EXPLANATION OF THE
1:500 000 HYDROGEOLOGICAL MAP 2127 MESSINA

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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 particularly 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, without doubt, be defined as mankind's most precious resource. It is said that to denied food, Man's body can sustain life for weeks, but refuse him water and death is likely to come within a few days. The availability of water in even the remotest area is thus vital to maintain this indispensable requirement 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 Messina Hydrogeological Map and the accompanying explanatory brochure introduce the current state of groundwater knowledge and the basic geohydrological characteristics of the map area. It should 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 than can be indicted on the map sheet.

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 livestock 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

Council for Geoscience (Pretoria) Geological information

Council for Geoscience (Polokwane) Geological information

DWA (Pretoria) National groundwater and water quality databases

DWA (Pretoria) Geohydrological Reports

DWA (Polokwane) Geohydrological Reports

GPM Consultants Groundwater information

Municipalities within the map area

VSA Leboa Geoconsultants Groundwater information

Cover page: *The confluence of the Shashi River and the Limpopo River, also known as Crookes Corner, currently part of the Greater Mapungubwe Transfrontier Conservation Area, photo taken from South Africa, Botswana left, Zimbabwe right. The Limpopo is the east west flowing river, the Shashi joining from the north. (Photograph: J.J. Van Zyl, 2007, Wikimedia)*.

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ABBREVIATIONS

DWA	Department of Water Affairs
DWAF	Department of Water Affairs & Forestry
EC	Electrical conductivity
HARMEAN	Harmonic mean
GRIP	Groundwater Resource Information Project
Mamsl	metres above mean sea level
Mbgl	metres below ground level
NGDB	National Groundwater Data Base
NGA	National Groundwater Archive
SANS	South African National Standard
SACS	South African Committee Stratigraphy
TWQR	Target Water Quality Range
TDS	Total dissolved salts
UNESCO	United Nations Educational, Scientific and Cultural Organisation
VES	Vertical electrical soundings
VSA	VSA Geoconsultants Group
WMS	Water Management System
WRPS	Water Resource Planning Systems

SYMBOLS AND UNITS

Km^2	square kilometre
ℓ/s	litres per second
m	metres
Ma	million years
Mm^3	million cubic metre
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
%	percentage

CHEMICAL SYMBOLS

Al	Aluminium
As	Arsenic
Cd	Cadmium
Ca	Calcium
Cl	Chloride
Cu	Copper
F	Fluoride
Fe	Iron
TH	Total hardness
Mg	Magnesium
Mn	Manganese
No_3	Nitrate
No_2	Nitrite
N	Nitrate (No_3) + Nitrite (No_2)
K	Potassium
Na	Sodium
SO_4	Sulphate
Si	Silica
Zn	Zinc

EXPLANATION OF THE
1:500 000 HYDROGEOLOGICAL MAP 2127 MESSINA

1 INTRODUCTION

1.1 General:

The **Messina Hydrogeological Map, sheet 2127,** 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 the 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 will also serve as an educational tool to promote groundwater as an interesting and scientific subject.

Groundwater occurrences are very heterogeneous in South Africa while the mapping standards, legends, 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 yields, aquifer types, 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 and quality of water for future generations.

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

2 MAP COMPILATION

2.1 Data sources:

Data sources for the compilation of the map include:

- The National Groundwater Archive (NGA) which replaced the National Groundwater Data Base (NGDB), under the custody of the Department of Water Affairs (DWA).
- Water Management System (WMS), Department of Water Affairs (DWA).
- Existing data from the former homeland Venda.
- Available geohydrological reports.
- Limpopo GRIP Data Base managed by GPM for DWA.
- Existing information from various consultancies stationed in Limpopo Province.

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

RECORDS EVALUATED				
NGA and GRIP - 6180		WMS and Limpopo - 4139		
Total number of borehole yields	Total number of water levels	Total number of EC measurements used	Total number of Nitrates and Fluorides used	Total number of complete chemical analysis used
5269	1063	2484	2484	2263

2.2 Main map:

Messina hydrogeological map: scale 1: 500 000. The map sheet covers an area of 2 498 969ha or 24 989.69km². It represents the first general synthesis of the groundwater resources north of latitude S23 º, thus presenting the northern part of South Africa. Three international borders frame the area i.e. Botswana in the west to northwest, Zimbabwe in the north and Mozambique in the 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 map compiler's choice. These lithologic units were then grouped together based on the expected groundwater occurrence viz. **Intergranular (a), Fractured (b), and Intergranular and Fractured (d). Karst (c) is part of the legend for map continuity although no dolomitic rocks occur within the map area.**

The borehole yield data available on the NGA (previously NGDB) 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 (borehole yield class) for each of the four classes (aquifer type) or 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 solid red circles of various sizes representing the annual volume of abstraction. Springs, thermal springs and artesian conditions are shown in pink (solid circle), orange (open circle) and pink (open circle). A network of water level recorders and monitoring points was only developed since the first publication of the main map (1995). The positions of these points are shown in figure 81 of the brochure.

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

2.2.1 Inset maps:

The following inset maps have been included on the Messina Hydrological map sheet 2127:

The Soutpansberg Supergroup and its sub-divisions: Due to the significant hydrogeological differences between the different Formations of the Soutpansberg Supergroup, which could not be displayed on the main map, an inset map depicting the Soutpansberg Supergroup with all its sub-divisions was inserted on the main map. Each of the Formations with its unique age symbol is displayed together with flow rates and the temperatures of springs where available. In addition most of the known faults are shown as these are important targets for groundwater development in the Supergroup.

Two hydrogeological cross-sections based on limited geological information and the author's own interpretation of the available information. The cross-sections display typical targets for successful groundwater development in the map area. The static water level is included to show its relationship with surface topography.

Distribution of borehole data: scale 1: 2 000 000: represent borehole data points per 1-minute grid. 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 mean sea level: scale 1: 2 000 000, contour intervals relevant to the map at either 200 or 400m. The elevation in the map area varies more or less between 200-1600mamsl.

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 distribution of problematic chemical species, namely 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 DWA 1996 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 than 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 which are important, but 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 availability & 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 Messina map sheet according to the origin and nature of the saturated interstices combined with subdivisions based on existing known blow yields (after Orpen, 1994).

Three modes of groundwater occurrences based on the dominant porosity type are depicted on the Messina map sheet namely:

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

The fourth karst (c) is included in the legend for mapping continuity although no dolomitic rocks occur within the map area.

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 Messina 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 livestock 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 livestock 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: Adapted hydrogeological classification of the principle occurrences of groundwater within the boundaries of the Messina Hydrogeological map sheet, according to origin and nature of the saturated interstices with subdivisions based on borehole yields (After Orpen, 1994)

<table>
<tr><th colspan="4">CLASS A</th><th colspan="4">CLASS B</th><th colspan="4">CLASS C</th><th colspan="4">CLASS D</th></tr>
<tr><td colspan="4">INTERGRANULAR</td><td colspan="12">HARD, CONSOLIDATED ROCK MATERIAL</td></tr>
<tr><td colspan="4" rowspan="2">A water saturated zone, generally unconsolidated but occasionally semi-consolidated. Groundwater storage and flow through intergranular interstices in porous and permeable medium.</td><td colspan="12">Fissured and fractured bedrock resulting from decompression and/or tectonic forces. Groundwater flow predominantly through fractures, faults, joints and fissures (acting as conduits), and micro-fissures in the bedrock, Rock matrix provides storage.</td></tr>
<tr><td colspan="4">Where the principal water strike is in a fracture or in the contact between two different rock types, interporosity groundwater flow can occur within the rock matrix (double-porosity matrix).</td><td colspan="4">In the case of carbonate rocks incipient fissures and fractures are enhanced through chemical dissolution. Some groundwater storage can be expected in in-situ weathered residuum.</td><td colspan="4">Fractured zone overlain by varying thicknesses of weathered saturated material. Storage and flow in both. Fractures act as conduits during abstraction, vertical recharge from intergranular zone.</td></tr>
<tr><td rowspan="2">Group</td><td colspan="2">Typical borehole yield</td><td rowspan="2">Colour code</td><td rowspan="2">Group</td><td colspan="2">Typical borehole yield</td><td rowspan="2">Colour code</td><td rowspan="2">Group</td><td colspan="2">Typical borehole yield</td><td rowspan="2">Colour code</td><td rowspan="2">Group</td><td colspan="2">Typical borehole yield</td><td rowspan="2">Colour code</td></tr>
<tr><td>Range</td><td>ℓ/s</td><td>Range</td><td>ℓ/s</td><td>Range</td><td>ℓ/s</td><td>Range</td><td>ℓ/s</td></tr>
<tr><td>a1</td><td>Un-economical</td><td>0.0-0.1</td><td></td><td>b1</td><td>Un-economical</td><td>0.0-0.1</td><td></td><td>c1</td><td>Un-economical</td><td>0.0-0.1</td><td></td><td>d1</td><td>Un-economical</td><td>0.0-0.1</td><td></td></tr>
<tr><td>a2</td><td>Very low</td><td>0.1-0.5</td><td></td><td>b2</td><td>Very low</td><td>0.1-0.5</td><td></td><td>c2</td><td>Very low</td><td>0.1-0.5</td><td></td><td>d2</td><td>Very low</td><td>0.1-0.5</td><td></td></tr>
<tr><td>a3</td><td>Low</td><td>0.5-2</td><td></td><td>b3</td><td>Low</td><td>0.5-2</td><td></td><td>c3</td><td>Low</td><td>0.5-2</td><td></td><td>d3</td><td>Low</td><td>0.5-2</td><td></td></tr>
<tr><td>a4</td><td>Moderate</td><td>2-5</td><td></td><td>b4</td><td>Moderate</td><td>2-5</td><td></td><td>c4</td><td>Moderate</td><td>2-5</td><td></td><td>d4</td><td>Moderate</td><td>2-5</td><td></td></tr>
<tr><td>a5</td><td>High</td><td>>5</td><td></td><td>b5</td><td>High</td><td>>5</td><td></td><td>c5</td><td>High</td><td>>5</td><td></td><td>d5</td><td>High</td><td>>5</td><td></td></tr>
<tr><td colspan="4">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

Examples:
Deposits along rivers such as the Limpopo, Mutale, Levhuvu, Nzhelele</td><td colspan="4">Sedimentary rocks of arenaceous origin. Acid volcanic rocks and other igneous rocks with very limited overlying residual weathered products.

Examples:
Malvernia-, Jozini-, Bosbokpoort- and Solitude Formation, Undifferentiated Ecca Group and Clarens Formation, Ecca Group, Soutpansberg Supergroup (quartzites and sandstones).</td><td colspan="4">Carbonate rocks including dolomite, limestone of marine origin

Examples:
No dolomitic rock occurs within the map area.</td><td colspan="4">Sedimentary. Igneous and metamorphic rocks with significant thicknesses of overlying saturated residual weathering.

Examples:
Letaba and Clarens Formation, dolerite, syenite and diabase intrusions, Soutpansberg Supergroup (basalt and lava), older Gneisses (Bulai, Sand River, Hout River, Alldays, Goudplaats), Messina Suite, Beit Bridge Complex</td></tr>
<tr><td colspan="4">INTERGRANULAR</td><td colspan="4">FRACTURED</td><td colspan="4">KARST</td><td colspan="4">INTERGRANULAR AND FRACTURED</td></tr>
</table>

4 PHYSICAL ENVIRONMENT

4.1 General

The Messina hydrogeological map sheet covers the northern part of South Africa with three international borders flanking the area i.e. Botswana in the west and northwest, Zimbabwe in the north and Mozambique in the east. The southern boundary is latitude S23º.

It covers an area of 24 989.69km² of which approximately 13.5% falls under Provincial and National parks, 15% is used by scattered settlements with the rest mainly privately owned farms utilized mostly for irrigation, livestock and game farming.

In the west and north-western part of the map sheet area, rainfall is low and irregular. Commercial irrigation farming is therefore limited to areas with surface water (along major rivers), or where irrigation from dams is available (Nzhelele Dam) or where high yielding groundwater sources are available from hard rock formations (Waterpoort area) or alluvial aquifers (Weipe area). Land use is dominated by livestock farming (mostly cattle) while there is an increasing tendency towards game farming. The higher laying areas in the south formed by the Soutpansberg which are the source for or head waters of the A8, A9 and B9 Secondary drainage regions, are mainly utilised for fruit farming and forestry. In the more rural areas (former homelands) small scale irrigation schemes, subsistence farming and livestock farming are practised. The eastern part of the map covers the northern area of the Kruger National Park.

Approximately 0.925 million people (2002 figures with a yearly 2% increment) are resident in the area with only about 5% living in urban areas. The remaining 95% live in scattered villages and farms. Urbanization involving an estimated 10% of the population as well as an influx from Zimbabwe due to economic reasons is influencing current demographics (ARC, Limpopo Basin study, 2010).

4.2 Terrain Morphology

Terrain Morphology is a function of the geology of the area with the east/west-trending Soutpansberg Mountain consisting of a sedimentary and volcanic assemblage forming the most prominent elevated feature within the map area. Faulting is responsible for the frequent structural repetition of the Soutpansberg Supergroup resulting in the sequence of mountains and valleys encountered when crossing the area perpendicular to regional geological strike. Elevations ranging between 800 and 1600mamsl occur in this area (Figure 1). Areas underlain by basement gneisses and rocks of the Karoo Supergroup have elevations between 400 to 800mamsl. The volcanic rocks within the Lebombo Basin have the lowest elevation of between 200 to 400mamsl trending lower towards the coastal plains of Mozambique in the east.

The area can be divided into four main terrain morphological units (Kruger, 1983), (Figure 4), viz.:

- Plains with low relief
- Plains with moderate relief
- Lowlands, hills, and mountains with moderate and high relief
- Closed hills and mountains with moderate and high relief

4.3 Types of soil

Soil types and the formation of soil profiles are generally directly related to the underlying geology, topography and climate. In the mountainous regions of the Soutpansberg shallow, stony soils of the Mispah, Glenrosa and Hutton forms are developed especially on the steeper slopes. The wetter zones (south-facing slopes) also comprise areas of deep, red apedal and structured dystrophic and mesotrophic sandy clay to clay soils even on the steeper slopes. These soils belong to the Hutton, shortlands and occasionally Glenrosa forms.

In the north to north-western part of the map area around Alldays and Messina, the area is characterized by plains with moderate relief and underlain by granitoid rocks. It gives rise to shallow or moderately deep, mainly reddish-brown apedal, eutrophic to calcareous sandy loams with zones of lithosols found on intruding rocky ridges and kopjes. The main soil forms are Hutton and Glenrosa. In the areas underlain by basaltic rocks of the Letaba Formation, the soils are moderately deep, greyish-black, structured, calcareous sandy clays of the Arcadia, Moyo and Bonheim soil forms. Lithosols are also common in this zone. These soils are very similar to soils found in the area underlain by basalt south of the Soutpansberg mountain range. Soils formed from alluvium are dark brown, weakly structured, mainly calcareous sandy clays and clays belonging to the Oakleaf and Vals River forms. Immediately adjacent to the Limpopo River, varying in width, a zone of deep, brown, weakly structured, alluvial sandy clay loam to clay soils, silty in places and often calcareous occur. Mainly belonging to the Oakleaf form, these deposits increase generally in width to the east especially at the confluence of the Levhuvu and the Limpopo River.

The south-eastern part of the map area is underlain by gneiss forming plains with low relief. The soils is shallow to moderately deep, reddish-brown apedal, often gravely, eutrophic sandy loams and sandy clay loams with zones of lithosols. Hutton and Glenrosa soil forms predominate. Soils found on the quaternary sand are deep, red and yellow apedal, mesotrophic sandy loams belonging to the Clovelly and Hutton soil forms. (Memoirs Agriculture National Resources. S. Afr. No 37. pages v to vi, 2003).

4.4 Climate

North of the Soutpansberg, the Mean Annual Precipitation (MAP) (Figure 2) varies between 300-400mm, decreasing to 200-300mm along the Limpopo River and the border with Zimbabwe. In the northeast at the confluence of the Levhuvu and Limpopo Rivers, the average MAP is 260mm. MAP increases westwards towards Musina with an average rainfall of 280mm. Further west at Pontdrif Border Post, the MAP is approximately 370mm.

In the Swartwater area towards the south-western corner of the map sheet, the climate can be described as semi-arid with dry warm winters and hot summers receiving an annual rainfall of 350mm. Variability in annual rainfall from one season to the next and between successive wet and dry cycles is high and gives rise to the frequent periods of drought documented for the area. Low and variable rainfall together with high potential evaporation result in low expectation of natural recharge to groundwater.

Towards the eastern side of the map area near and within the Kruger National park, MAP varies between 400-600mm. From Punda Maria (430mm) the rainfall increases towards the mountainous area in the south with an average of 800 – 1000mm/annum. Within the Kruger Park the rainy season stretches from November to March with a peak during January and February. Very little rain falls from June to August (Du Toit, 1998). Thohoyandou with a MAP of 1053mm, is the town with the highest rainfall within the map area.

Rainfall events are usually in the form of downpours in the summer months i.e. October-March. Cyclonic rains caused by the movement of cyclones through the Mozambique Channel also occur though very infrequently. The last occurrence was in January 2000 resulting in most areas receiving more than twice their average rainfall within a two week period. Excessive damage to infrastructure resulted and a few mudslides and rock falls were reported in the southern part of the Soutpansberg. The static groundwater level was not influenced as expected. Less rain but more frequent downpours influences the static water level more (Verster, personal communication, 2010). As a result of the generally high summer temperatures and low humidity, evaporation is high (Figure 3) over most of the area and varies from 1300mm in the Soutpansberg mountain area increasing to 2000mm towards the north and northwest. From a replenishment point of view it seems that the area gains relatively little benefit from the rainfall as it is concordant with periods of when evaporation is at its peak (Fayazi *et al.,* 1981).

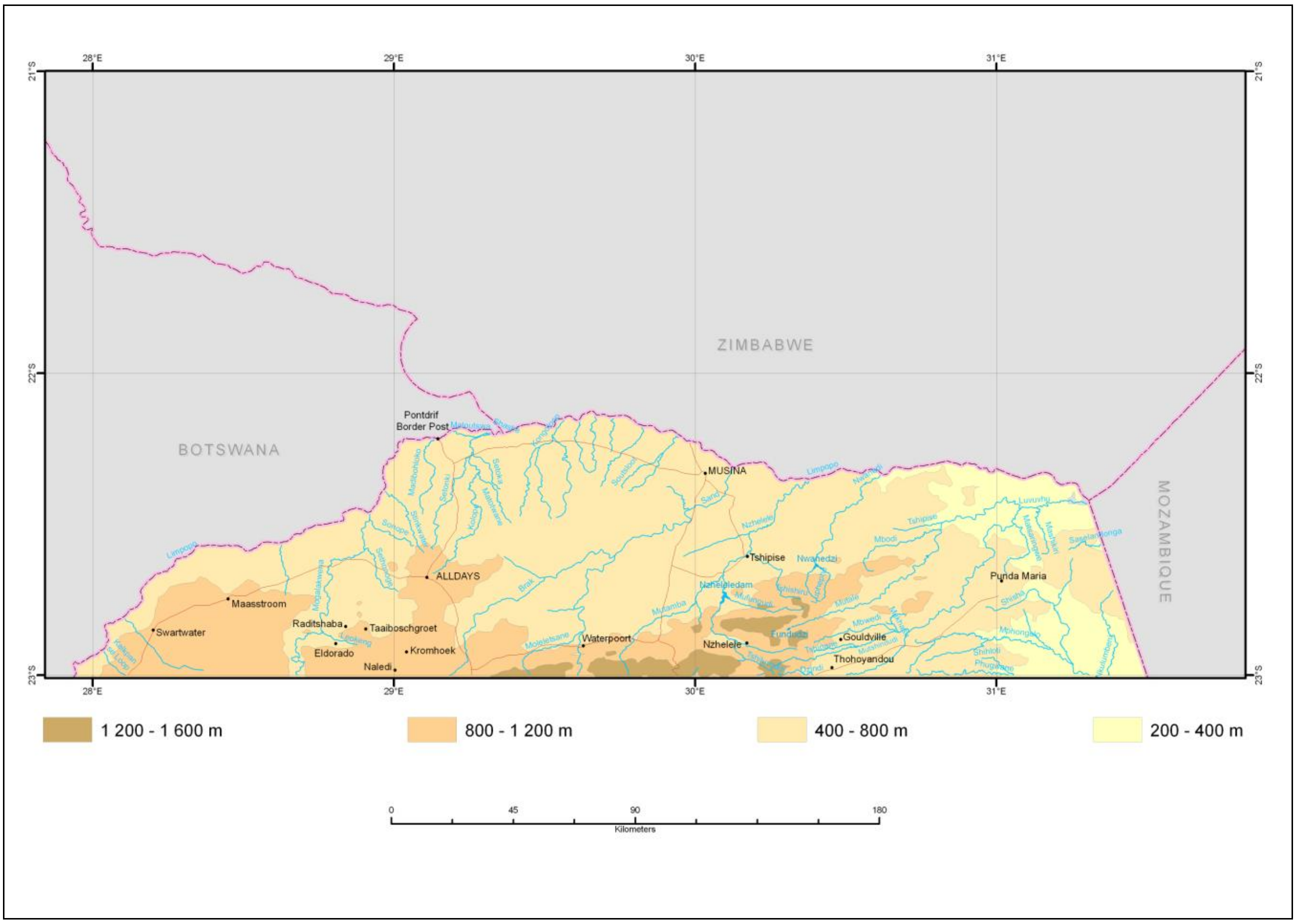

Figure 1: Elevation metres above mean sea level.

