. Both are situated on the Welgevonden fault zone. The water has a temperature of 51.3°C and flows at a rate of approximately 10ℓ/s. As discussed under hot springs, it is most probably related to deep circulating water recharged at a higher altitude.

9 GROUNDWATER RELATED MATTERS

9.1The National Water Act (Act 108 1998)

The **National Water Act** (Act 108 of 1998) replaces the old Water Act (Act 56 of 1956). The most important implications to groundwater users is 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 Affairs 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 as a whole. It must be managed in an integrated manner according to the principles of the Act (sustainability, equity and efficiency).

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 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. These new institutions will be representative of and facilitate the involvement of communities and other stakeholders in decision making.

At present the Department of Water Affairs is responsible for administering all aspects of the Act on the Minister's behalf. As regional CMA's (19 CMA's are planned) and other local water management institutions are established the Department will over time delegate or assign water resource management responsibilities to these institutions. 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 not falling under Schedule 1 must register their use or apply for a licence. Aspects that will be considered before allocating water to users in a catchment, will be water needed for strategic purposes such as Escom, inter catchment water transfers and international obligations.

9.1.1 Water user registration and licences

Licensing of water use is compulsory reserving the right to the minister of DWA to publish a notice in the Government Gazette requiring all existing and potential water users except Schedule 1 users to apply for licences. The application for a Water User's Licence does not differentiate between users of surface or groundwater.

Schedule 1 users are relatively low water users such as domestic household supplies, non-commercial small gardens, livestock watering for subsistence use, (not feeding pens), storing and using run-off water from a roof. The use is not excessive in relation to the available source and needs of other users.

Continuation of existing lawful use: Existing users who were already using water legally before the National Water Act came into operation must register that use and may continue using the water without having to apply for a licence. This is a transitional measure until the water use needs to be formally licensed. The window period was between September 1996 and October 1998. These users must inform DWA of their usage and DWA 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 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.

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 different water uses are summarised below:

- 21 (a) Taking water from a water resource (Abstraction),
- 21 (b) Storing of water,
- 21 (c) Impending or diverting the flow of water in a water course,
- 21 (d) Engaging in a stream flow reduction activity,
- 21 (e) Engaging in a controlled activity identified as such in section 37 or declared under section 38(l),
- 21 (f) Discharging waste or water containing waste into a water resource,
- 21 (g) Disposing of waste in a manner which may detrimentally impact on a water resource,
- 21 (h) Disposing in any manner of water which contains waste from, or which has been heated in, any industrial power generation process,
- 21(i) Altering the bed, banks, course or characteristics of a watercourse
- 21 (j) Removing, discharging or disposing of water found underground,
- 21 (k) Using water for recreational purposes

If the user receive 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 licences will be issued with conditions to ensure that the water use authorized by the licence 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 25 litre/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

Resource Directed Measures (RDM) is a strategy developed by The Department of Water Affairs to ensure the protection of water resources as outlined in the NWA. A series of measures falling under the RDM that must be addressed includes a classification system, classification of each major resource unit, determination of resource quality objectives and setting the reserve. The objective is to balance protection and development by assess as accurately as possible how much water can be abstracted from a system before the reserve is affected.

A class is allocated to each resource unit representing the level op 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 sustainable (future state). The classification process involves stakeholder participation and consultation as users must know the current state and to decide how the future state must look 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 DWA is responsible to set the reserve. Basic human needs are set at 25 litre/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 quality, 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. The DWA is responsible to set up National water monitoring systems that will facilitate the continued and co-ordinated monitoring of various aspects of water resources by collection relevant information and data through established procedure and mechanisms, from a variety of sources including organs of state, water management institutions and water users. Monitoring of aspects such as quantity, quality, the use and rehabilitation are some of the aspects. As part of the water user licence, users can be required to supply information on abstraction, water levels and quality on a time frequency negotiated between DWA and the licence 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.