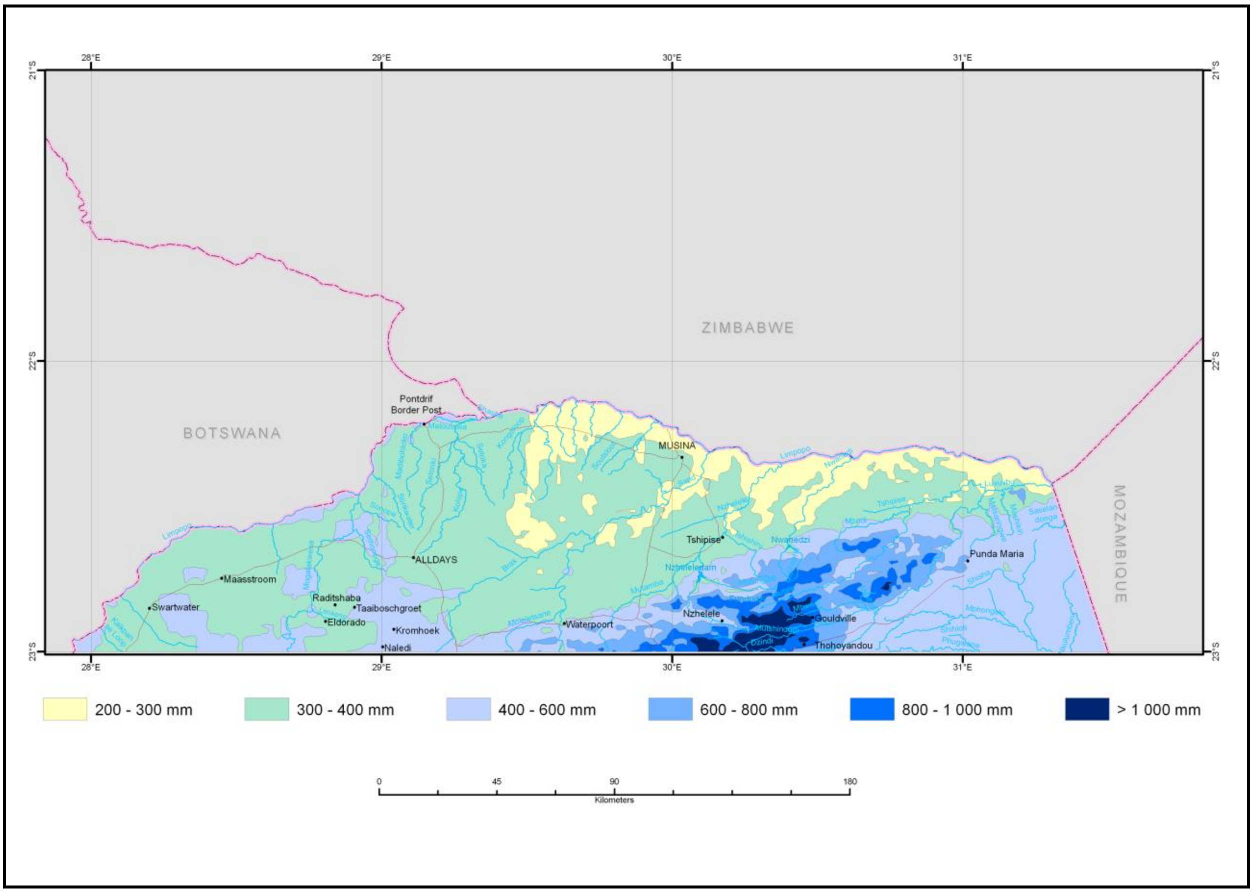

Figure 2: Mean Annual Precipitation.

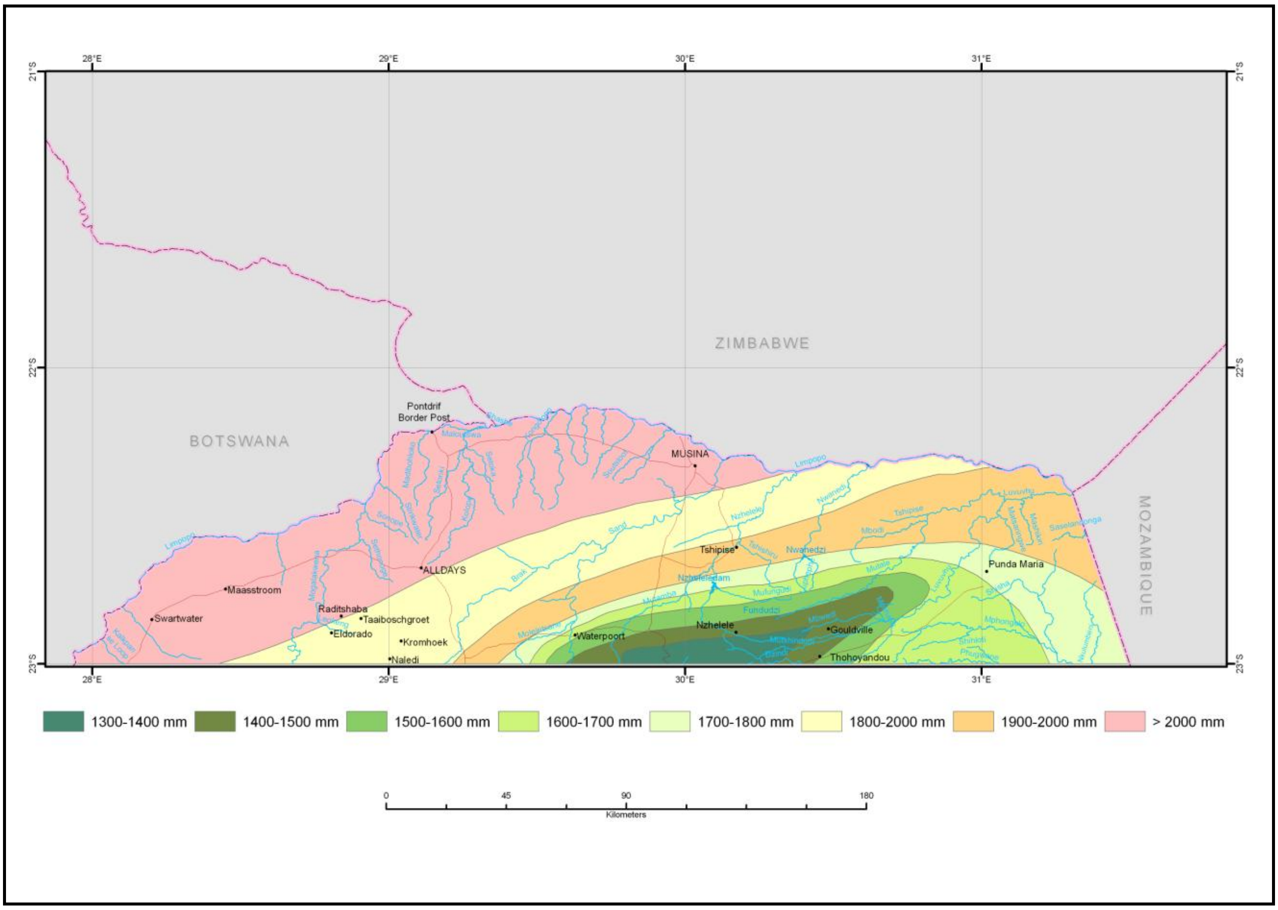

Figure 3: Mean Annual Evaporation.

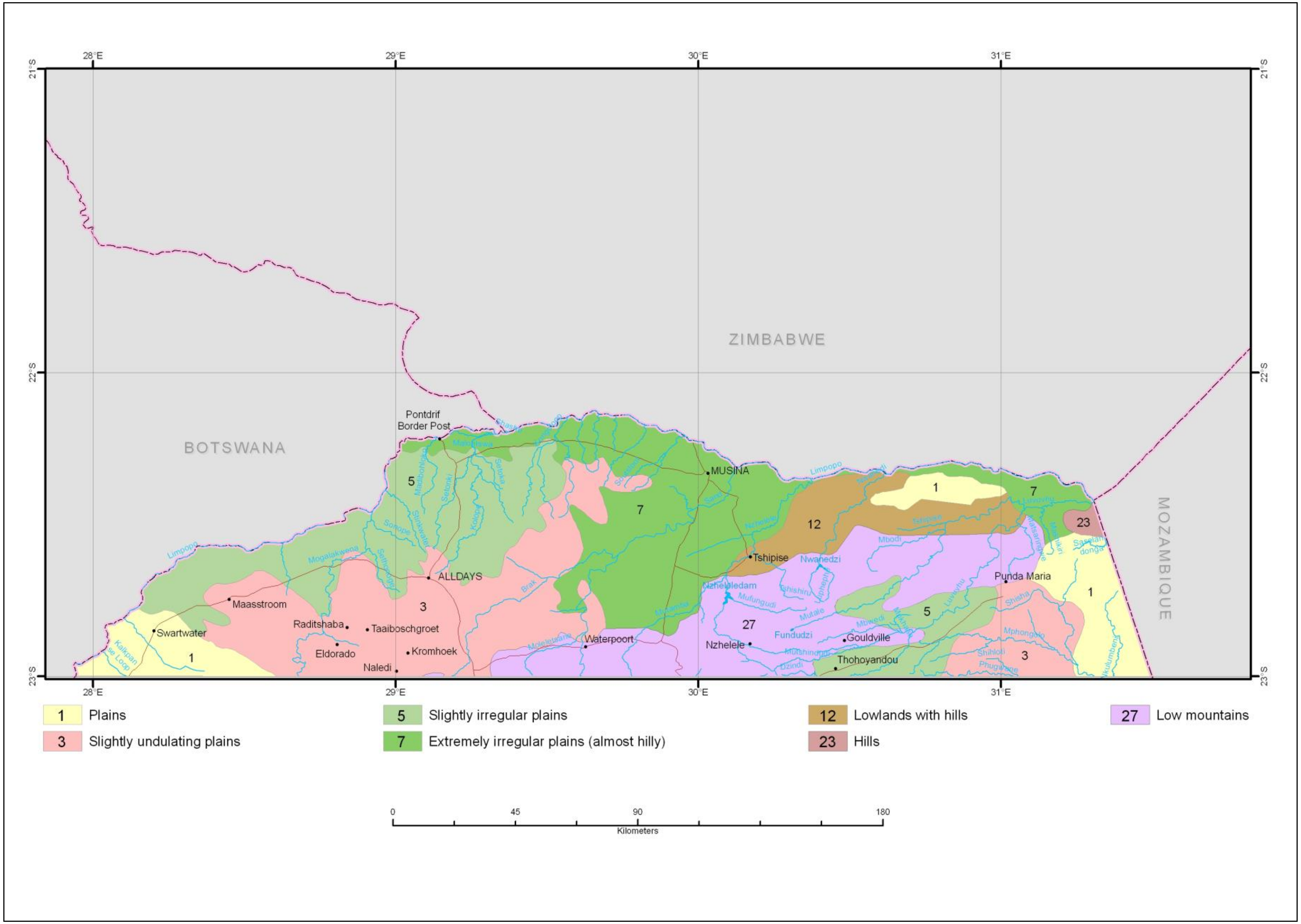

Figure 4: Terrain Morphology (Kruger, 1983)

Table 3: Explanation for Figure 4, 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	5	Slightly irregular plains	low – medium 0 - 2	> 80%
	7	Extremely irregular plains (almost hilly)	high 2 - 3.5	
Lowlands, hills and mountains with moderate to high relief	12	Lowlands with hills	low - medium 0.5 - 2	50 - 80%
Closed hills and mountains with moderate and high relief	23	Hills	medium 0.5 - 2	< 20%
	27	Low mountains		

*Note: Drainage density is calculated by dividing the *total length of drainage channels by the area in km²*

4.5 Surface Hydrology

The area is divided into **two Primary drainage regions** i.e. the Limpopo system (A) which drains approximately 75% of the area, and the Levhuvu/Letaba system (B). In the west relatively short non-perennial tributaries of the Limpopo River drain the area in a north to north-north-western direction. West of the town of Musina, the Mogalakwena and Sand are the only perennial rivers. East of Musina perennial rivers are more abundant with their headwaters in the Soutpansberg such as the Mutamba, Nzhelele, Tshipise, Mutale, Mutshindudi and Levhuvu Rivers that all drain more or less north-east towards the Limpopo River.

Plate 1: Lake Fundudzi was created by a landslide which formed a natural obstruction within the Mutale valley. It is the only inland perennial lake in South Africa. It is one of the many beautiful areas that form part of the Ivory route. This lake is the source of the Mutale River. Photo obtained from Google images in December 2010. (The photographer is not known)

In the eastern part of the map area, the Shisha and Mphongolo are perennial rivers draining southeast to join the Shingwedzi River. Non-perennial rivers joining the Mphongolo before flowing into the Shingwedzi River are the Nkulumbeni and Phugwane Rivers. Figure 5 displays the location of the two main surface water drainage basins as well as the major dams with their storage capacities depicted in Table 4.

Many of the perennial rivers in the map area, including the Limpopo River, can stop flowing in exceptionally dry years. Water used for irrigation contributes to the reduction in flow. The 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 to groundwater. Respectively this interaction is dependant on factors such as the water level of the river, depth of erosion channel and type of river bed material, geology and structures, riparian vegetation, abstraction points near the river and the static water level in the vicinity of the river.

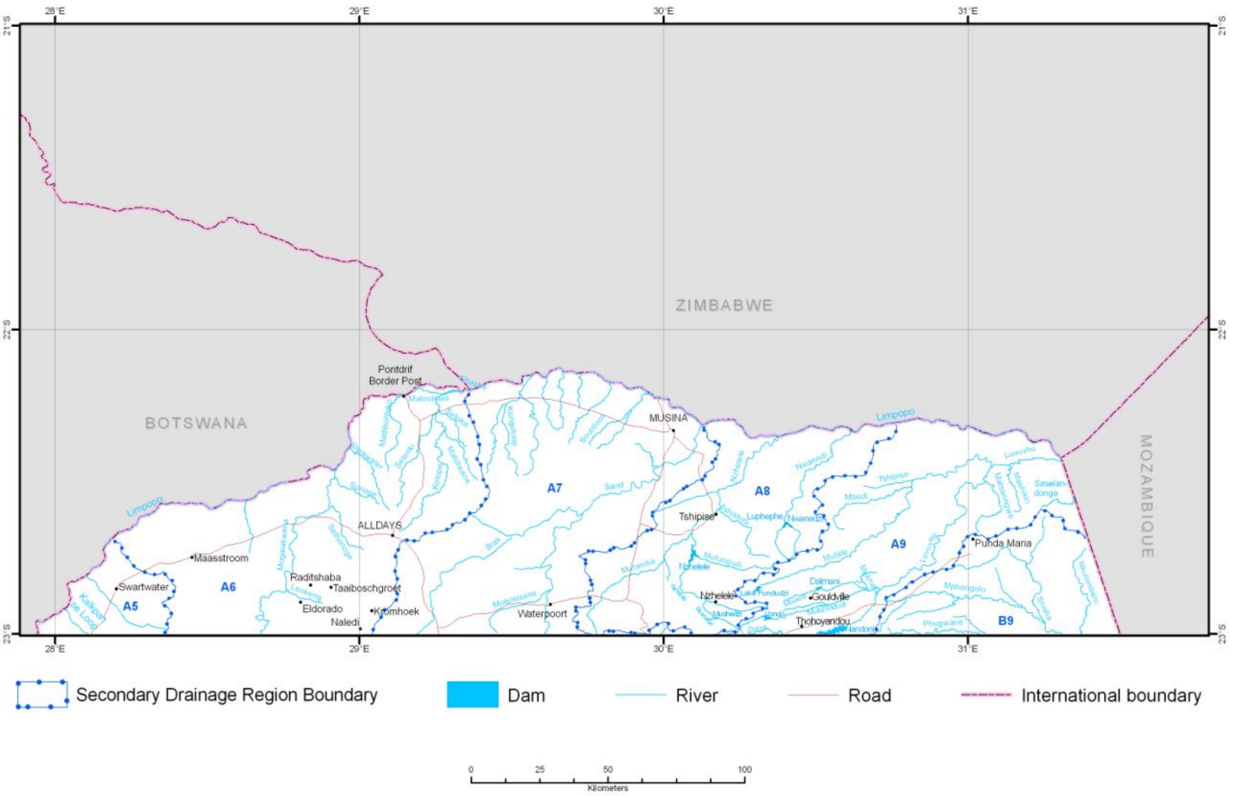

Figure 5: Drainage regions and major dams (HRU, 1981)

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

DAM NAME	DRAINAGE BASIN	RIVER	STORAGE CAPACITY (Mm^3)
Dalmani	A9	Luthava	12.7
Luphephe	A8	Luphephe	14
Mutshedzi	A8	Mutshedzi	2.4
Nandoni	A9	Levhuvu	166.2
Nwanedzi	A8	Nwanedzi	5.2
Nzhelele	A8	Nzhelele	51.3
Vondo	A9	Mutshindudi	30.5

5 GEOLOGY

5.1 Regional geology

The geology occurring on the Messina Hydrological map sheet area spans the length of the South African geological history and contains some of the major stratigraphic groups in the country. A simplified geological map (Figure 6) was compiled from the following 1: 250 000 published geological map sheets and explanatory booklets (Council for Geoscience):

- 2228 Alldays
- 2230 Messina

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 in the map area are as follows:

- The Basement Complex
- Soutpansberg Group
- Diabase dykes and sills
- Karoo Supergroup
- Dolerite dykes and sills
- Cretaceous
- Quaternary

The Basement Complex

The south-eastern part of the map sheet consists essentially of leucocratic biotite gneiss, leucocratic granite and pegmatite, grey biotite gneiss and migmatite, [Goudplaats Gneiss (Zgo)]. Within this gneiss scattered enclaves occurs of the Giyani Group (Zy) consisting of amphibolite, metaquartzite, magnetite quartzite and lesser of metapelite. In the east small enclaves consisting of metapyroxenite and serpentinite (Zym) occurs within the gneiss. North of major northeast-striking fault zones, the Central Zone of the Limpopo Belt occurs. It is represented by the supercrustal rocks of the Beit Bridge Complex that is divided into the [Mount Dove Group (Zbo), Malaya Drift Group (Zba) and Gumbu Group (Zbg)]. The sequence was intruded by anorthosite and metaleucogabbro of the Messina Suite (Zbm), the resistant metasyenite of the Madiapala Syenite (Zma), and the various varieties of the Sand River Gneiss (Zsa) i.e. the grey biotite–bearing gneisses of the Alldays Gneiss (Zal) and the large batholithic intrusion of predominantly porphyroblastic gneiss of the Bulai Gneiss (Rbu).

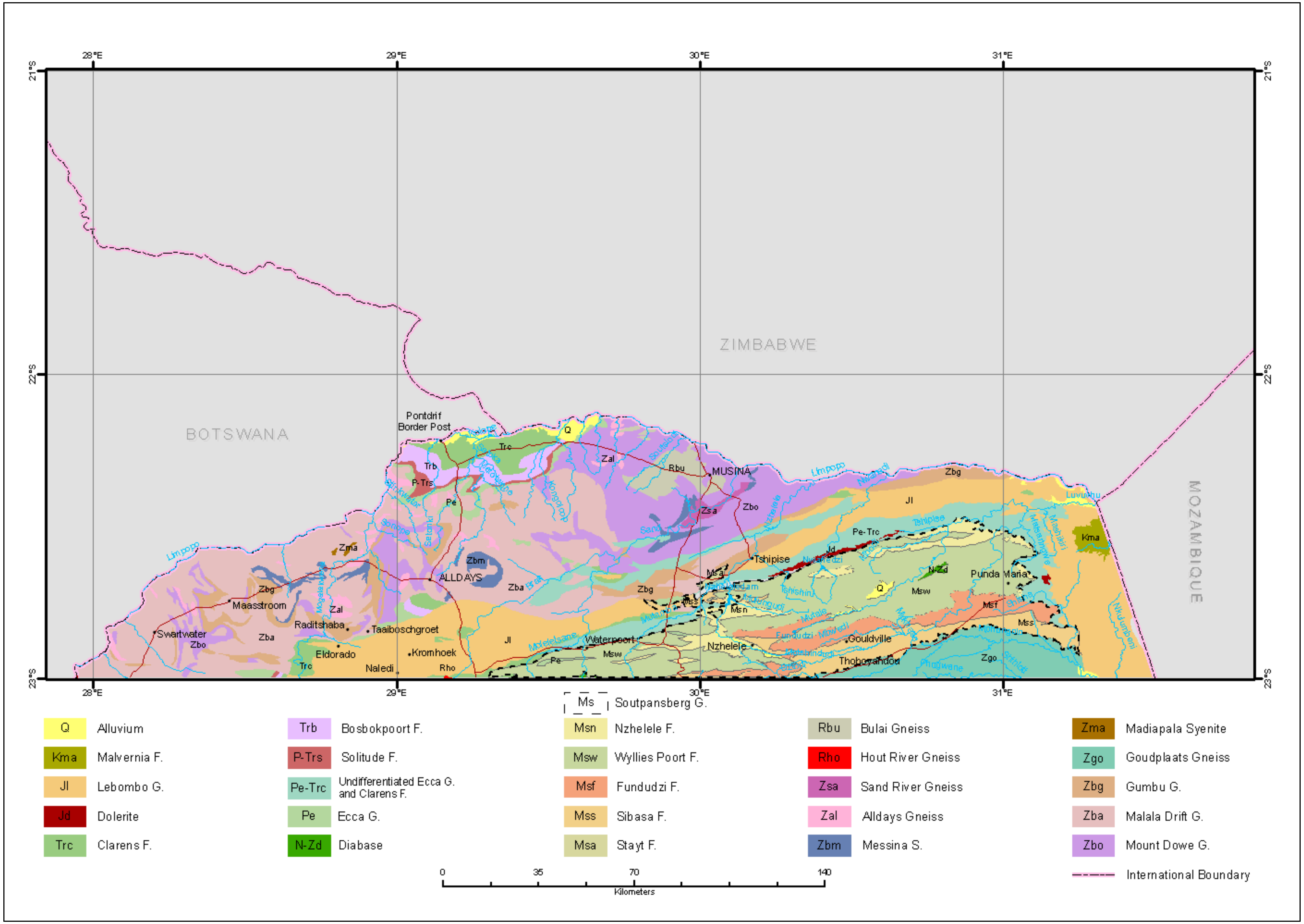

Figure 6: Simplified regional geology of the map area.

Soutpansberg Group

The Soutpansberg Group (Ms), named after the Soutpansberg Mountain range, underlie mountainous terrain that ranges from Vivo in the east towards the border of the Kruger National Park in the west. It is a volcanic sedimentary succession with a total thickness of approximately 12km deposited in an elongated fault bounded depression which developed by rifting along a major zone of weakness between the central and southern marginal zones of the Limpopo Mobile Belt (Jansen, 1975). Various fault zones varying in geological age transect the area in two prominent directions namely east to west and north to south. The Group is divided into several Formations of which five are depicted on the map sheet. It includes the **Sibasa Formation (Mss)** unconformable overlaying basement gneisses with an estimated maximum thickness of 3300m and consisting mainly of volcanic material and thin intercalations of arenaceous sediments. The poorly exposed **Fundudzi Formation (Msf)** with a maximum thickness of 2800m consists mainly of sandstone with interbedded siltstone, sandy shale, shale and intercalated bands of lava. The **Wyllie's Poort Formation (Msw)** usually occupying high ground and has a maximum thickness of 4000m in the Thengwe and Ha-Makuya areas. This Formation consists mainly of arenaceous rocks comprising two main varieties namely purple or reddish sandstone and a pink to white quartzite or quartzitic sandstone. The **Stayt Formation (Msa)** has a maximum thickness of approximately 1800m consisting of a lower basaltic lava overlaid by argillaceous rock predominantly shale interbedded with siltstones and sandstone with the top of the formation predominantly quartzite. The **Nzhelele Formation (Msn)** consists of a volcanic assemblage at the base followed by argillaceous and arenaceous sediments. The Tshifhefhe Formation at the base of the Soutpansberg Group and the Mabiligwe Formation that occurs as an isolated succession of sediments near the Mabiligwe village, is not indicated on the map sheet as it is insignificant regarding the occurrence of groundwater.

Diabase dykes and sills

Diabase (N-Zd) dykes and sills occur in almost all the pre-Karoo formations in the area. Sills within the Beit Bridge gneisses are mainly concentrated around Venetia Mine. Sills within the Soutpansberg Group are common where it preferably intruded contacts between the argillaceous and arenaceous rocks or the interface between lava and sediments. Dykes and sills within the Soutpansberg Group tend to form low laying areas while forming high, narrow ridges in the older granitoid rocks. Dykes are more common in the Soutpansberg Supergroup and Goudplaats Gneiss than in the Beit Bridge Gneisses.

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 consists of a variety of sediments that reflects the environmental changes during the mitigation of the Gondwana continent over a period of 200 million years from polar to lower latitudes. Sedimentation was terminated by the outpouring of basaltic magma associated with the final breakup of the Gondwana continent (Brandl, 2002). The Supergroup is divided in a few geographical areas with three well defined areas within the map sheet. In the first area occurring south of the Limpopo River in the Pontdrif area, is the east/west-trending fault bounded **Tuli basin** with a preserved width of 80km. The area is characterized by slightly irregular plains to extremely irregular plains, almost hilly in the north (Figure 4). The second area located between the Soutpansberg and the Tshipise fault in the north, is defined as the northeast trending **Tshipise basin** characterized by lowlands with hills. Minor outliers consisting of the older formations occur in down-faulted blocks between these two basins. The north/south-trending **Lebombo basin** which links up with the latter two basins, is underlain by rocks of the Lebombo Group (Jl) characterized by plains grading into more hilly landscape to the north. The Lebombo Group that presents the final magmatic phase is divided into two formations within the map area with the Letaba Basalt Formation being the dominant one. The youngest formation of the Karoo Supergroup, the Jozini rhyolite Formation occurs only on the eastern edge of this basin along the border with Mozambique.

Dolerite dykes and sills

The outpouring of Karoo lava was closely followed by the intrusion of numerous dolerite (Jd) dykes and sills which accompanied the fragmentation of Gondwana (Brandl, 2002). Within the argillaceous sediments in the lower part of the Karoo Supergroup thick concordant sheets (up to 200m) occur. North-northwest-trending dykes are developed in the north-eastern portion of the map area while dolerite dykes in the rest of the map area show no preferable orientation.

Cretaceous

The Malvernia Formation (Kma) is believed to be of Cretaceous age as similar lithologies in Mozambique pass laterally in a coast-wise direction into fossiliferous, marine upper Cretaceous sediments (Haughton, 1969). It lies discordant on the lavas of the Karoo Supergroup along the eastern boundary of Kruger National Park. In places it has been deposited in ravines and narrow valleys cut deep into the underlying lavas (Venter, 1990). It dips moderately to the east with a maximum depth of about 80m (Schutte, 1986). It comprises a succession of conglomerate, sandstone, merril and limestone.

Quaternary

Quaternary deposits depicted on the map are limited to alluvium (Q) along rivers and palaeo flood channels. Alluvial deposits are found along most of the major rivers and vary in thickness from a few centimetres up to as much as 45m along the Levhuvu River. Extensive deposits occur along the Limpopo (Weipe area) where large scale abstraction from the alluvial aquifer is taking place for agriculture and mining purposes. The alluvium generally comprises alternating layers of clay and poor to well-sorted and gravel deposits.

5.2 Structural geology

Dykes:

The south-eastern area of the map sheet underlain by basement gneisses is characterised by the occurrence of numerous diabase dykes with a predominant north-easterly strike. The presence of these dykes is usually indicated by boulders forming small ridges and spherical weathering patterns in road cuttings. In the search for high yielding boreholes these dykes and contacts with the host rocks are generally regarded as poor targets.

Fewer lineaments occur in the area of the map underlain by rocks of the Beit Bridge Complex (Figure 7). The presence of these lineaments is mostly concluded from the interpretation of remote sensing data as the area is covered by overburden. These lineaments are predominantly striking north-easterly and to a lesser extend east, north and north-westwards. Work done in the Swartwater and Beauty areas identified these lineaments as granophyre-, amphibolite-, diabase-, and dolerite dykes and also fault and/or shear zones. Dominant strike directions in the Swartwater area are northeast/southwest and east/west in the Beauty area (Bush, 1989).

In the Swartwater area linear features such as dolerite and diabase dykes do not possess good hydrogeological properties for groundwater development and should rather be avoided as drilling targets. It was found that dyke/host rock contacts are usually devoid of fracturing or that those fractures which occur at the contact or within the dyke itself are in filled with calcareous or other deposits. In the Swartwater area it is concluded that zones of fracturing, shearing or faulting form favourable target zones for groundwater exploration in regions where rest water levels do not exceed 35m. At depths greater than this the probability of intersecting open cracks and fissures is reduced despite the fact that jointing/fracturing usually extends to these levels. In some cases boreholes drilled in favourable areas had poor results due to the infilling of fractures. There is no evidence of any favourable fracturing, jointing or weathering occurring at the contacts between any of the lithological rock types in the Swartwater area. There is also no evidence of such features occurring within gneissic banding. All contacts were found to be welded or transitional in nature, a consequence of metamorphism (Bush, 1989).

In the area underlain by rocks of the Soutpansberg Supergroup diabase dykes occur mainly in the upper formations of the Supergroup in an area bounded approximately by the Klein Tshipise Fault in the north, the Mufungudi Fault in the southwest, the Thengwe Fault in the south and the Lavhurala Fault in the southeast. The strike length of these dykes is extensive, the trend being mainly east-northeast and to a lesser extends west-northwest and north-northwest.

The diabase intrusions generally predate the main period of faulting. South of the Klein Tshipise Fault a few northeast-trending diorite dykes occurs (Brandl 1981).

Rocks of the Karoo Supergroup are underlying three geographical areas within the map area with minor outliers consisting of the older formations occurring in down-faulted blocks between the Tuli and Tshipise basins. Dolerite dykes are most prominent in the Tuli basin striking easterly to north-north-easterly with minor north to north-westerly trends. Within the Tshipise basin dolerite dykes are less developed with no predominant strike. In the vicinity of the Taaibos Fault, exploration drilling into and adjacent to dolerite dykes produced disappointing borehole yields with no conclusive results obtained (Fayazi & Orpen, 1989). In the north-eastern part of the Lebombo basin the dolerite dykes trend north-northwest

Faults and shear zones

In the south-eastern sector of the map sheet (Figure 7) geological lineaments are predominantly related to dyke intrusions. Minor faults occur within the area but these are confined to a zone around the contact between the Gneiss and the Sibasa Formation. The faults are trending northerly with almost 2/3 of the strike length within the basalt and 1/3 within the gneiss. Minor shear zones occur within the gneiss dominated by a north-eastern strike and a minor southern strike with both trends having a limited extend.

The regional grain of the north-western part of the map underlain by rocks of the Beit Bridge Complex is defined by large-scale north-trending folds and large closed structures. Geological lineaments occurring in the area underlain by these rocks were predominantly concluded from the interpretation of remote sensing data and are believed to be mostly related to dyke intrusions. Regionally the trends are predominantly north-easterly and easterly and to a lesser extend southerly.

A number of brittle shear zones are developed in the map area trending east-northeast or easterly. They are generally normal faults with a downthrown to the south. The **most prominent faults are the Bosbokpoort, Tshipise, and Voorburg faults** with estimated vertical displacement of approximately 500m. The Bosbokpoort fault was investigated near Sigonde village for water supply. The fault was drilled without finding any water. The fault will be investigated further by DWA. The Tshipise fault was successfully drilled for water supply for various villages (Lubbe, personal communications, 2009). The **Senotwane fault**, just north of the Blouberg, in contrast with the above mentioned fault zones, have a northerly downthrow. The displacement is approximately 1500m in the west decreasing to approximately 600m near Soutpan 459MS and disappearing within the Karoo sediments further east. Near Musina the **Dowe-Tokwe fault and the Messina fault** are strike-slip shear zones with a right-lateral displacement. Displacement by the Dowe-Tokwe fault at Schoonoord 230MS is approximately 1800m as seen in the displacement of a prominent north trending magnetite quartzite outcrop. The near vertical fault zone interpreted as a strike-slip shear forms a 200m wide breccia zone in the Limpopo River on Eersteling 138MR (Brandl, 2002). The country rock adjacent to the Dowe-Tokwe fault is referred to as a grey granitic-gneiss. The fault itself is commonly evident on the surface and recognized by the occurrence of brecciated, epidotisation and chloritic gneiss, quartz and epidote. Within the fault various coloured feldspathic quartzite, hydrothermal quartz, epidote and pyrite are typical. The fault is commonly intruded by amphibolite and dolerite and in places by younger granites (Fayazi & Orpen, 1983).

Within the Soutpansberg Group, fault zones occur more frequently. Two intersecting fault systems are described. The first is trending east-northeast, is parallel to the regional strike, is delineating major horst-and-graben structures, and responsible for the frequent structural repetition of the Soutpansberg Formations. The **Klein Tshipise fault** is a typical example. The second fault system is oblique to the regional strike and has faults trending west-northwest to northwest. The most prominent fault of this system is the **Siloam fault** with an estimated vertical displacement of 1500m (Brandl, 1981). Within the Tshipise basin intense block-faulting caused the development of a series of stepped half-grabens resulting in the repeatedly occurring narrow strips of Karoo rocks.

The northeast-trending **Taaibos fault** is an important regional aquifer for rural villages up to and including Alldays. Exploration drilling on the farms Ysselmonde 322MR, Rhone 321MR and Greenfield 333MS showed that it appears to be a normal fault with a dip of 70 – 80^{o} towards the southeast. Further eastwards the fault looses its clear definition as it becomes assimilated into a wide shear zone on the farms Gansvley 335MS and Presumption 337MS. The fault also changes direction in a wide curve and eventually narrows again into the **Vetfontein fault** where it strikes northwest to southeast. The western part of the shear zone coincides with a major groundwater divide and appears to be an area unfavourable for the occurrence of groundwater. A number of lineaments in the basalt converge on the Taaibos fault at an angle of about 45º suggesting that their occurrence is related to the lateral displacement of the fault. These lineaments are clearly discernible on aerial photographs as linear concentrations of dense vegetation. As these lineaments approach the fault a 200 to 250m wide zone south of the fault and within the basalt appears to contain a dense network of fractures creating favourable conditions for the occurrence of groundwater. A number of high-yielding boreholes have been drilled into this zone. The groundwater flow along the Taaibos fault takes place in both an easterly and westerly direction and the dividing point is situated on the farm Rhone 321MR. The **Dzundwini fault**, an east-west-striking fault within the Soutpansberg Supergroup was investigated for water supply. A single borehole with a yield of 15*l/s* was drilled in this fault. This water was, however, very brackish and could not be used (Burger, 1949).

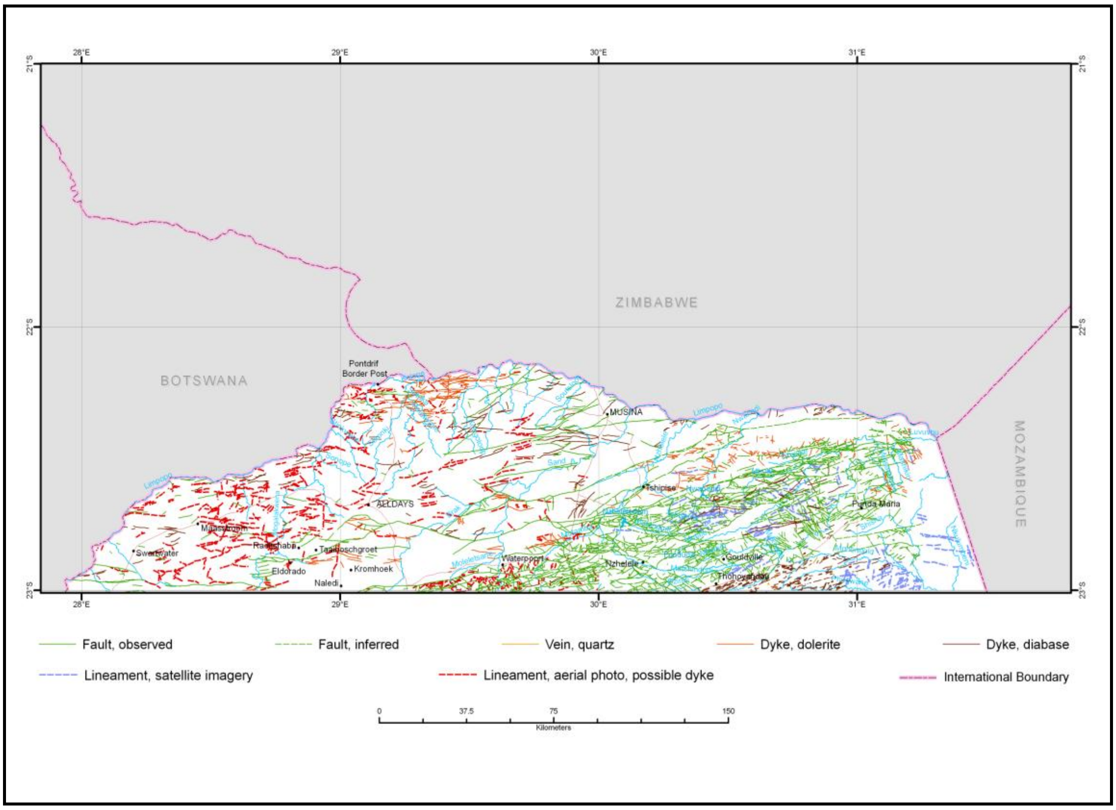

Figure 7: Inferred and observed geological lineaments.

6 GENERAL HYDROCHEMISTRY

The chemical composition of groundwater reflects the result of chemical, physical, and biological processes such as weathering, dissolution, evaporation, evapotranspiration, ion exchange and organic decomposition along the path (movement and time) from rainwater through various media (various soils and rock types) to the aquifer. The processes occur in the unsaturated and saturated zone with nature trying to establish chemical and biological equilibrium. As with surface water, anthropogenic activities are increasingly influencing the natural groundwater on a small to regional scale predominantly leading to a decrease in water quality.

In order to characterise and compare the chemical composition of groundwater in the various rock formations complete chemical analysis of 2263 groundwater samples taken during the period from 1968 to 2008 were used. These were chosen from a total of 4139 available analysis. The balance of groundwater samples was mostly due to incomplete analysis. The harmonic mean was calculated using multiple samples taken at the same sampling point over time which further reduced the total samples used for the report.

The accuracy of the chemical analysis was further checked by the plausibility of the electrical conductivity (EC) and the electro neutrality (E.N) of the chemical analysis. The calculation used for the EC is [∑anions (meq/L) = ∑cations (meq/L)] = EC/100(µS/cm) and for electro neutrality 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. Most of the units are a combination of two or more of the major types dominated by a combination of calcium-magnesium-bicarbonate, sodium-bicarbonate and chloride water. Detailed hydrochemical classification of the individual units is undertaken in chapter 7. Six of the hydrogeological units display slightly elevated sulphate concentrations namely Tertiary-quaternary alluvial deposits (Q), the Bosbokpoort Formation (Trb), Solitude Formation (P-Trs), Bulai Gneiss (Rbu), Alldays Gneiss (Zal) and Gumbu Group (Zgo).

- **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 the Tertiary-quaternary alluvial deposits (Q), Ecca Group (Pe), Nzhelele Formation (Msn), Wyllies Poort and Fundudzi Formation (Msf) and the Bulai Gneiss (Rbu) show a tendency to this water type.

- **Sodium bicarbonate water**

This water type is predominantly present in the geological units of the study area. It was encountered in the Lebombo Group (Jl), Ecca Group (Pe), Dolerite (Jd), Diabase (N-Zd), Solitude- (P-Trs) and Clarens Formations (Trc), Alldays Gneiss (Zal), Goudplaats Gneiss (Zgo), Gumbu Group (Zbg), Malala Drift Group (Zba) and Mount Dowe Group (Zbo). 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^-.

•Sulphate water

SO_4^{2-} and Ca^{2+} or Mg^{2+} and occasionally Na^+ dominate this type of water. No SO_4^{2-} type of water was characterized in this study area.

•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 Tertiary-quaternary alluvial deposits (Q), Bosbokpoort (Trb), Undifferentiated Ecca Group and Clarens formation (Pe-Trc), Ecca Group (Pe), Clarens Formation (Trc), Diabase (N-Zd), Nzhelele Formation (Msn), Wyllies Poort and Fundudzi Formation (Msf), Bulai Gneiss (Rbu), Alldays Gneiss (Zal), Messina Suite (Zbm), Goudplaats Gneiss (Zgo), Gumbu Group (Zbg), Malala Drift Group (Zba), Mount Dowe Group (Zbo). A predominance of Na^+ and Cl^- indicates an end point of discharge or stagnation of water.

For an overall picture various chemical elements were plotted on the same map. The first observation is that in certain units single sampling points with poor chemistry are distributed randomly while in other units these points are in close proximity to each other. The clusters with poor chemistry could be attributed to geological features and/or possible anthropologic activities. Further investigations should be carried out if there is reason to believe that the cause may be anthropologic. A second observation is that the problematic sample points usually have more than one chemical element falling outside the acceptable water class.

Table 5 provides some guidelines on the suitability of water quality based on electrical conductivity (EC) measurements for domestic, livestock and irrigation purposes (DWA, 1996). Figure 8 gives an overview of the area for EC values, nitrate and fluoride concentrations. The ranges in Tables 6-9 is as per SANS 241:2005 specification.

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

ELECTRICAL CONDUCTIVITY RANGE (mS/m)	SUITABILITY		
	DOMESTIC	LIVESTOCK	IRRIGATION
<70	Suitable	Suitable	Suitable
70 - 150	Suitable - slightly salty taste	Suitable	Suitable - salt sensitive crops may show a 10% decrease in yield. Wetting of foliage should be prevented
150 - 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

6.1 Aquifer Hydrochemistry

Data obtained from various sources, but predominantly from the National Water Quality Database (WMS), was utilised for hydrochemical data analysis and interpretation. The data points representing the chosen chemical analysis were plotted on a base map showing the surface occurrence of the aquifer units. These points were sorted accordingly to these units. The hydrochemical results calculated to represent a single harmonic mean value for the major parameters are summarized for each aquifer unit in Table 6. In Table 7-9 these values for various parameters are grouped into three domestic water classes (ideal, acceptable and maximum allowed) according to the South African National Standards for domestic water use (SANS 241, 2005) document. Further in the document under the discussion for each unit, the hydrochemistry are presented as a stiff diagram showing the major anions and cations.

Six of the units did not have any chemistry data available for analysis. They are the Malvernia Formation (Kma), Lebombo Group (Jl) (fractured aquifers), Stayt Formation (Msa), Hout River Gneiss (Rho), Madiapala Syenite (Zma) and Sand River Gneiss (Zsa). Where the concentration displayed in Table 6 exceeds the maximum allowed limit (SANS 241, 2005), they are displayed in bold red.

Table 6: Harmonic mean of various chemical parameters from each unit of the Messina map sheet.

Symbol	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 241:2005 Class 2. (Max. allowable for limited duration) (mg/l) except pH										
					4-10	370	20	1.5		400	100	600	600	100	300
Category A: Intergranular aquifers															
Q	96	165	157	92	8.2	60.6	0.08	0.27	96.5	37.9	19.0	13.9	40.7	1.5	19.9
Category B: Fractured aquifers															
Kma	No data														
Jl	No data														
Trb	2	2	2	2	7.5	**474.1**	2.8	**1.5**	761.8	**838.9**	81.7	294.0	**886.9**	12.9	38.9
P-Trs	1	1	1	1	8.3	97.8	5.6	0.87	455	113.9	48.3	103.2	21.5	6.4	61.3
Pe Trc	144	229	219	138	8.0	128.4	0.11	0.47	135.7	122.1	11.1	23.5	144.9	3.1	22.2
Pe	57	108	102	56	8.0	106.4	0.44	0.51	374.6	105.4	37.9	10.2	75.9	1.5	36.9
Msn	116	205	188	108	7.9	69.0	0.25	0.31	190	45.3	29.1	11.5	56.4	0.69	31.2
Msw	310	484	413	270	7.5	18.7	0.17	0.15	30.6	12.0	4.5	4.2	16.1	0.57	5.8
Msf	149	271	234	135	7.7	22.8	0.19	0.14	57.7	12.3	8.8	3.5	12.6	0.39	11.5
Category C: Intergranular and fractured aquifers															
Jl	429	744	656	395	8.2	86.1	0.41	0.42	193.2	70.5	9.02	8.1	62.3	1.5	24.7
Jd	18	27	22	15	8.0	70.9	0.17	0.29	147.3	62.9	22.9	21.0	86.2	2.7	26.5
Trc	85	114	113	84	7.9	90.0	0.15	0.42	159.5	68.2	9.06	9.9	82.5	2.0	33.1
N-Zd	6	8	8	6	7.6	51.6	010	0.39	156.8	46.3	20.9	9.6	43.7	0.62	24.3
Mss	282	455	407	242	7.9	34.8	0.27	0.17	113.8	14.8	9.1	4.1	15.8	0.32	17.4
Msa	No data														
Rbu	33	88	67	29	7.9	151.5	0.42	1.1	310.7	130.5	63.5	64.3	156.4	3.3	47.0
Rho	No data														
Zal	18	25	24	17	7.9	136.4	0.58	1.4	228.1	128.7	11.9	26.04	82.9	1.9	71.7
Zbm	6	6	4	4	7.6	165.6	0.16	1.0	109.9	116.5	41.3	30.3	156.9	1.9	102.9
Zma	No data														
Zsa	No data														
Zgo	221	443	376	196	8.0	70.8	0.23	0.31	244.4	42.7	28.5	7.7	34.0	0.9	41.3
Zbg	63	87	82	59	7.8	155.9	1.3	0.56	428.2	118.4	46.0	32.9	104.4	3.8	55.6
Zba	321	538	476	293	7.9	88.5	0.81	0.8	266.6	98.1	15.6	18.7	76.9	2.6	60.8
Zbo	126	136	129	120	7.8	130.6	0.68	0.87	146.7	105.2	53.5	35.7	92.8	3.6	54.6
Total	2484	4138	3682	2263											

Table 7: Percentage samples in each unit classed for domestic use for chloride, nitrate and sulphate concentrations.