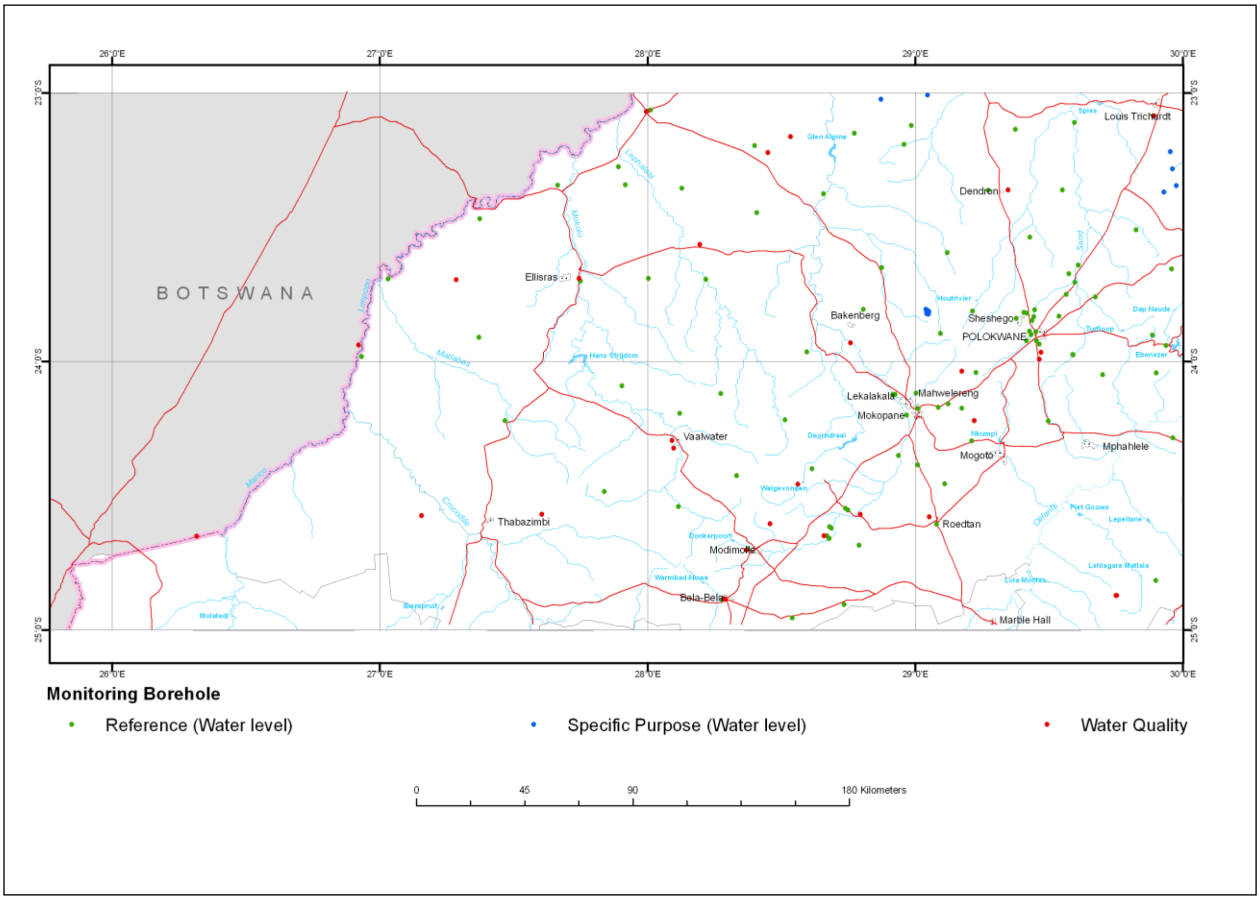

Figure 164: DWA monitoring boreholes.