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	92	51.1%	13.0%	21.7%	14.1%	85.7%	6.6%	5.5%	2.2%	37.0%	31.5%	13.0%	18.5%
Category B: Fractured aquifers													
Jd	1	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Trb	2	0.0%	0.0%	0.0%	100.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
P-Trs	1	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Pe Trc	138	16.7%	27.5%	31.2%	24.6%	65.6%	10.4%	9.6%	14.4%	87.0%	5.8%	2.2%	5.1%
Pe	56	60.7%	12.5%	23.2%	3.6%	53.6%	21.4%	23.2%	1.8%	98.2%	1.8%	0.0%	0.0%
Msn	108	43.5%	16.7%	24.1%	15.7%	63.1%	8.7%	12.6%	15.5%	100.0%	0.0%	0.0%	0.0%
Msw	270	85.6%	6.7%	5.6%	2.2%	91.1%	3.5%	2.7%	2.7%	99.2%	0.8%	0.0%	0.0%
Msf	135	85.2%	5.2%	8.9%	0.7%	85.4%	7.7%	4.6%	2.3%	100.0%	0.0%	0.0%	0.0%
Category C: Intergranular and Fractured aquifers													
Jl	395	59.8%	24.6%	11.1%	4.6%	39.4%	16.4%	25.1%	19.2%	98.2%	1.0%	0.5%	0.3%
Jd	15	46.7%	33.3%	13.3%	6.7%	78.6%	7.1%	0.0%	14.3%	100.0%	0.0%	0.0%	0.0%
Trc	84	42.9%	21.4%	22.6%	13.1%	59.0%	9.6%	14.5%	16.9%	92.9%	3.6%	3.6%	0.0%
N-Zd	6	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Mss	242	96.3%	2.5%	0.4%	0.83%	69.1%	12.3%	14.8%	3.8%	100.0%	0.0%	0.0%	0.0%
Rbu	29	10.3%	48.3%	24.1%	17.2%	24.1%	17.2%	37.9%	20.7%	72.4%	13.8%	3.5%	10.3%
Zal	17	47.1%	29.4%	11.8%	11.8%	41.2%	11.8%	29.4%	17.7%	88.2%	0.0%	0.0%	11.8%
Zbm	4	25.0%	25.0%	25.0%	25.0%	25.0%	0.0%	25.0%	50.0%	75.0%	0.0%	25.0%	0.0%
Zgo	197	77.2%	15.7%	6.1%	1.0%	56.9%	12.2%	12.8%	18.1%	99.5%	0.0%	0.0%	0.5%
Zbg	59	39.0%	17.0%	22.0%	22.0%	27.6%	24.1%	19.0%	29.3%	83.1%	10.2%	1.7%	5.1%
Zba	293	47.4%	27.7%	21.5%	3.4%	28.3%	22.5%	19.5%	29.7%	91.5%	3.1%	3.8%	1.7%
Zbo	120	36.7%	27.5%	29.2%	6.7%	23.3%	25.8%	24.2%	26.7%	84.2%	10.0%	4.2%	1.7%

Table 8: Percentage samples in each unit classed for domestic use for calcium, potassium, magnesium and sodium concentrations.

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	92	70.7%	17.4%	10.9%	1.1%	98.9%	1.1%	0.0%	0.0%	37.0%	31.5%	13.0%	18.5%	63.0%	14.1%	14.1%	8.7%
Category B: Fractured aquifers																	
Jd	1	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Trb	2	50.0%	50.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	50.0%	0.0%	50.0%	0.0%	0.0%	0.0%	100.0%
P-Trs	1	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Pe Trc	138	73.9%	17.4%	3.6%	5.1%	95.6%	2.9%	1.5%	0.0%	18.8%	34.1%	21.0%	26.1%	30.4%	23.9%	17.4%	28.3%
Pe	56	89.3%	7.1%	3.6%	0.0%	100.0%	0.0%	0.0%	0.0%	17.9%	62.5%	14.3%	5.4%	44.6%	33.9%	16.1%	5.4%
Msn	108	59.8%	31.8%	8.4%	0.0%	100.0%	0.0%	0.0%	0.0%	26.2%	34.6%	20.6%	18.7%	50.9%	25.0%	16.7%	7.4%
Msw	270	94.4%	4.5%	1.1%	0.0%	99.6%	0.4%	0.0%	0.0%	79.6%	14.4%	2.6%	3.3%	88.5%	7.8%	2.2%	1.5%
Msf	135	91.9%	6.7%	1.5%	0.0%	100.0%	0.0%	0.0%	0.0%	73.3%	20.7%	4.4%	1.5%	91.9%	6.7%	0.7%	0.7%
Category C: Intergranular and Fractured aquifers																	
Jl	395	88.6%	8.9%	2.3%	0.3%	99.2%	0.5%	0.0%	0.3%	31.1%	40.5%	18.5%	9.9%	54.6%	33.0%	7.1%	5.3%
Jd	15	80.0%	13.3%	6.7%	0.0%	100.0%	0.0%	0.0%	0.0%	46.7%	26.7%	6.7%	20.0%	73.3%	26.7%	0.0%	0.0%
Trc	84	77.4%	16.7%	2.4%	3.6%	100.0%	0.0%	0.0%	0.0%	32.1%	50.0%	9.5%	8.3%	48.8%	23.8%	15.5%	11.9%
N-Zd	6	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	50.0%	50.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Mss	242	93.4%	6.2%	0.4%	0.0%	100.0%	0.0%	0.0%	0.0%	58.3%	38%	2.5%	1.2%	98.4%	1.2%	0.0%	0.4%
Rbu	29	65.5%	20.7%	6.9%	6.9%	96.6%	3.5%	0.0%	0.0%	6.9%	44.8%	31.0%	17.2%	20.7%	55.2%	6.9%	17.2%
Zal	17	70.6%	17.7%	0.0%	11.8%	100.0%	0.0%	0.0%	0.0%	5.9%	64.7%	17.7%	11.8%	23.5%	64.7%	0.0%	11.8%
Zbm	4	25.0%	50.0%	25.0%	0.0%	100.0%	0.0%	0.0%	0.0%	25.0%	25.0%	25.0%	25.0%	25.0%	0.0%	75.0%	0.0%
Zgo	197	81.2%	16.2%	2.5%	0.0%	100.0%	0.0%	0.0%	0.0%	27.9%	62.9%	6.1%	3.1%	76.7%	20.3%	3.1%	0.0%
Zbg	59	59.3%	28.8%	8.5%	3.4%	91.5%	6.8%	1.7%	0.0%	6.8%	40.7%	13.6%	39.0%	30.5%	37.3%	13.6%	18.6%
Zba	293	67.2%	27.3%	3.8%	1.7%	97.6%	2.4%	0.0%	0.0%	10.2%	57.0%	21.5%	11.3%	41.3%	42.7%	13.0%	3.1%
Zbo	120	75.0%	19.2%	5.8%	0.0%	95.8%	4.2%	0.0%	0.0%	9.2%	43.3%	25.0%	22.5%	30.8%	37.5%	21.7%	10.0%

Table 9: Percentage samples in each unit classed for domestic use for Electrical Conductivity (EC), pH and fluoride concentration.

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	0.7	1	1.5	>1.5
Category A: Intergranular aquifers													
Q	92	35.9%	32.6%	25.0%	6.5%	0.00%	100.00%	0.00%	0.00%	81.5%	5.4%	5.4%	7.6%
Category B: Fractured aquifers													
Jd	1	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%
Trb	2	0.0%	0.0%	0.0%	100.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	50.0%	50.0%
P-Trs	1	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%
Pe Trc	138	8.7%	35.5%	33.3%	22.5%	0.7%	98.5%	0.7%	0.0%	54.0%	12.7%	23.0%	10.3%
Pe	56	0.0%	67.9%	28.6%	3.6%	0.0%	100.0%	0.0%	0.0%	66.7%	11.1%	14.8%	7.4%
Msn	108	29.0%	29.9%	31.8%	9.4%	0.0%	100.0%	0.0%	0.0%	83.0%	6.0%	6.0%	5.0%
Msw	270	81.5%	11.5%	6.3%	0.74%	1.9%	98.0%	0.8%	0.0%	92.4%	1.6%	4.4%	1.6%
Msf	135	78.5%	13.3%	8.2%	0.0%	0.0%	100.0%	0.0%	0.0%	98.3%	0.9%	0.0%	0.9%
Category C: Intergranular and Fractured aquifers													
Jl	395	20.3%	60.0%	17.5%	2.3%	0.0%	95.9%	3.8%	0.3%	65.6%	17.2%	14.0%	3.2%
Jd	15	40.0%	33.3%	26.7%	0.0%	0.0%	100.0%	0.0%	0.0%	92.3%	7.7%	0.0%	0.0%
Trc	84	26.2%	41.7%	25.0%	7.1%	1.2%	98.8%	0.0%	0.0%	55.0%	18.8%	13.8%	12.5%
N-Zd	6	50.0%	50.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%
Mss	242	78.9%	18.6%	2.1%	0.4%	0.4%	98.0%	1.3%	0.4%	100%	0.0%	0.0%	0.0%
Rbu	29	3.5%	51.7%	27.6%	17.2%	0.0%	100.0%	0.0%	0.0%	10.3%	10.3%	41.4%	37.9%
Zal	17	0.0%	70.6%	17.6%	11.8%	0.0%	100.0%	0.0%	0.0%	5.9%	35.3%	5.9%	52.9%
Zbm	4	0.0%	25.0%	75.0%	0.0%	0.0%	100.0%	0.0%	0.0%	25.0%	25.0%	0.0%	50.0%
Zgo	197	34.5%	55.3%	10.2%	0.0%	0.0%	100.0%	0.0%	0.0%	87.5%	4.2%	7.7%	0.6%
Zbg	59	1.7%	50.9%	28.8%	18.6%	0.0%	100.0%	0.0%	0.0%	39.0%	17.0%	18.6%	25.4%
Zba	293	4.4%	63.5%	29.4%	2.7%	0.3%	99.6%	1.0%	1.0%	27.1%	24.0%	26.0%	23.0%
Zbo	120	5.0%	50.8%	39.2%	5.0%	0.8%	99.2%	0.0%	0.0%	20.8%	21.7%	25.0%	32.5%

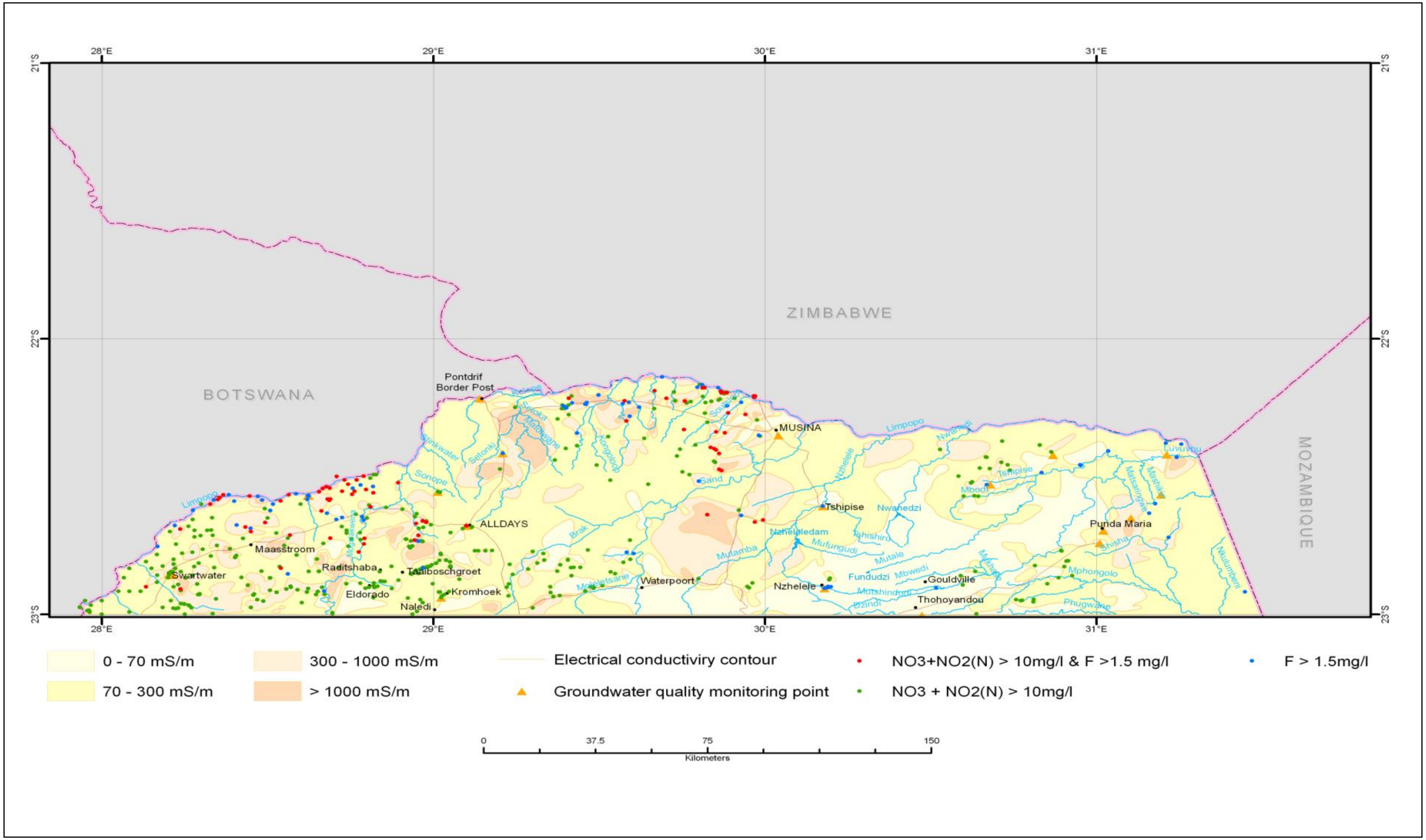

Figure 8: Electrical conductivity, (EC) with points representing boreholes with nitrate and fluoride values exceeding the acceptable levels for human consumption (DWA 1996).

7 CHARACTERISTICS AND DESCRIPTION OF THE HYDROGEOLOGICAL UNITS.

In this chapter the characteristics of the various geohydrological units are briefly described in terms of its geographical location, lithology, general use, quality, quantity, results of previous research and its importance as a groundwater resource. Available data for each unit were statistically analysed and presented in a pre-described format as required for the hydrogeological map series. For yield data, the results are presented as borehole yield frequency diagrams and for the hydrochemistry as stiff diagrams. Table 10 summarize statistics for each unit obtained from the yield frequency diagrams with yield frequency expressed as a percentage.

Table 10: Statistical summary of the Messina Map obtained from the yield frequency diagrams.

Aquifer Unit	Unit extent as % of map area	Total number dry boreholes	Total number wet boreholes	% dry boreholes	Yield Groupings				
					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	1.4%	5	63	7%	10%	11%	24%	19%	37%
Category B: Fractured aquifers									
Kma	0.48%	2	2	50%	50%	50%	0%	0%	0%
Jl									
Trb	1.52%	0	76	0%	36%	24%	24%	17%	0%
P-Trs	0.45%	0	17	0%	18%	35%	29%	18%	0%
Pe Trc	6.92%	36	231	13%	12%	17%	32%	20%	20%
Pe	1.55%	5	79	6%	11%	18%	32%	18%	22%
Msn	2.22%	31	135	19%	5%	14%	36%	31%	14%
Msw	12.2%	91	398	19%	7%	27%	31%	19%	18%
Msf	2.88%	25	193	11%	6%	12%	42%	27%	13%
Category D: Intergranular and Fractured aquifers									
Jl	16.1%	56	645	8%	6%	17%	30%	23%	24%
Jd	0.35%	11	27	29%	11%	4%	19%	26%	41%
Trc	3.01%	3	174	2%	10%	24%	30%	18%	18%
N-Zd	008%	3	3	50%	0%	33%	33%	0%	33%
Mss	3.61%	43	293	13%	5%	20%	36%	23%	16%
Msa	0.11%	4	11	27%	9%	27%	27%	27%	9%
Rbu	1.42%	16	42	28%	12%	17%	36%	21%	14%
Rho	0.001%	No data							
Zal	1.17%	8	66	11%	12%	29%	33%	15%	11%
Zbm	1.29%	1	79	1%	25%	38%	29%	5%	3%
Zma	0.04%	0	6	0%	50%	17%	33%	0%	0%
Zsa	0.36%	No data							
Zgo	4.22%	44	277	14%	8%	19%	35%	27%	10%
Zbg	4.63%	23	193	11%	11%	28%	36%	14%	10%
Zba	21.75%	60	1365	4%	13%	28%	36%	15%	9%
Zbo	12.15%	53	372	12%	13%	28%	33%	19%	7%
Total		522	4747						

7.1 PRIMARY AQUIFERS

Primary aquifers or unconfined aquifers, also known as water table aquifers are where the upper boundary of the aquifer is the static water table and equal to atmospheric pressure. The water level is therefore free to rise and fall. It consists of unconsolidated material with the volume of water released from storage per unit surface area of aquifer per unit decline of the water table known as the drainable pore space or Specific Yield of the aquifer. It is also known as effective porosity as water can only move through pores that are interconnected.

7.1.1 CATEGORY A: INTERGRANULAR AQUIFERS

7.1.1.1 Tertiary-quaternary alluvial deposits (Q)

Quaternary alluvial deposits of limited lateral extent and thickness occur along most river terraces in the map area. Major deposits depicted on the map include deposits along the Limpopo, Mutale, Levhuvu, Shisha and Nzhelele Rivers. The deposited material relates to the upstream regional geology and the sorting, grain size distribution and deposition is a function of the river flow. The intensity of flow in the rivers within the study area is only rapid during floods. During these times the dumping and re-working of river sediments is most active. The main river within the map area is the Limpopo River that forms the border between South Africa, Botswana and Zimbabwe in the northwest and north respectively. Deposits along this river include unconsolidated high-level gravels that are mainly confined to the reaches of the river. At some prominent exposures observed on the farm Eersteling 138 MR these gravels occur 15—50m above the present level of the river. Rounded to semi-rounded clasts are found within these deposits. Near the deposit depicted east of Pontdrif (Figure 9) on the farm Riedel 48, alluvial gravel occurs 5km south of the Limpopo River up to 50m above the current level of the river. Mining for alluvial diamonds revealed that the gravel deposit is up to 30m thick with well rounded clasts. Large areas flanking the major rivers are covered in thick, light grey to brownish, muddy to silty alluvium (Brandl 2002). The most extensive deposits occur along the Limpopo, Levhuvu and to a lesser extent along the Mogalakwena and Brak Rivers where it forms fertile soils.

As with most alluvial deposits along rivers, the success of obtaining a high yielding source depends on various factors including the depth, extent, material and sorting of the deposit as well as the flow regime of the river. Past exploration projects along major rivers such as the Limpopo highlighted the varying groundwater potential within alluvial deposits over relative short distances. It is therefore critical to investigate the depositary character of the river to obtain the best position for a sandpoint. Such points can be on the inner slower moving depositary side of a river bend or within horseshoe bends in matured rivers where alluvial deposits accumulated.

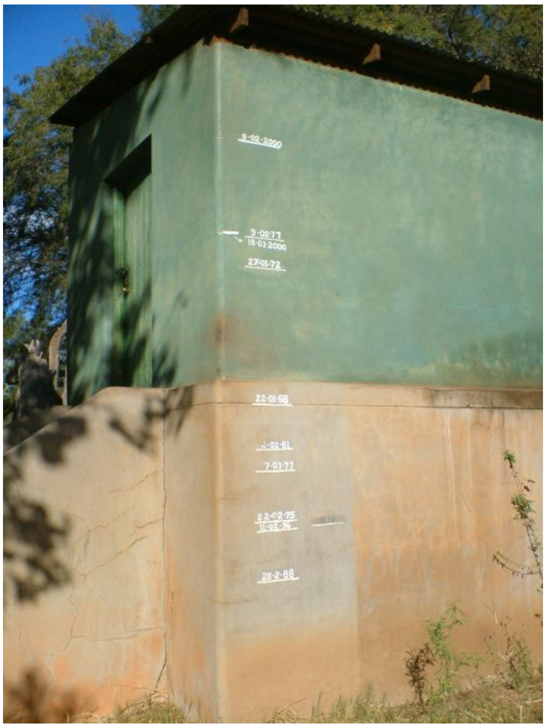

Plate 2: Sandpoint supplying the Pafuri Police Station and the Border Post with water. A thick alluvial deposit formed at the confluence of the Levhuvu and Limpopo River. During excessive rain the area is flooded. Flood markings in white from top are 9/2/2000, 9/2/77,18/01/2000, 27/01/1972, 22/01/1958, 1/02/1981, 7/3/1977, 22/2/1975, 11/02/1996, and 28/2/1988. (Photo, C.J.Sonnekus, 18/04/2008)

Plate 3: Boreholes in the Limpopo River supplying Beit Bridge border post. In the foreground is borehole H18-0699. Within a 100m radius two other production boreholes exists (H18-0690 and H18-0698). These boreholes are equipped with submersible pumps with the top of the casing approximately 1m below surface. The area is about 2km east of Beit Bridge with South Africa on the left and Zimbabwe on the right. 5 days after the photo was taken the river was in flood. (Photo, C.J. Sonnekus, 3/10/2010)

From about 3.5km downstream of Beit Bridge up to the confluence of the Sand River, the average width of the sand bed in the Limpopo River is 300m and the average thickness of water saturated sand is 3.5m. The specific yield is 24% by volume. The bedrock floor is extremely irregular with an average sand thickness of 4.5m. In the tributaries of the Limpopo River, such as the Sand River, the bedrock floor is more uniform in shape and considerably deeper up to 20m in places. Probing in the Sand River revealed numerous silt lenses. This was also found in other tributaries of the Limpopo like the Mogol River where the amount of silt increased markedly near the confluence with the Limpopo (Mulder, 1973).