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 Polokwane map sheet is dependant 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 map area is in general a "dry" region and not many perennial rivers exist from which continuous recharge can take place. Recharge must be seen as a seasonal occurrence mostly when the rivers flow during the rainy season. In some cases groundwater is actually "lost" to rivers through seepage and springs thus contributing to base flow. 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.

Some irrigation farmers on the Springbok Flats irrigate from earth dams, which are fed from boreholes. It appears that recharge is taking place from these dams. Some farmers in the Dendron area are practising recharge from earth dams to ensure sustainable borehole yields. They utilize surface run-off, which is generated during rainfall events. 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 are controlled by factors such as amount and frequency of rainfall, vegetation cover, soil type, topography, slope, geology, depth to water level and others. Although no detail information is yet available, the order of recharge is estimated using various methods to be between 2-15% of the mean annual rainfall depending on the above-mentioned factors.

Surface water percolates through the unsaturated weathered zone to the saturated zone where all openings are filled with water. Storage related to structural features such as fault zones, fracture zones, joints and bedding planes can be major depending on the ratio of the openings to the solid rock. These structural features are usually the preferential pathways for water movement where they act as conduits rather than to contribute to storage. Fractures enhanced by solution to form cavities (mainly in the dolomites) will contribute more to storage due to the extent of the openings.

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. Storage capacity decreases rapidly as the depth of weathering and/or alluvial thickness decreases.

Storage in the rock matrix is in micro pores and fractures. In igneous and metamorphic rocks these storage can be very small while it is usually much more in sedimentary rocks. It is important to note that the rate at which an aquifer can yield water (borehole yield) is merely a function of its permeability. It is not a measure of the volume of water in storage or sustainability of the yield. This is determined from the interpretation of the results of a scientifically conducted pumping test on a borehole.

Groundwater on the map sheet generally flows in the same direction as surface water. The groundwater level mimics more or less the topography with the result that the groundwater divides approximately coincide with the surface water divides. Where extensive abstraction occurs the natural groundwater flow direction is disturbed because of the cone of depression that develops around the points of abstraction. The natural flow direction is restored when abstraction is stopped and the groundwater levels are allowed to recover fully.

9.3 Borehole siting

Table 11 depicts the different geophysical survey techniques that can be employed in the search for geological features that might relate to the occurrence of groundwater. The choice of technique for each of the different hydrogeological resource units are based on current available techniques, proven track records in the application of the technique in each unit, knowledge of targets and geology in each unit, the designed application of each technique and natural parameters that can be measured and the expected response that can be obtained from the geological setting within the resource unit.

Table 11: Recommended geophysical survey techniques to employ in each resource unit.

GROUP/FORMATION	HYDRO-GEOLOGICAL UNIT	CATEGORY	1a	1b	2a	2b	3	4	5
Tertiary - Quaternary alluvial deposits	Q	A	***	**	**			**	**
Chuniespoort Group	Vh	B		**	**	*	***		
Chuniespoort Group	Vh	C		*	*	*	***	***	
Pietersburg Group	Zp	D	**	*	***	*	***		
Beit Bridge Complex	Z	D	**	**	***	**	***		
Unnamed Granitoids, gneisses	Zz	D	**	**	***	**	***		
Granite Intrusives	Vnh,Vtu, Vz, Rat, Rut, Rui, Rlu, Rmo, Rma, Rhu, Rge, Rga,	C	**	**	***	**	***		
Koedoesrand Formation, Pretoria Group , Soutpansberg Group, Black Reef Formation, Wolkberg Group, Platberg Group,	Mko, Vp, Ms,Vbl,Vw,Rp	B		**	***	**	***		
Crocodile River Fragment	Vco,	D	*	*	**	*	**		
Glenover Complex, Palala Granite, Unnamed Mokolian Rocks, Rashoop Suite, Spitskop Complex, Modipe Complex, Messina Suite, Bandelierskop Complex,	Mge, Mpa, Mz, Vrg, Msp, Zmo, Zbm, Zga	B D	**	***	***	*	***		
Waterberg Group	Mw,	B		*	***	*	***		
Ecca Group	Pe	B,D	**	**	***	***	***		
Unclassified Perm-Triassic Formations, Irrigasie, Bosbokpoort, Solitude Formation, Dwyka Group	P-Tri,Trb, P-Trs, C-Pd	B,D	**	**	***	***	***		
Clarens Formation	Trc	D		**	***	**	***		
Goudplaats (Zgo) en Hout River (Rho) Gneiss	Zgo, Rho	D	***	**	***	*	**		
Rustenburg Layered Suite	Vr	D	***	**	**	*	**		
Soutpansberg Group	Ms	D	*	**	***	**	***		
Lebombo Group, Diabase, Platberg Group, Kanye Formation, Klipriviersberg Group, Bothaville Formation, Rooiberg Group	Jl, N-Zd, Rp, Rka, Rk,Vb	B D	*	**	***	**	***		*