In another study (Van der Westhuizen, 1983) using data from three investigations done over a 30 year period, including the work of (Mulder, 1973)) a 2km long section of the Limpopo River close to the Soutsloot-Limpopo confluence was investigated to assess the potential of available groundwater resources contained in the sandy riverbed with the following findings:

- The sand is coarse to very coarse grained and remarkably free of any silt.
- There is very little variation in composition of the sand with increasing depth.
- Full saturation (porosity) varied from 33.6 to 36% by volume.
- Specific retention (field capacity) varied little from 9.3 to 9.9%.
- Specific yield (effective porosity) ranged from 23.7% to 25.3% by volume, averaging 24% for all samples taken.

The geohydrological parameters and conditions reveal no significant changes over the 30 year period of investigation. The average thickness of the saturated sand is 3m and the average width of the sand bed is 300m with an extremely irregular bedrock rock floor. Porosity is calculated at a value of 30% by volume, for the alluvial aquifer.

Extensive irrigation from the alluvial aquifers along the Limpopo River occurs from the confluence of the Maloutsi River in the west up to the farm Overvlakte in the east. More than 60 million m^3/annum is abstracted along this reach of the river.

De Klerk and Wiegmans (1990) investigated an area east of the confluence of the Shashi and Limpopo Rivers on the farm Greefswald 37MS) to determine the thickness and base elevation of the aquifer and the presence of clay layers in the river bed. Using geophysical methods and contouring the resulting data, the aquifer was interpreted to be within a continuous deep channel with an average saturated thickness of 20m and width of about 100 metres. The aquifer consists of interlayered gravel, sand and clay horizons.

A study by Venter (1990) in the north-eastern section of the map revealed that most major rivers have alluvial deposits formed along the stream bed changing in thickness from a few centimetres up to 45m along the Levhuvu River.

Numerous hand dug wells are found within ephemeral stream beds, characterized by a sandy to gravel filled streambed with a shallow perched water level. These wells are seldom protected by concrete rings as in more formal developed sand points and are usually destroyed after the first rains. These are mostly used by small scale farmers in the rural areas.

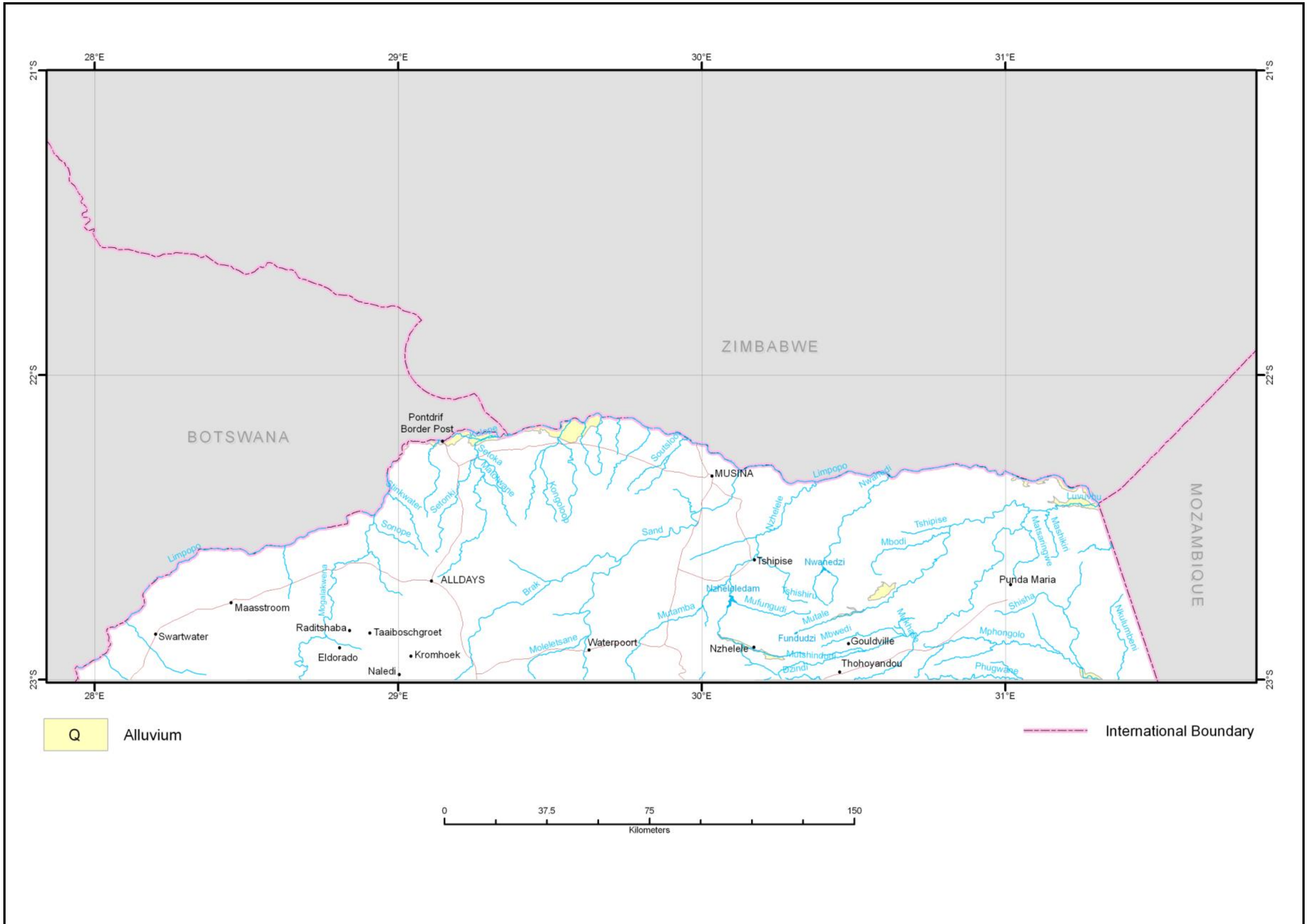

Figure 9: Geographical distribution of the intergranular aquifers (Q) and the associated groundwater sampling points

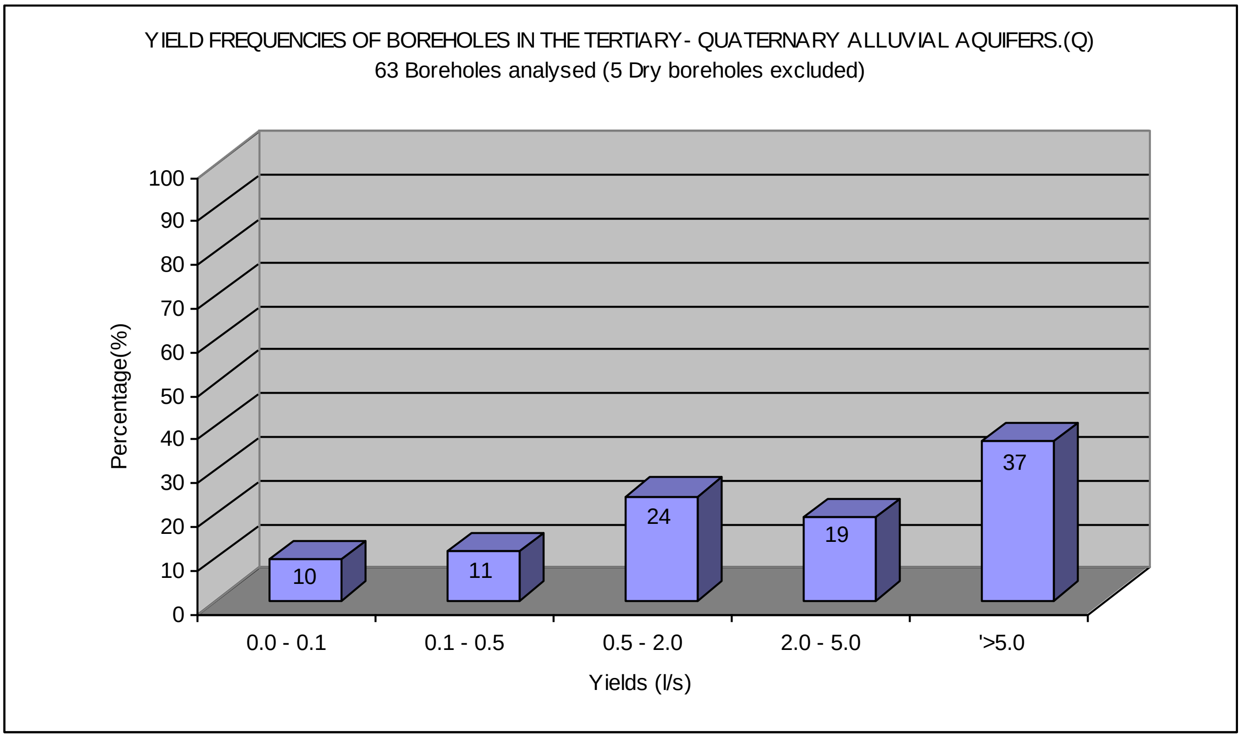

Figure 10: Yield frequency for Tertiary-Quaternary alluvial (Q) aquifers

Figure 10 is a representative frequency diagram of yields within the alluvial aquifers. The diagram shows that existing borehole yields are generally high with 37% of the successful boreholes in excess of 5ℓ/s.

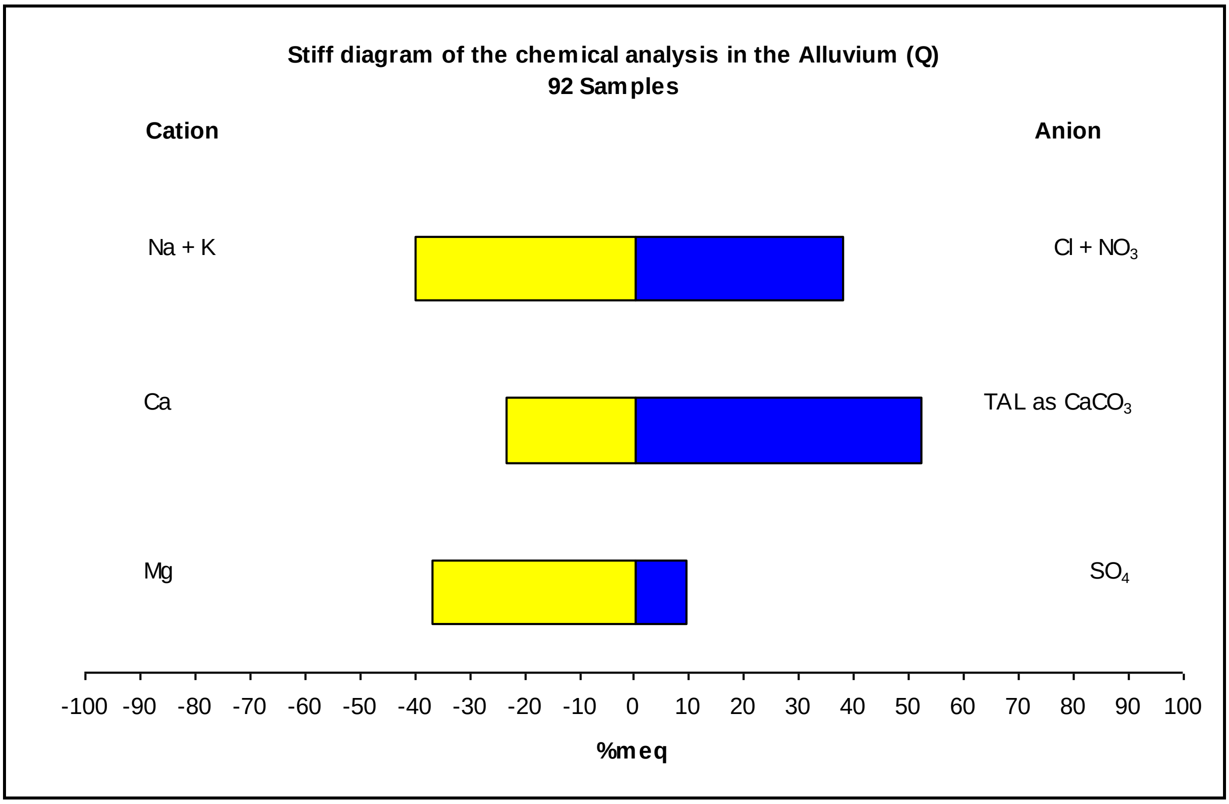

Figure 11: Stiff diagram representing chemical analysis of the alluvial deposits (Q)

The Stiff diagram (Figure 11) shows the broad classification according to anions and cations. From this diagram the groundwater can relate to sodium-magnesium-bicarbonate and chloride water types. The water quality is moderate to poor with EC values ranging from 6 to 1570mS/m and the harmonic mean calculated as 60.6mS/m falling comfortably within the acceptable limit (EC < 150mS/m). A possible cause of concern is the fact that the EC values of 25% of the sampled boreholes are above the maximum allowable value of 370mS/m indicating potential water quality problems. 18.5% of the magnesium, 18.5% of the sulphate and 14.1% of the chloride concentrations exceed the maximum allowable limit (Mg >100mg/l, SO_4 and Cl >600mg/l). Elevated concentrations of sodium and fluoride were reported in some of the samples. Samples from the alluvial aquifer along the Limpopo River in the Tuli Basin as well as a stretch between Pontdrif and Saamboubrug have elevated Mg, SO_4 and Cl concentrations. The quality seems to improve eastwards from Musina as more perennials join the Limpopo River.

In terms of water resources and provision, these alluvial aquifers are playing an essential role. Recharge to these aquifers occur almost immediately after river flows and the quality within the alluvial deposits is generally of an acceptable standard. The quality of the groundwater as well as the type and character of the underlying rock will have an influence on the water chemistry of the alluvial deposits (Du Toit, 1998). Quality problems reported in some of the samples within the alluvial deposits of the map area might be due to the influence of the underlying Lebombo and Karoo sediments.

7.2 SECONDARY AQUIFERS

The map area is predominantly (± 98.6%) underlain by consolidated hard rocks of sedimentary, igneous and metamorphic origin that formed over the whole length of the South African geological history. Primary porosity is the ratio of the volume of openings to the total rock mass during formation of the rock. The primary porosity of dense solid rock may be zero while the primary porosity of granular geological formations can be significant. Secondary porosity formed after the formation of the rocks to include micro cooling fractures, interconnecting vesicles in volcanic rocks, fractures formed by tectonic deformation (folding, faulting), re-crystallising and cooling in the contact area with intrusive rocks, or unloading through erosion, enhanced by weathering, dissolution (carbonate rocks) and solution cavities in the hard rocks of the map area. The secondary aquifer types shown on the map includes fractured and intergranular & fractured aquifers. Karst aquifers are included in the legend for mapping continuity although no dolomitic rocks occur within the area.

7.2.1 CATEGORY B: FRACTURED AQUIFERS

- Malvernia Formation (Kma)
- Lebombo Group (Jl)
    - Jozini Formation
- Bosbokpoort Formation (Trb)
- Solitude Formation (P-Trs)
- Undifferentiated Ecca Group and Clarens Formation (Pe-Trs)
- Ecca Group (Pe)
- Soutpansberg Group (Ms)
    - Nzhelele Formation (Msn)
    - Wyllies Poort Formation (Msw)
    - Fundudzi Formation (Msf)

The geographical distribution of the fractured rock aquifers is shown in Figure 12. The fractured rock aquifers cover approximately 28.22% of the total map area. Dolerite (Jd) is incorrectly displayed on the main map as fractured aquifers whereas it is in fact only part of the fractured and intergranular aquifers.

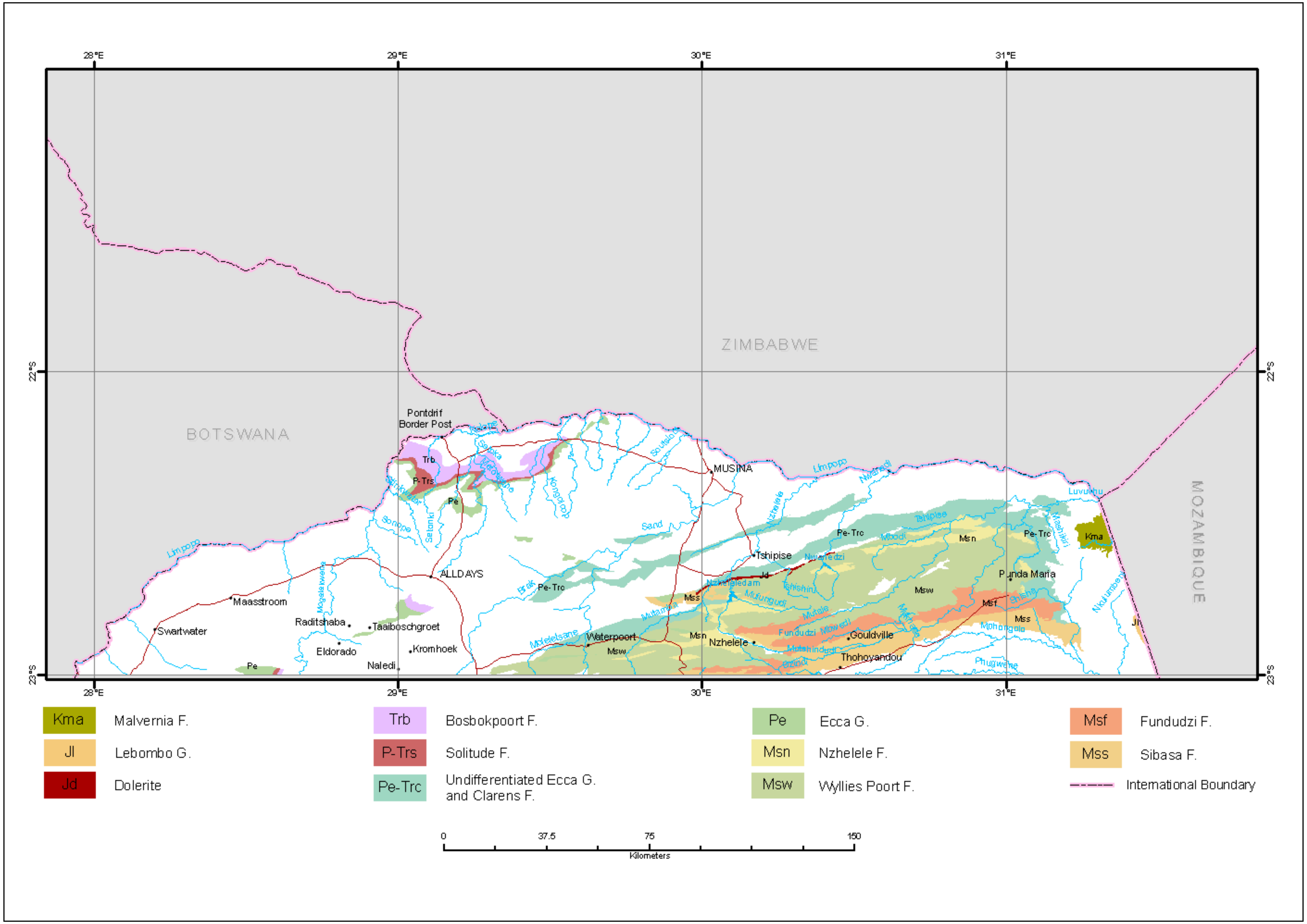

Figure 12: Geographical distribution of the fractured rock aquifers

7.2.1.1 MALVERNIA FORMATION (Kma).

The Formation forms an extensive plateau south of Pafuri (Figures 4 and 13) in the north-eastern sector of the map area. Minor occurrences northeast and northwest of Masisi are not indicated on the map. The Formation which is of Cretaceous Erathem is unconformable overlaying the basalt of the Letaba Formation. It is dipping eastwards at 5-10 degrees to obtain a maximum thickness of approximately 80m along the eastern boundary of the Kruger National Park. Whitish, coarse-grained and gritty sandstones and conglomerate with limestone and marl intercalations characterise the formation (Keyser, 1972). The pebbles of the conglomerate are rounded to sub-rounded, have a maximum diameter of 500mm and are derived partly from the Soutpansberg Supergroup and partly from granitic terrain. The matrix of the arenaceous sediments is usually calcareous.

The unit has a limited thickness (20 to 80m) and extent (0.48% of the map area). It is located within the National Kruger Park restricting its current and future development as an aquifer. The existing data from the unit shows that the aquifer is potentially low yielding. Groundwater development in this sector of the map area usually targets geological lineaments at depths > than 40m. Future groundwater development in this area might therefore focus on targets within the underlying basalt. The data base has information on 4 boreholes of which two are dry. The remaining two have yields of 0.07*l/s* and 0.2*l/s* respectively with no chemical data. From the above it is likely that the yield frequency will follow the tendency as for the fractured aquifer of the Lebombo Group described in section 5.2.1.2. The chemical result might reflect higher calcium concentrations. A piezometric contoured map compiled for the Kruger National Park groundwater study revealed the Malvernia Formation as a groundwater recharge area as groundwater drains from it (Du Toit, 1998).