The geophysical method is listed as follows:

- 1a Electrical Resistivity –

- 1b Electrical Resistivity – profiling
- 2a Electromagnetic - EM-34
- 2b Electromagnetic - Genie SE
- 3 Magnetic
- 4 Gravity
- 5 Seismic

The rating to it successful application is as follows:

- *** Essential
- ** Useful
- * Not essential

Geological targets that can be related to the occurrence of groundwater are described for most of the hydrogeological units in Chapter 7. The success of the application is enhanced by using other available scientific aids such as aerial photographs, LANDSAT images, Terra Aster satellite imagery, geological maps, existing information for the area and aeromagnetic data. An experienced geohydrologist will also take vegetation, topographical setting, soil changes and other visible signs into consideration during the survey.

9.4 Subterranean water control areas

Four subterranean water control areas occur on the map sheet namely Nyl River, Crocodile River, Dorps River and Houdenbrak (Dendron): As required by the new Water Act these control areas will transform to be managed by the Water User Associations (WUAs). If established the areas will be managed under the framework of the NWS and DWA guidelines.

The Nyl River control area, situated between Modimole (Nylstroom) and Mokopane (Potgietersrus), was proclaimed in March 1971 in order to protect abstraction from the alluvial aquifer along the Nyl River thus preserving this resource for future urban use.

The Crocodile River control area, situated south of Thabazimbi, was proclaimed in October 1981 in order to control abstraction from the alluvial aquifer and to stabilize flow in the river. An imaginary red line-bounded area has been established along the river, which coincides more or less with the extent of the alluvial deposits. Groundwater occurring within this red line-bounded area is regarded and treated as river or surface water.

The Dorps River control area is situated in the Dorps River catchment east of Mokopane (Potgietersrus). It was proclaimed in February 1990 in order to safeguard this dolomitic resource against over-abstraction and to preserve it for present and future urban utilization. The Mokopane (Potgietersrus) Municipality owns most of the land within this control area.

The Houdenbrak control area, which was declared a control area in April 1994, has not been implemented yet. The irrigation farmers have requested the control of groundwater resources in this area. This control area situated in the Dendron area is unique in the sense that the farmers will control themselves. This self-control approach aroused interest amongst other farmers with the result that several farmer unions are now requesting similar self-control.

9.5 Groundwater management

As discussed the new Water Act the **Minister of the Department of Water Affairs 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 as a whole. 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 operates 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 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 Affairs 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 is a general problem especially where extensive irrigation is practised such as the Dendron and Springbok Flats areas, or in poorly managed well field areas utilized for large scale town supplies. This can be prevented and controlled through sound groundwater management practises.

Part of the licence requirements can be that water users must monitor abstraction and quality at all levels from local authorities such as the Polokwane (Pietersburg) municipality down to individual farmers. During the period or at the renewal date of the water user licence DWA can request monitoring data from licence holders. As licensing is compulsory holders should familiarized themselves with the licence requirements as the licence 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 in order 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 these can be obtained from the Institute for Resource Quality Studies of the Department of Water Affairs at Roodeplaat Dam.