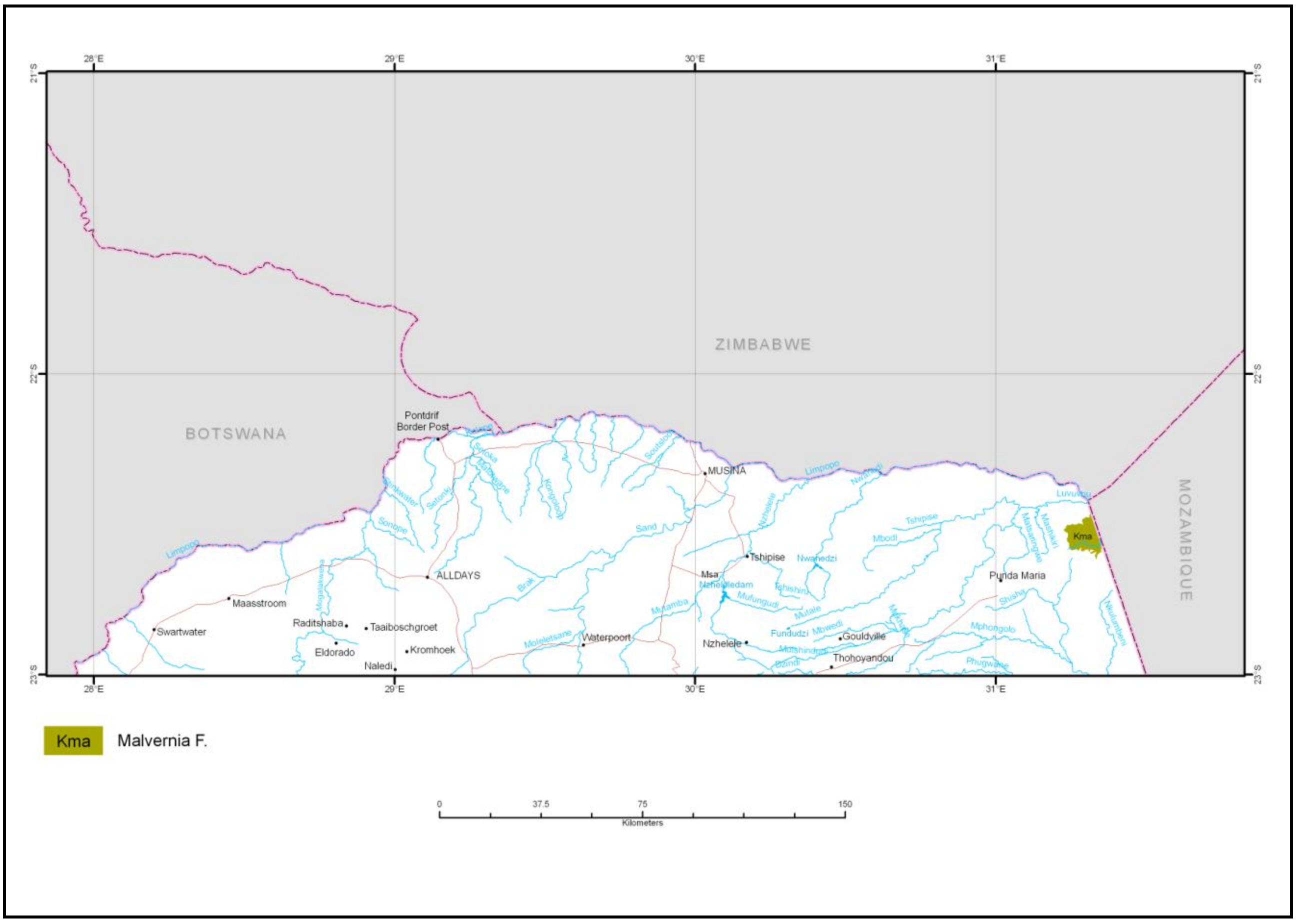

Figure 13: Geographical distribution of the Malvernia Formation (Kma)

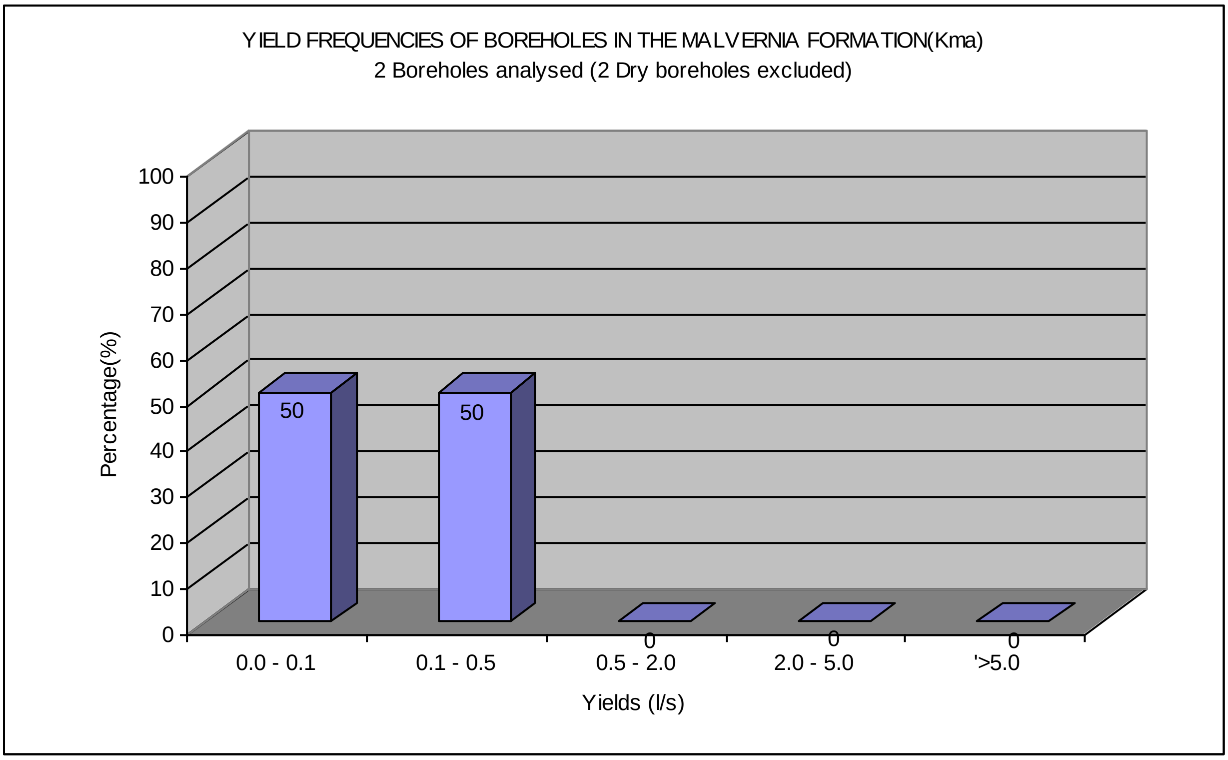

Figure 14: Yield frequency for fractured aquifers of the Malvernia Formation (Kma)

7.2.1.2 LEBOMBO GROUP (Jl) –Jozini Formation.

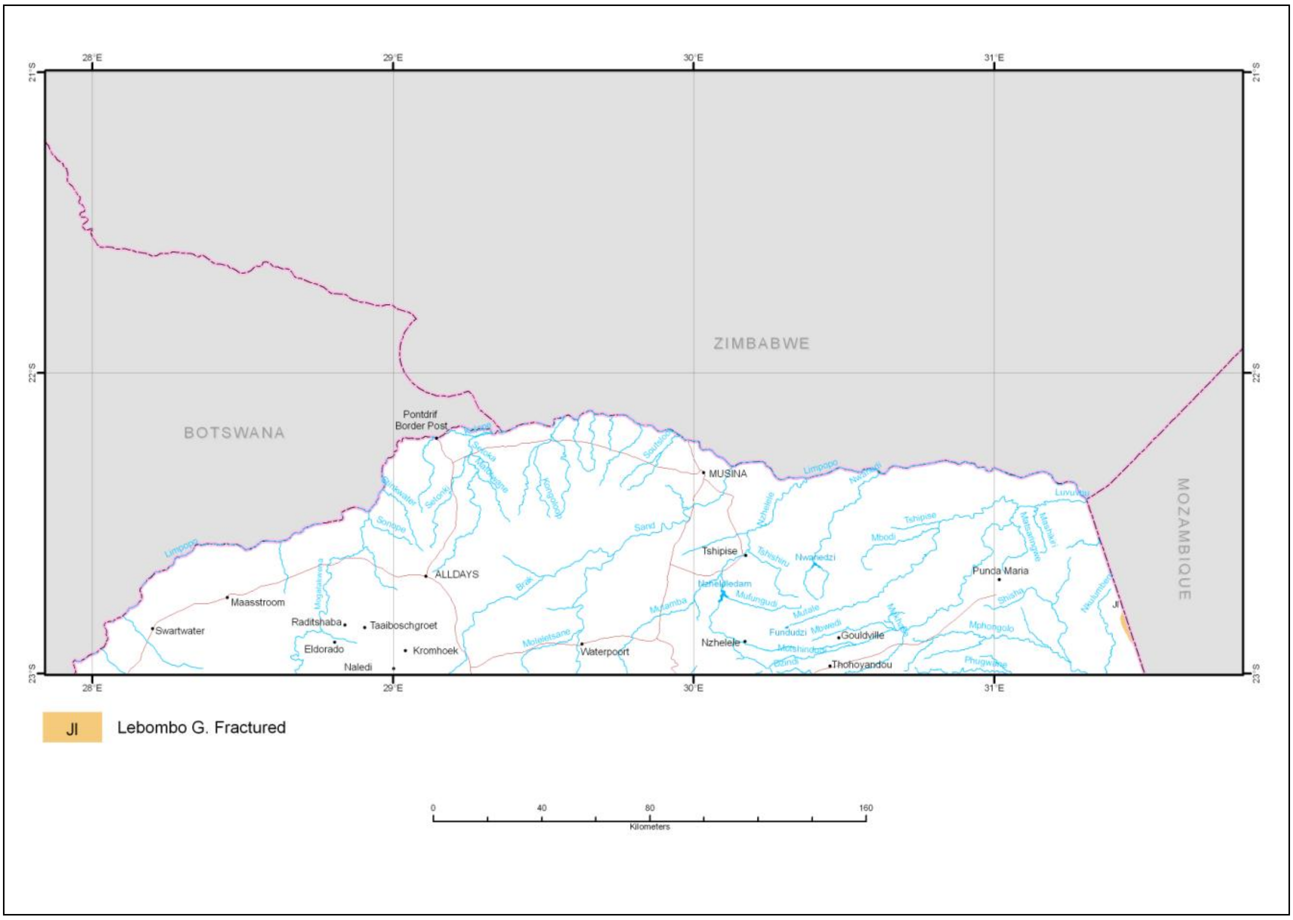

Figure 15: Geographical distribution of the fractured aquifers of the Lebombo Group (Jl)

The outpouring of lava marked the end of the sedimentary deposits of the Karoo Supergroup. Two Formations of the Lebombo Group occurs within the map sheet. The **Jozini Formation** representing the youngest Formation of the Lebombo Group within the map area occurs along the eastern border of the Kruger National Park (Figure 15) where it forms a conspicuous cliff. It consists of massive, resistant, red, brown, purple to green **rhyolite** with a thickness of approximately 70m (Brandl, 1981). Outside the map area to the south if forms part of the Lebombo Mountain range with a thickness of approximately 8000m. The texture is porphyritic to glomeroporphyritic and the rock is flow-banded.

The groundwater potential is considered low as the rock is dense with limited transmissivity resulting in total dewatering (drying up) of boreholes. The recharge to these aquifers is not consistent and the interpretation of the water chemistry shows the water to be ‘old water’, with a predominance of Na^+ and Cl^-. In the search for groundwater deep weathered and fractured zones must be targeted (Du Toit, 1998).

No chemical data or borehole yield data were available for analyses.

7.2.1.3 BOSBOKPOORT FORMATION (Trb).

Rocks of the Karoo Supergroup occur in three well-defined areas as described in the relevant section for the Supergroup in chapter 3. The Bosbokpoort Formation occurs within two of the basins (Tuli and Tshipise) and within one of the outliers between the basins. The occurrence within the Tshipise basin was grouped by the map compilers under the undifferentiated Ecca and Clarens Formation as described in section 7.2.1.5. Within the Tuli basin the Bosbokpoort Formation is up to 60m thick consisting of brick-red to purplish mudstone with subordinate white siltstone horizons developed mostly in the upper half. Calcareous nodules and concretions are often present (Brandl, 2002). The description of the hydrogeological character of the unit is for the occurrence within the Tuli basin and a single outlier as depicted in figure 16.

As expected from the lithology and confirmed from yield data, the unit can be regarded as a poor to average aquifer. 60% of the existing boreholes yield less than 0.5*l/s*. However, no dry boreholes were recorded. 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 is also targeted in the search for groundwater.

From the stiff diagram representing the chemical analysis of the **two sampled** boreholes (Figure 18), the water is of poor quality. It is classed as a sodium-bicarbonate and chloride water type. The magnesium and fluoride concentration is unacceptable in 50% of the samples. The high Electrical Conductivity (EC) measurements are a clear indication of water quality problems. Due to limited data additional sampling should be done to determine if the above holds true for the whole of the unit or whether these quality problems are related to pollution sources. Groundwater in this formation is abstracted for livestock watering and where the taste permits, for domestic purposes.

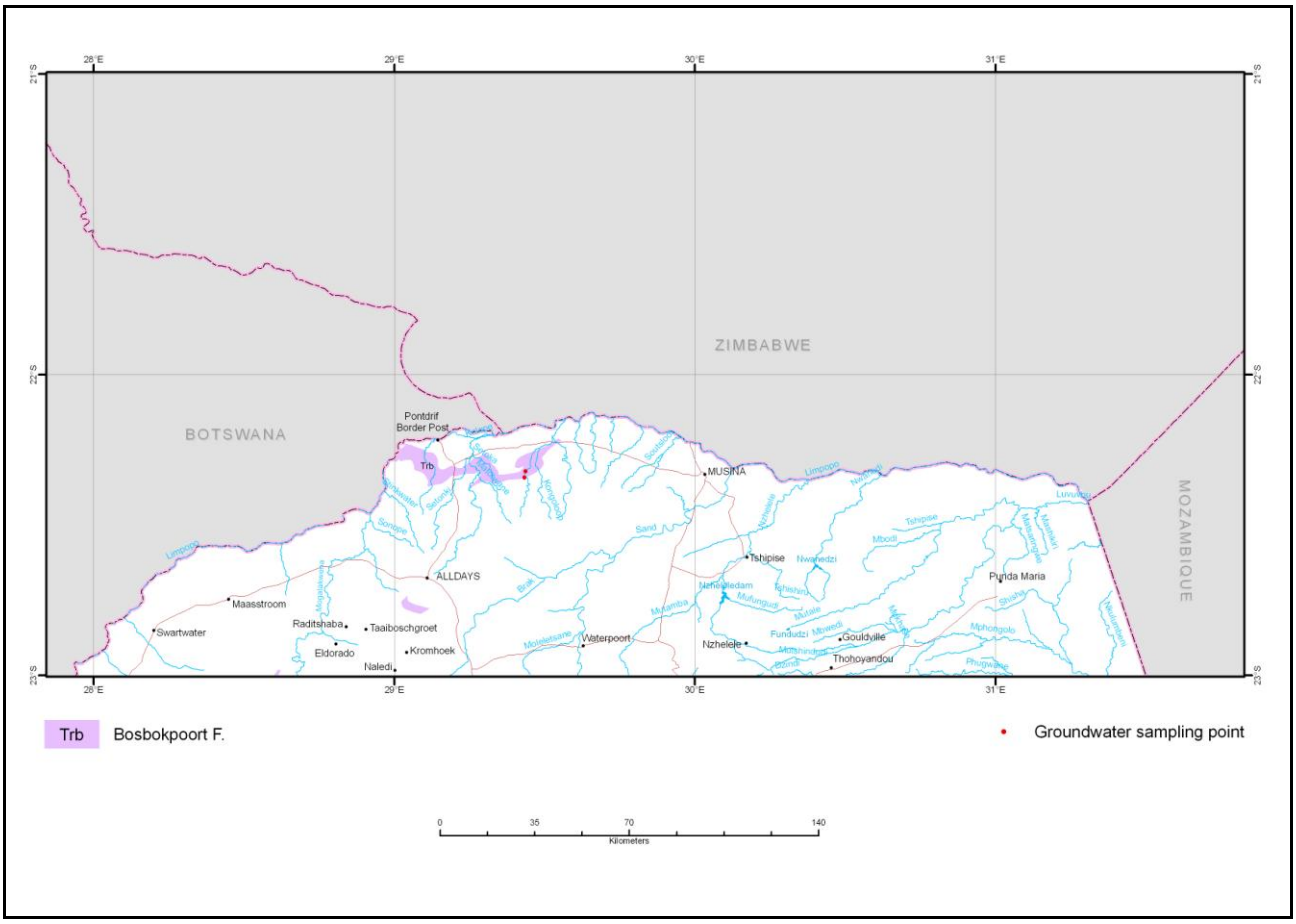

Figure 16: Geographical distribution of the Bosbokpoort Formation (Trb) and some of the associated groundwater sampling points

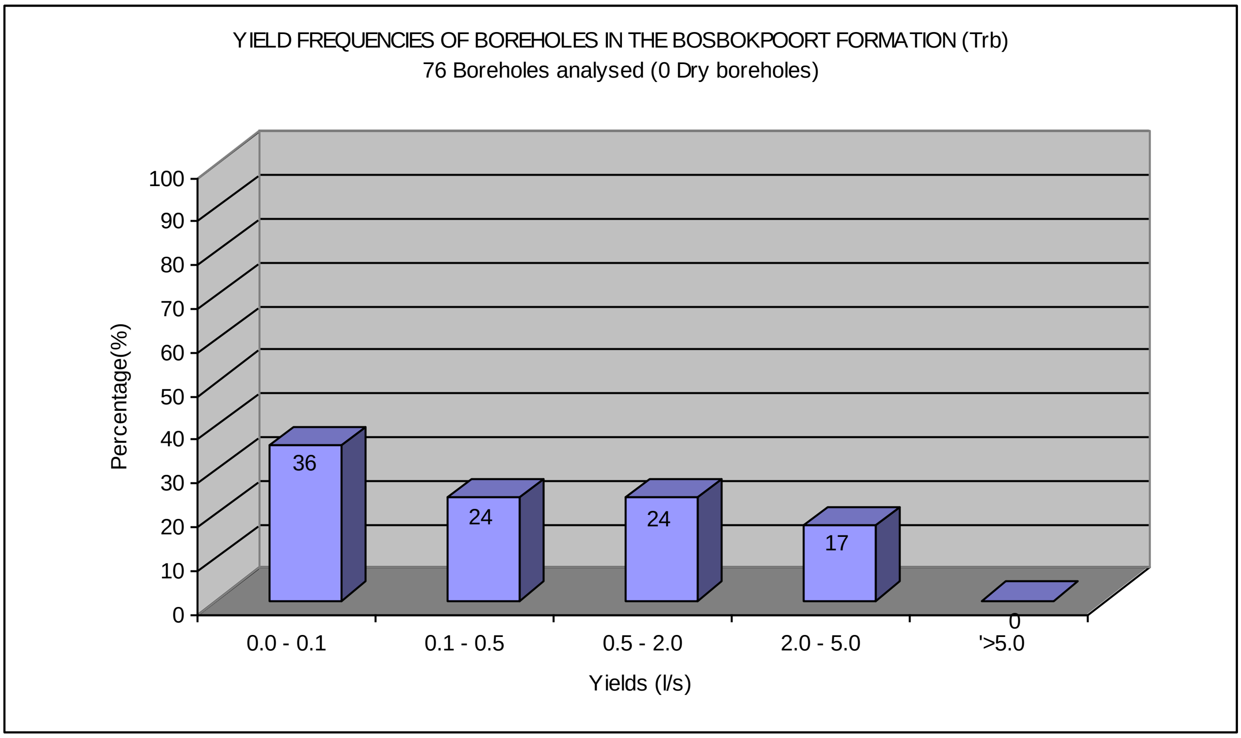

Figure 17: Yield frequency for fractured aquifers of the Bosbokpoort Formation (Trb)

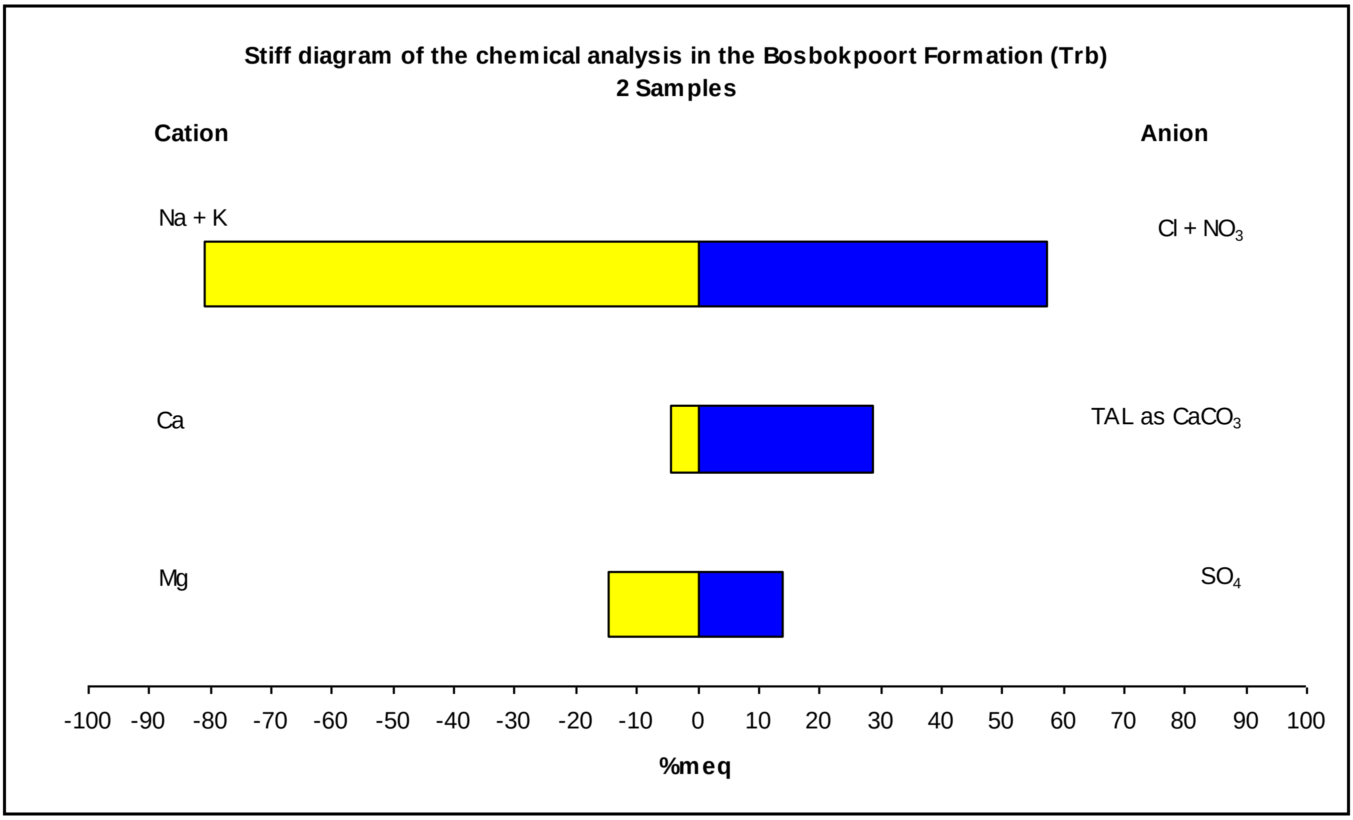

Figure 18: Stiff diagram representing chemical analysis of the Bosbokpoort Formation (Trb)

7.2.1.4 SOLITUDE FORMATION (P-Trs).

The occurrence of the Solitude Formation within the Tuli basin and within minor outliers as depicted in Figure 19 consists of white to buff, pink, green, red and khaki siltstone and very fine-grained sandstone with subordinate grey mudstone. The contact with the upper Bosbokpoort Formation becomes arbitrary where reddish colours are developed in the upper part of the Formation (Brandl, 2002). As with the Bosbokpoort Formation, the occurrences of the Solitude Formation outside the Tuli basin and outliers are discussed under undifferentiated Ecca and Clarens Formations in section 7.2.1.5.

The sedimentary rocks of the Formation have a low to a very low primary permeability and storage potential. Statistics indicate that 82% (Figure 20) of the successful boreholes yield less than 2*l/s* with the remaining 18% between 2 – 5*l/s*. No data of dry boreholes or with yields exceeding 5*l/s* were available.

Targets in the search for groundwater will relate to secondary fracturing associated with geological lineaments such as fault zones or intrusive dykes. Joints, bedding planes and contacts between sediments may also be targeted if no lineaments occur within the area of groundwater development.

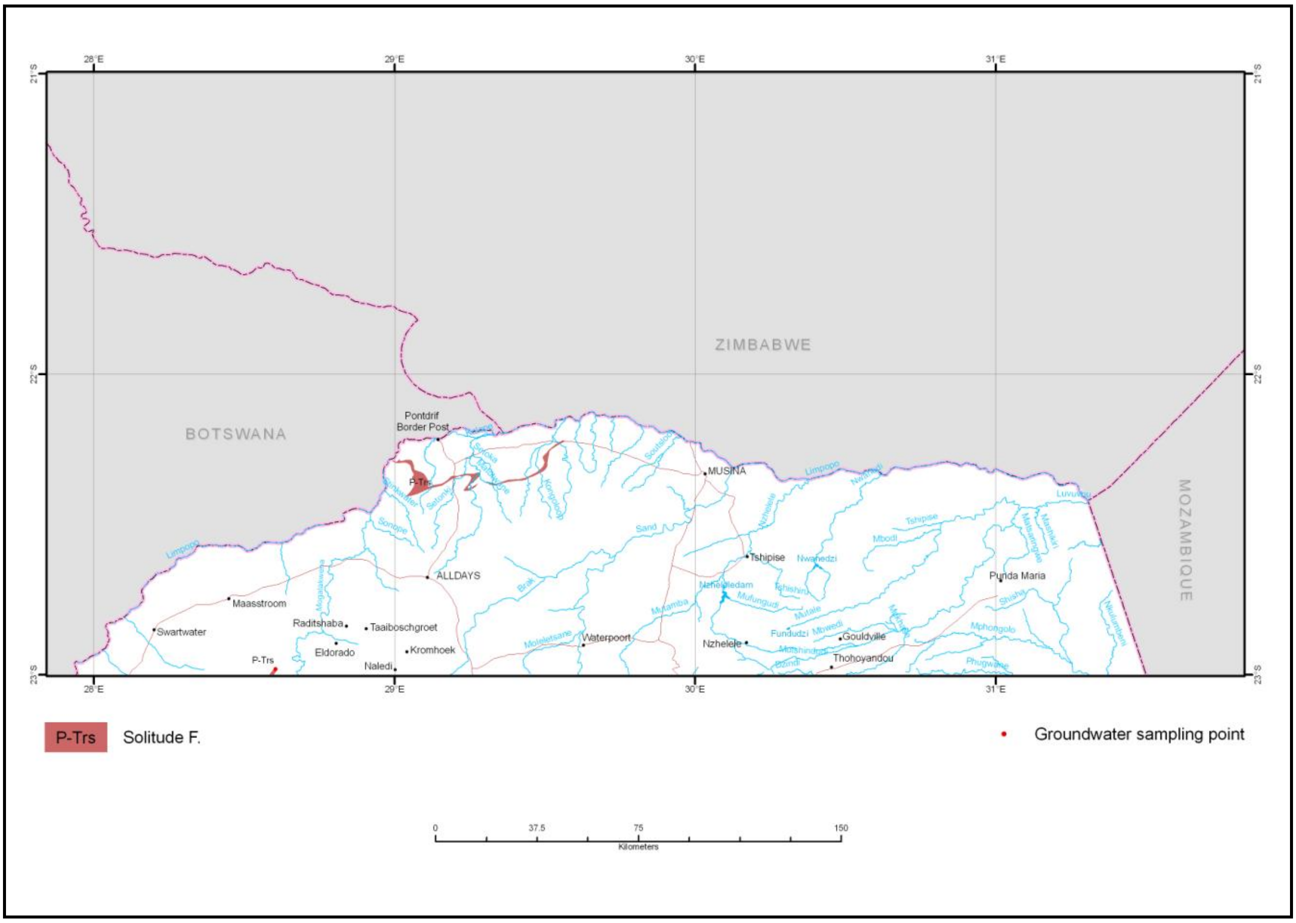

Figure 19: Geographical distribution of the Solitude Formation (P-Trs) and the associated groundwater sampling points

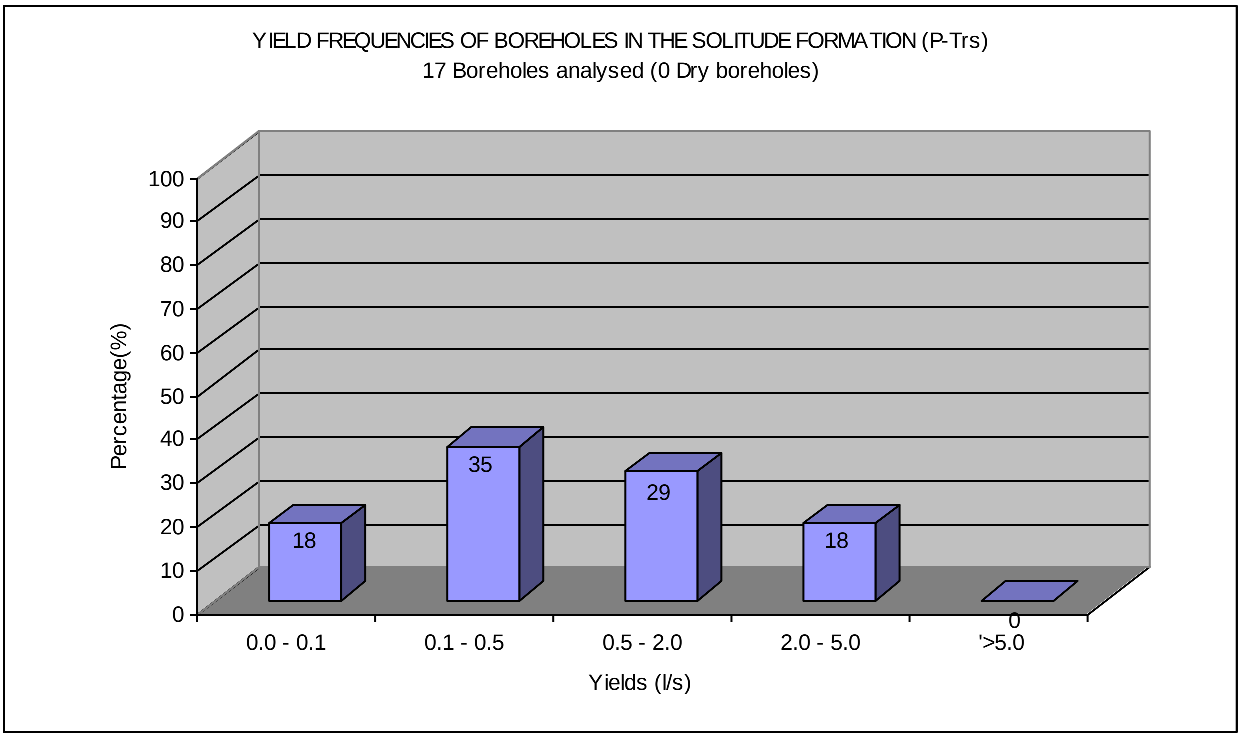

Figure 20: Yield frequency for fractured aquifers of the Solitude Formation (P-Trs)

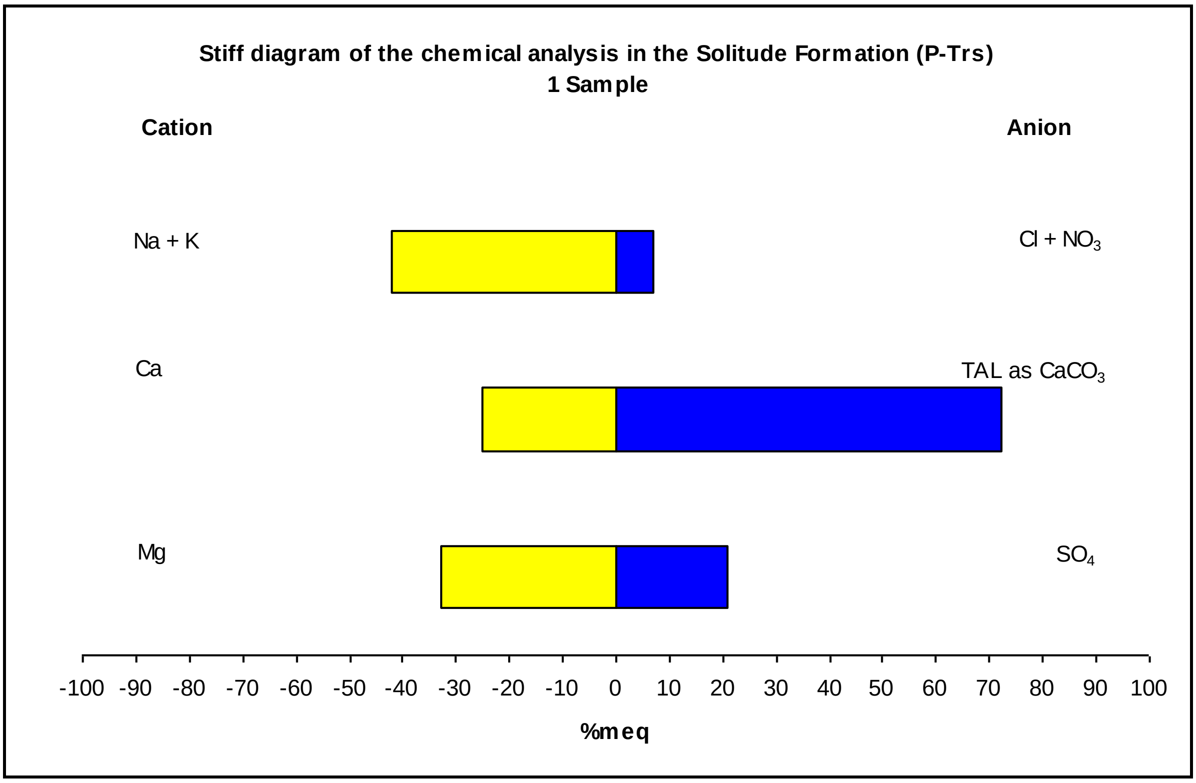

Figure 21: Stiff diagram representing chemical analysis of the Solitude Formation (P-Trs)

The stiff diagram (Figure 21) represents the results of one available chemical analysis that exhibits a sodium-magnesium-bicarbonate water type. The calcium and sulphate concentrations are slightly elevated but still within acceptable limits. In order to characterize and compare the chemical composition of the groundwater in this unit more chemical analysis is required to obtain a representative population for statistical analysis.

7.2.1.5 UNDIFFERENTIATED ECCA GROUP AND CLARENS FORMATION (Pe-Trc).

Various formations of the Karoo Supergroup occurring within the Tshipise basin are grouped under this heading. The map scale and area extend of the relevant formations made it very difficult to differentiate between them. All the Karoo rocks occurring south of the Voorburg, Bosbokpoort and Tshipise faults are regarded part of the Tshipise basin (Van der Berg, 1980). The trend of the basin is northeast with the southern border more or less delineated by the Klein Tshipise fault and rocks of the Soutpansberg Supergroup. The formations included under this heading are Clarens, Bosbokpoort, Klopperfontein, Solitude, Fripp, Mikambeni, Madzaringwe and Tshidzi Formations. The combined thickness of the sedimentary succession is approximately 1000m. In contrast with the outlay of the document, the Formations are described from oldest to youngest.

The **Tshidzi Formation** formed in a fluvioglacial environment and is confined to a few sporadic outcrops which probably developed in pre-Karoo depressions. The maximum thickness is 20m and it is composed of angular and rounded clasts imbedded in a sandy or bluish grey, muddy matrix.
The overlaying **Madzaringwe Formation** with a maximum thickness of 200m formed in a swamp environment. It consists of carbonaceous shale, shaly coal, coal, grey-black shale, brownish siltstone and laminate micaceous sandstone.
The **Mikambeni Formation** with a maximum thickness of approximately 150m comprises dark and pale mudstones, black shale and thin coal seams deposited in a swamp environment (Brandl, 1981).
The **Fripp Sandstone Formation** with a maximum thickness of approximately 110m forms a sharp contact with the underlying **Mikambeni Formation** and consists of white or greyish white, cross-bedded, very feldspathic medium to coarse grained sandstone. The sediments were transported from

the northeast and deposition in braided streams is envisaged (Van Vuuren, 1979). Within the Tshipise basin the **Solitude Formation** has a maximum thickness of 170m and is dominantly composed of alternating multi-coloured shale and mudstone. Sedimentation took place in a fluviatile environment.

The **Klopperfontein Sandstone Formation** is lithologically similar to the Fripp Formation with a thickness between of 10 and 20m. In the Tshipise area reddish colours prevail due to an abundance of red feldspar. The overlaying **Bosbokpoort Formation** is characterized by dominantly red lithologies with a maximum thickness of approximately 100m in the Tshipise area and thinning gradually towards the east. The lower part consists mainly of massive mudstone followed by siltstone which occasionally grades into (minor) very fine sandstone. Calcareous concretions are frequently scattered throughout the exposures. The clayey and silty material of the succession seems to have been deposited in a flood basin under moderately hot and arid conditions (Brandl, 1981).

The **Clarens Sandstone Formation** with a maximum thickness of 300m is divided into the **Red Rocks Sandstone Member** and the **Tshipise Sandstone Member**. Deposition of this Formation seems to have occurred mainly in an aeolian environment. In the south-eastern part of the map area the Formation unconformable overlies rocks of the Soutpansberg Group and basement gneiss. The absence of the lower Karoo Formations in this area points to the existence of a pre-Karoo higher area (Brandl, 1981). Thin Letaba basalt sills and dykes 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 <0.5*l/s*. However, higher yielding water strikes are generally intercepted in the Clarens sandstone between 40 and 75m below the main basalt/sandstone contact. The EC values are lower in the sandstone than the overlaying basalt.

The groundwater potential in the argillaceous sediments is considered to be very low. The change of finding water in strikes beyond 80m is very low. Secondary fracturing related to geological lineaments such as the major fault zones (Klein Tshipise and Tshipise Faults) are primary targets in the search for groundwater. Other targets include secondary fracturing related to dolerite dykes and sills, bedding planes and sedimentary contacts (Du Toit, 1998). The Tshipise Sandstone member of the Clarens Formation is regarded as the best aquifer (quality and quantity) within this geohydrological unit.

The yield frequency distribution (Figure 23) indicates that 29% of the successful boreholes yield less than 0.5*l/s*, 32% between 0.5 and 2ℓ/s, and 40% more than 2*l/s*. The higher yielding boreholes are largely attributed to secondary fractures related to faults, dykes and sills.

The chemical analyses of 138 samples, (Figure 24) are representative of the formations grouped under this unit. The sample distribution covers more or less the whole unit (Figure 22). It must be kept in mind that the results do not differentiate between the different formations as boreholes might have intersected more than one formation. It is known from field notes that the water quality found in the Clarens Formation is superior to the water found in the mainly argillaceous sediments of some of the other Formations.

Plate 4: The Tshipise basin, photographed from the northeast. The ridge on the left is the northern part of the Soutpansberg (Wyllies Poort Formation). The ridge on the right is formed by the Clarens Sandstone Formation of the Karoo Supergroup. The landscape is typical of the north-eastern sector of the map sheet and north of the Soutpansberg, Mopani, Matopi and Baobab trees dominate. The overburden in the foreground is reddish sand and calcrete, further to the southwest it changes to deep red sand and semi round quartzitic pebbles from the Wyllies Poort Formation (Photo, C.J. Sonnekus, 11/02/2011).

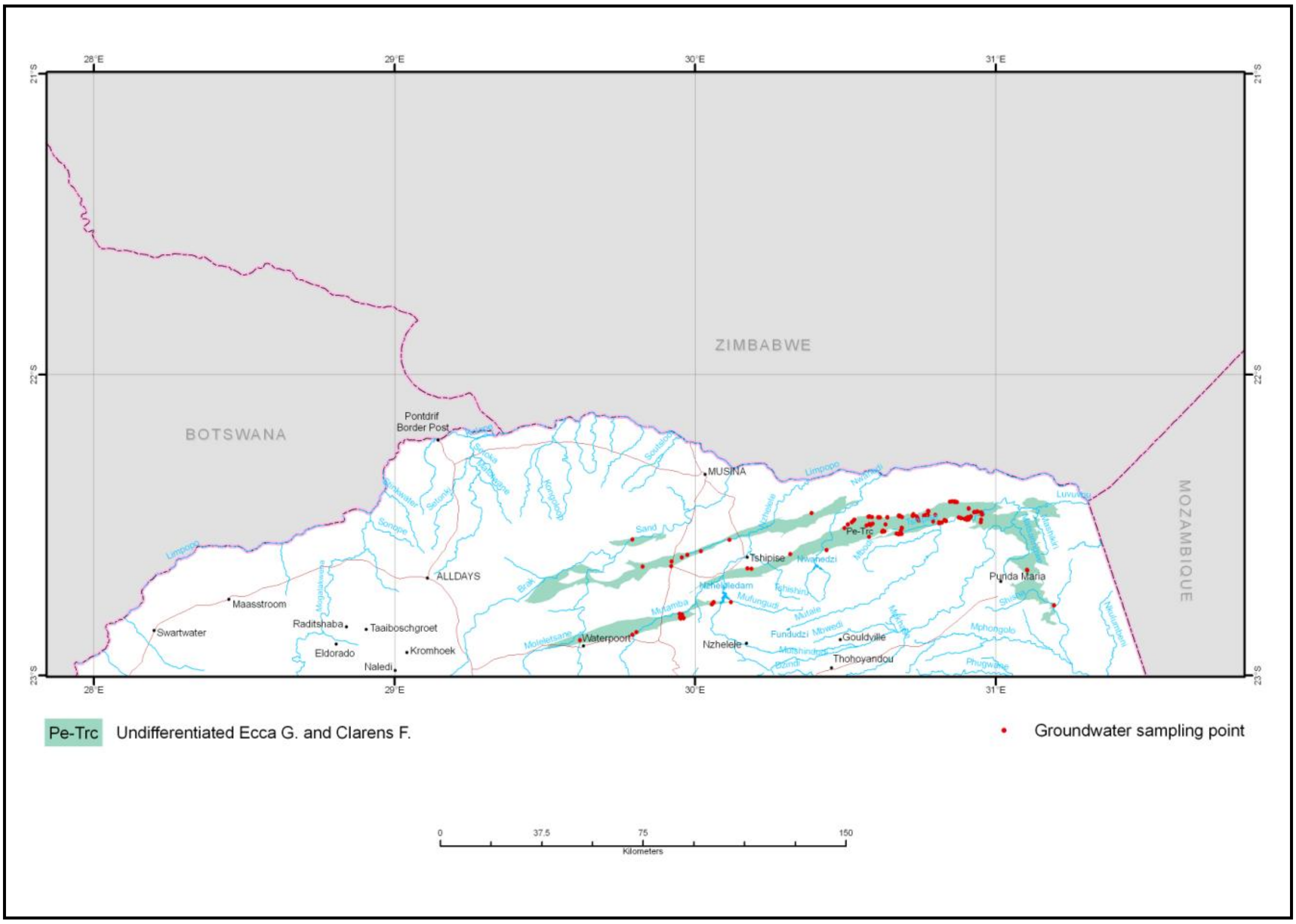

Figure 22: Geographical distribution of the Undifferentiated Ecca Group and Clarens Formation (Pe-Trc)

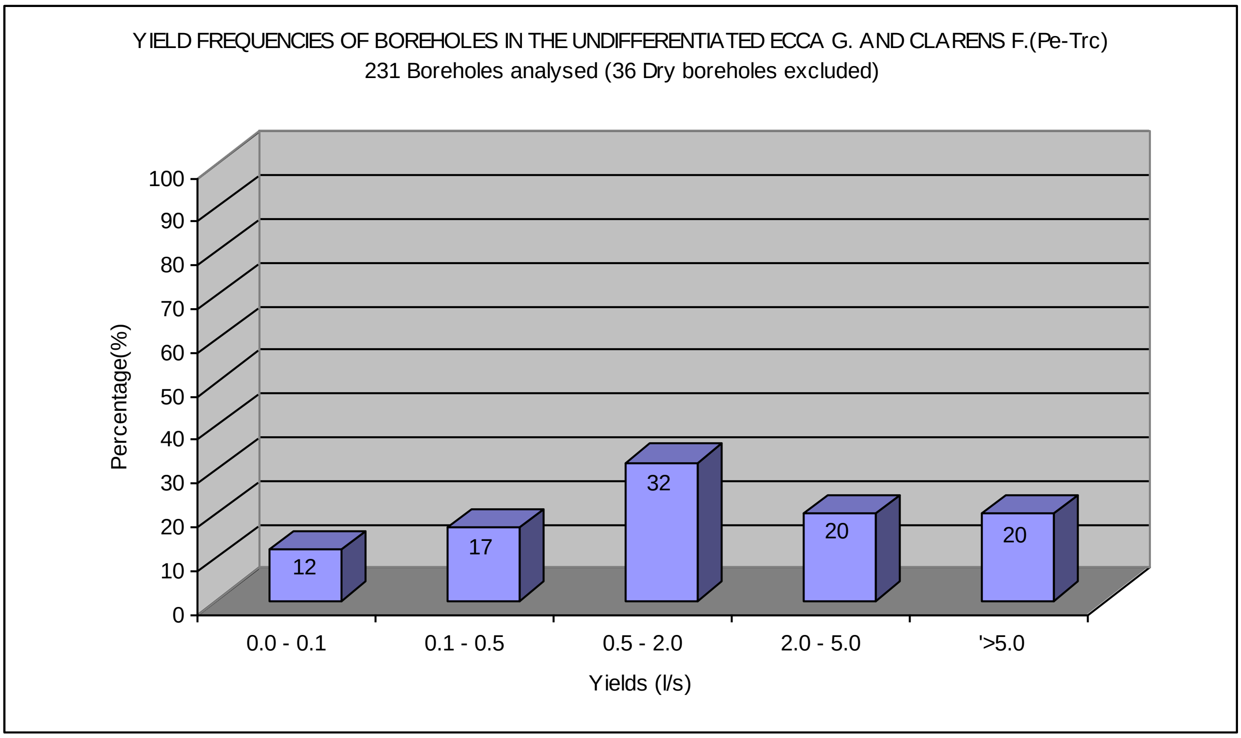

Figure 23: Yield frequency for fractured aquifers of the Undifferentiated Ecca Group and Clarens Formation (Pe-Trc)