In the licence application no distinction is made between surface water or groundwater use as it is all part of the hydrological cycle. From a hydrogeological view the 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 Affairs has a large number of monitoring boreholes equipped with electronic data loggers within the map sheet area (Figure 164). Most of them monitor ambient water level fluctuations and trends on a regional scale. There are number of specific purpose monitoring stations that are monitoring water level fluctuations in existing well fields such as those in and around Bela Bela (Warmbaths), Modimole (Nylstroom), Mookgophong (Naboomspruit), Mokopane (Potgietersrus), Polokwane (Pietersburg) and Louis Trichardt. The data are available on request from the Department's National Groundwater Archive (NGA) in Pretoria.

9.5.1 Groundwater contamination and pollution

Groundwater contamination is defined as the introduction of any substance into groundwater by the action of man and pollution is defined as the direct or indirect alteration of the physical, chemical or biological properties of a water resource so as to make it-

a) Less fit for any beneficial purpose for which it may reasonable expected to be use.
b) Harmful or potentially harmful-
   - to the welfare, health of safety 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 its 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 in order to protect vulnerable aquifers. The establishment or closure of such sites is strictly controlled by the Department of Water Affairs in order 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 bigger towns and cities 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. In the districts of Kutama and Sinthumule southwest of Louis Trichardt nitrate levels of up to 250mg/l have been measured in some boreholes. High nitrates also occur in the Dendron and Springbok Flat areas. Other occurrences are displayed on the 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 such as around Mokopane (Potgietersrus), Northam, Rooiberg, Thabazimbi and the colliery west of Lephalale (Ellisras) are all potential sources of pollution if not properly managed.

9.5.2 Groundwater utilization

Groundwater is in many cases the only source of supply especially in the rural areas. The water is used for domestic, live stock watering, and irrigation purposes. Many of the larger towns such as Bela Bela (Warmbaths), Modimole (Nylstroom), Mookgophong (Naboomspruit), Mokopane (Potgietersrus), Polokwane (Pietersburg) and Louis Trichardt use surface and groundwater conjunctively. Due to the lack of perennial rivers and suitable dam sites more and more users rely on groundwater to meet their demands. The agricultural sector is the largest consumer of groundwater in the map area. Large-scale groundwater abstraction occurs at several localities of which some is depicted in Table 12. The harvest potential map (Figure 165) gives a quantitative depiction of sustainable volumes of groundwater potentially available for abstraction.

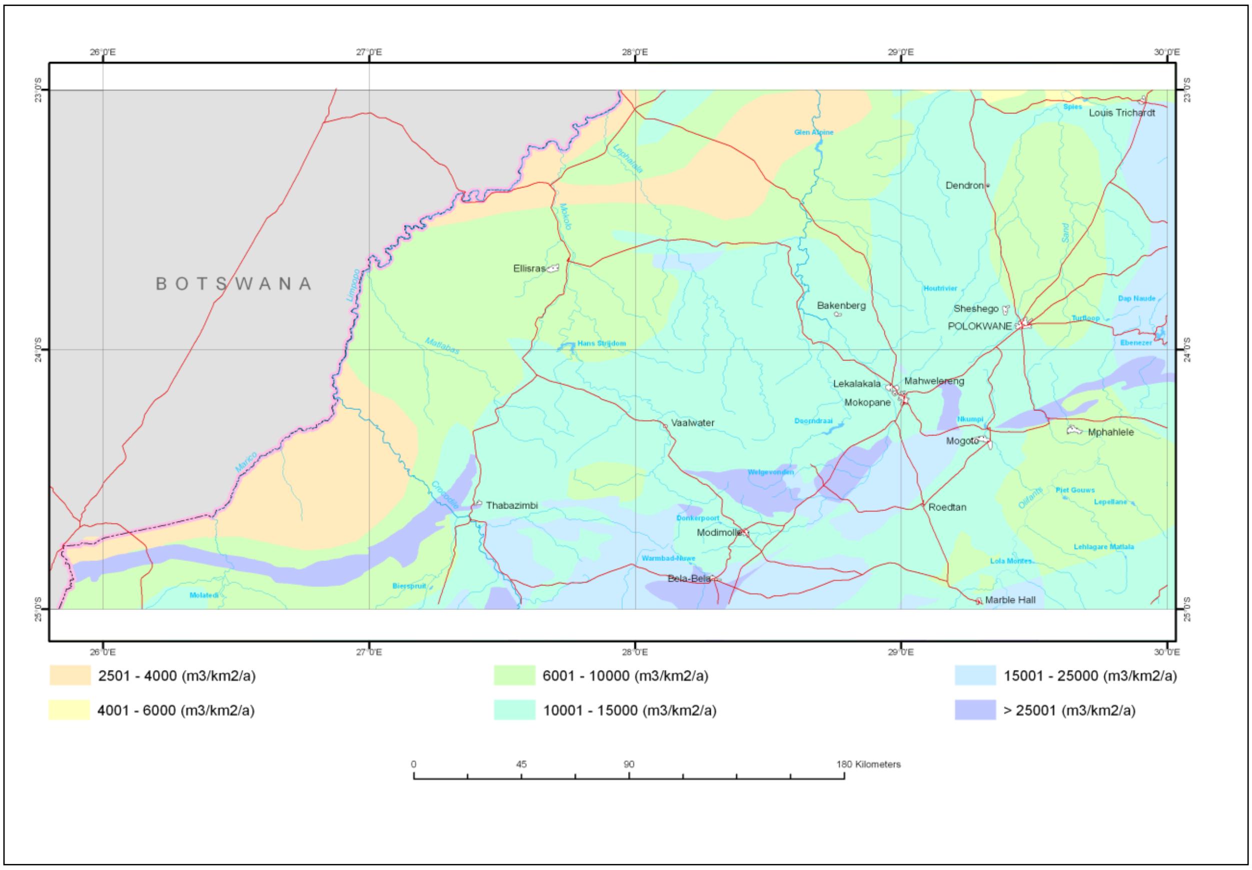

Figure 165: Harvest potential (Seward, Baron & Seymour, 1996)

Table 12: Localities where large-scale groundwater abstraction (>400 000 M³/a) are taking place.

LOCALITY/AREA	APPROXIMATE ABSTRACTION (10^6 m³/a)	
	DOMESTIC	AGRICULTURAL
Polokwane (Pietersburg)	7,0-10,0	
Mokopane (Potgietersrus)	5,0	
Bela Bela (Warmbaths)	0,7	
Louis Trichardt area	1,6	1,9
Modimole (Nylstroom)	0,6	
Dendron area		25,0
Springbok Flats		40,0
Mookgophong (Naboomspruit)	0,4	
Sand River area		20,0
Mara area	1,0	
Upper Crocodile River area		31,0
Lower Crocodile River area		25,0

9.6 Future groundwater exploration

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. To be able to absorb this anticipated pressure the country should invest in groundwater exploration in order to maintain and manage existing resources and develop new resources. The following possible subjects are suggested:

- Recharge from earth dams,
- Influence of forestry on groundwater,
- Limpopo and Mpumalanga dolomites as a regional source,
- Establishment of new subterranean water control areas,
- Role of pegmatites in the occurrence of high yielding boreholes,
- Prevention of high concentrations of nitrates in rural areas,
- Geophysical exploration techniques to detect deep aquifers in hard rock formations,
- Application of remote techniques (LANDSAT imagery, geophysics, etc) for early identification of potential groundwater target areas,
- Determination of recharge to the different hydrogeological units and techniques to improve it,
- Exploration into the occurrence and utilization of deeply (>200m) seated aquifers,
- Influence of intrusives such as batholiths and stocks on the surrounding host rock in terms of groundwater occurrence,

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