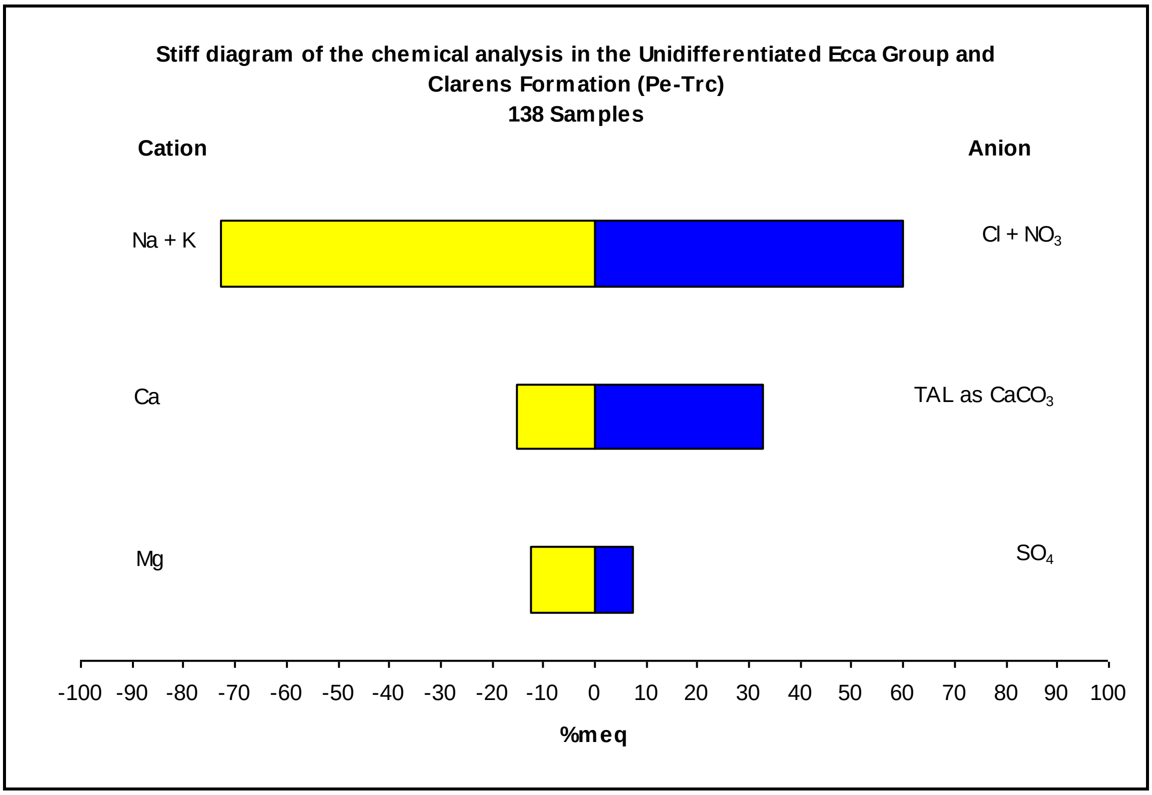

Figure 24: Stiff diagram representing chemical analysis of the Undifferentiated Ecca Group and Clarens Formation (Pe-Trc)

The chemical analysis of 138 sampled boreholes indicates a sodium-bicarbonate and chloride water type. This is a typical classification for Karoo sedimentary rocks. The quality of the water is moderate to poor with EC values ranging between 12-4610mS/m. The harmonic mean is calculated as 128mS/m with 22.5% of the samples with values exceeding the maximum allowable limit (EC > 370mS/m). 14.4% of the samples falling outside the acceptable limit for nitrate (N > 20mg/l), 10.3% are outside the fluoride limit (F > 1.5mg/l) and 24.6% are exceeding the maximum allowable limit for chloride (Cl > 600mg/l). The concentration of magnesium and sodium also display problems as respectively 26.1% and 28.3% of the samples falls outside the maximum allowable limits (Mg > 100mg/l, Na > 400mg/l) for domestic water. 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+}). Most of the problematic water samples occur near the Klein Tshipise fault.

7.2.1.6 ECCA GROUP (Pe).

Rocks of the three lower Formations of the Karoo Supergroup occurring within the Tuli basin and within the down-faulted blocks between the Tuli and Tshipise basins are grouped under this heading. The Formations includes the **Mikambeni, Madzaringwe and Tshidzi Formation**. In contrast with the outlay of the document, the succession of the unit is described from oldest to youngest.

The **Tshidzi Formation** was deposited on a markedly uneven floor of Beit Bridge gneisses and consists of local angular blocks and fragments within a matrix of coarse sand or grit. The occurrence is irregularly and infrequently. Other localised diamictite occurs as 20m thick deposits of randomly oriented blocks of the underlying metaquartzite, with a distinctive 6-7cm purple ferruginous band developed approximately 1m from the top. Where diamictite deposits are absent grits are found to overlay the basement gneiss. The grits pass upwards into grey to brownish weathered laminated shale of the **Madzaringwe Formation** with intermittent lenses of red and yellowish grit in the lower part and layered coal seams totalling 20m in the upper part within the shale. A purplish red mudstone occurs occasionally overlain by coarse micaceous sandstone up to 10m thick that forms the top of the Formation. Mining companies are exploring for and mining coal within this Formation that might lead to possible pollution of groundwater in these areas. The overlying **Mikambeni Formation** consists generally of 15m of grey, sometimes carbonaceous, shale and siltstone with occasional coal seam lets (Brandl, 2002).

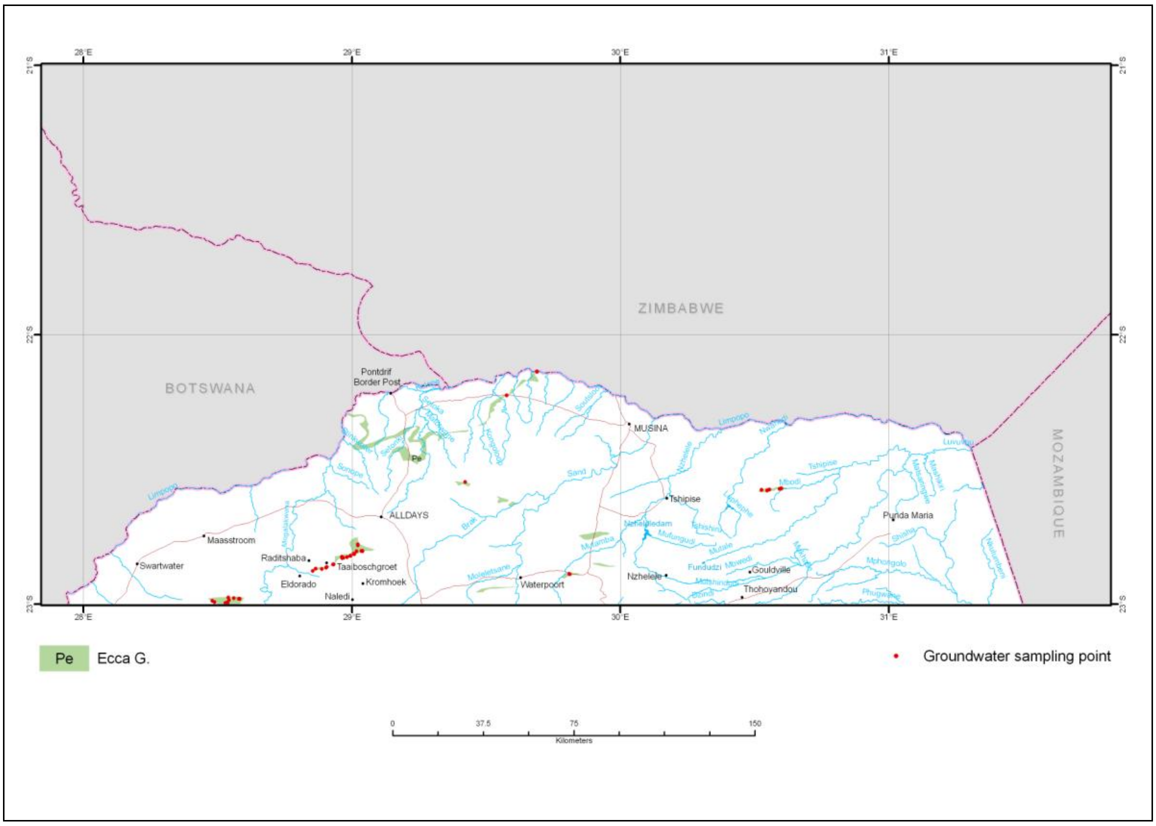

Figure 25: Geographical distribution of the Ecca Group (Pe) and the associated groundwater sampling points

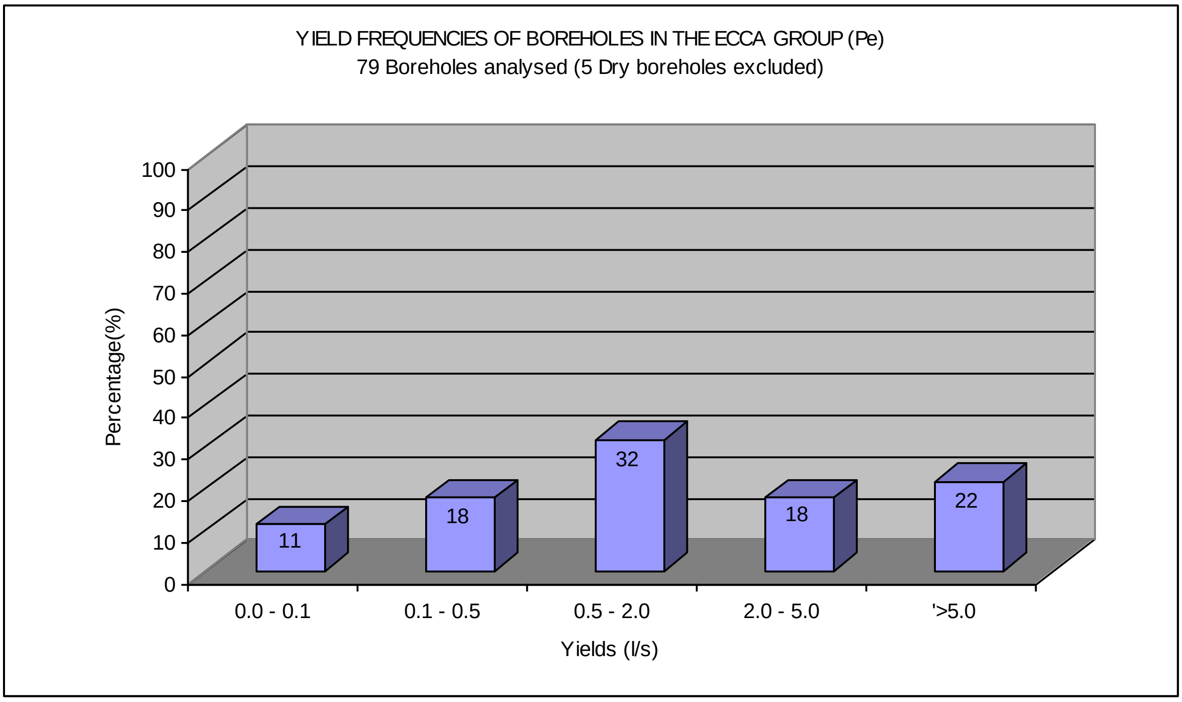

Figure 26: Yield frequency for fractured aquifers of the Ecca Group (Pe)

The analysis of 79 borehole records indicates that 32% of the yields are between 0.5 and 2*l/s*. 29% are less than 0.5*l/s* and 40% are more than 2*l/s* (Figure 26).

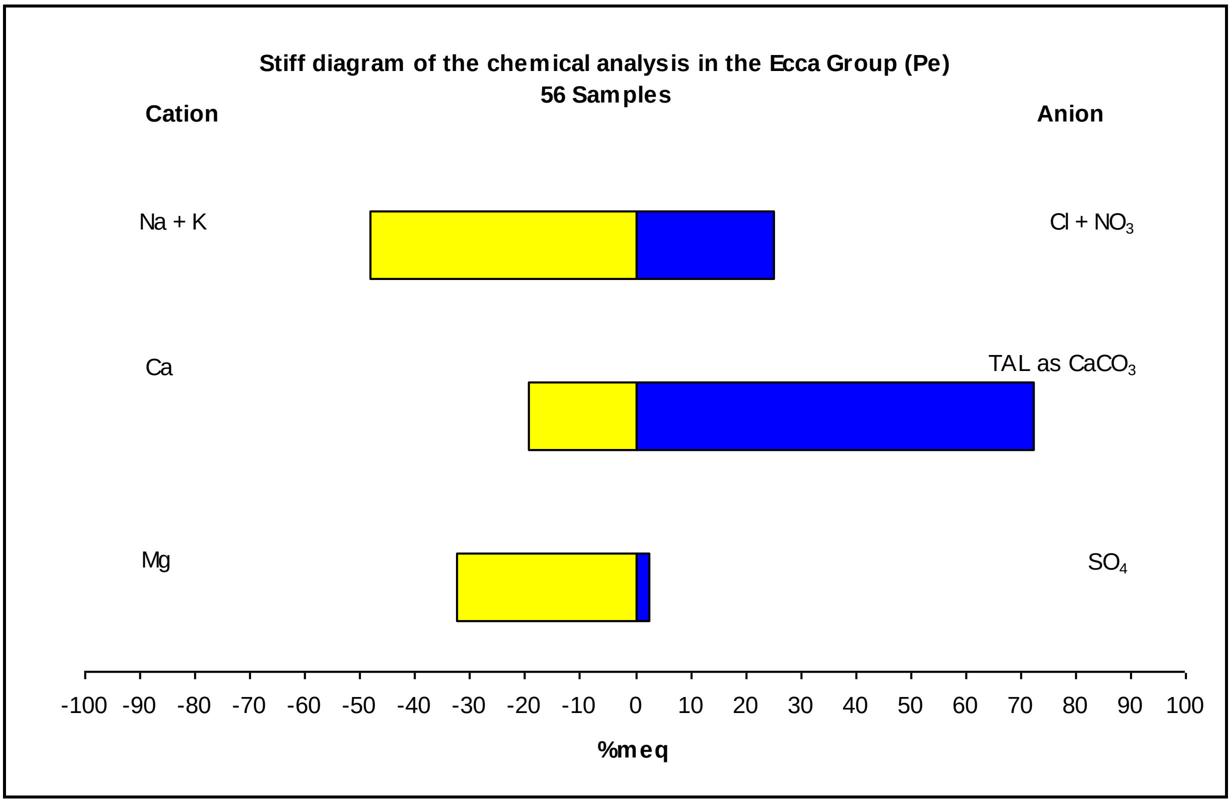

Figure 27: Stiff diagram representing chemical analysis of the Ecca Group (Pe).

Chemical data representing 56 samples is presented in the stiff diagram (Figure 27). The water is of a sodium-bicarbonate and chloride type with elevated magnesium and calcium concentrations most likely due to reverse ion exchange (This is a typical classification for Karoo sedimentary rocks). EC values vary between 73 - 389mS/m with a Harmonic mean of 106mS/m for the unit.

The water quality is ideal to acceptable in approximately 40% of the sampled sources. Fluoride is a problem in 7.4% of the sampled sources as it exceeds the maximum allowable limit of 1.5mg/l. The water quality differs randomly throughout the unit.

7.2.1.7 SOUTPANSBERG GROUP (Ms).

The Soutpansberg Group comprises a volcanic and sedimentary rock succession, laid down in an elongated, fault-bounded depression. A major centre of volcanic activity was probably located in the Sibasa area and a minor one east of Klein Tshipise. The deposition of arenaceous and argillaceous sediments within fluviatile and shallow-water conditions followed the period of volcanic activity (Brandl, 1981). The fractured hydrogeological unit of the Soutpansberg Group comprises the Nzhelele, Wyllie's Poort and Fundudzi Formations. Each of the Formations is described separately. Groundwater data for this Group is of a high standard and a high number of boreholes have been scientifically selected. This is especially true for data from 1992 when the Department of Water Affairs developed sources as part of a drought relief programme. Continuous programmes such as investigations of the Tshipise Fault zone and the Groundwater Resource Information Project (GRIP) ensured good quality data up to 2007.

7.2.1.7.1 NZHELELE FORMATION (Msn).

The Nzhelele Formation has an estimated thickness of between 500 and 1000m in the west and a thickness of between 1000 and 2000m in the east (Figure 28). It consists of a lower volcanic assemblage approximately 400m thick at the base followed by argillaceous and arenaceous sediments. Chemically the lava is of a basaltic composition, greenish grey, slightly amygdaloidal and varies in grain size from fine to coarse. In the east lenses of white quartzite up to 25m thick, red shale, tuffaceous rocks and chert are present at various levels in the lava. The lava is overlain by shaly micaceous sandstone, fine, thinly bedded sandstone and dark-red shale. The upper portion of the formation consists of light-coloured, tabular and trough-cross-bedded sandstone and quartzite with minor thin shaly intercalations (Brandl, 1981, 2002).

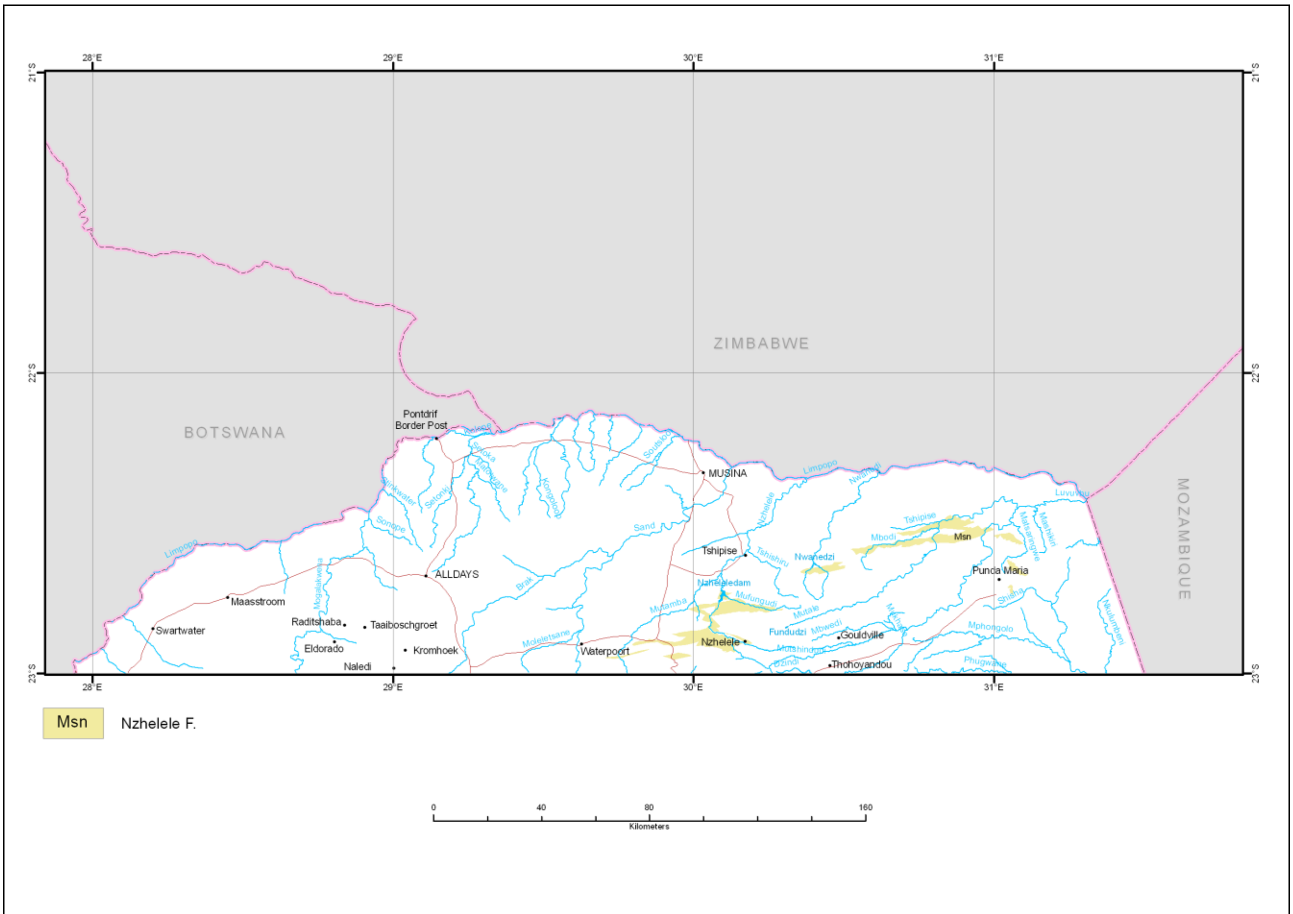

Figure 28: Geographical distribution of the Nzhelele Formation (Msn)

Figure 29 indicates the Nzhelele Formation has a good potential as 36% of the boreholes yield between 0.5 and 2*l/s* and 44% more than 2*l/s*. The high number of higher yielding boreholes can be attributed to secondary fracturing associated with the numerous faults that borders or cut through the unit, diabase dykes and joints. Water strikes associated with bedding planes, contact zones between sediments, and the contact with the lava are usually resulting in lower yields. Although not distinguished on the map some of the high yielding boreholes can be attributed to alluvial along the Nzhelele River.

Groundwater abstraction is for the supply of small-scale irrigation, livestock and rural domestic requirements. EC values range between 10 – 555mS/m with 9.4% of the samples exceeding the maximum allowed limit of 370mS/m. Fluoride concentrations exceed the maximum allowable limit in 5% (F > 1.5mg/l), sodium in 7.4% (Na > 400mg/l), magnesium in 18.7% (Mg > 100mg/l), nitrate ($N0_2$ + $N0_3$ presented as N) and chloride in 15% of the samples (N > 20mg/l, Cl > 600mg/l). The samples with elevated Cl, F and Na concentrations is clustered around Siloam. This might relate to a pollution source and should be investigated. The samples with elevated N, Mg concentrations and higher EC values are scattered throughout the unit. The water character is a magnesium-sodium-calcium-bicarbonate-chloride water type.

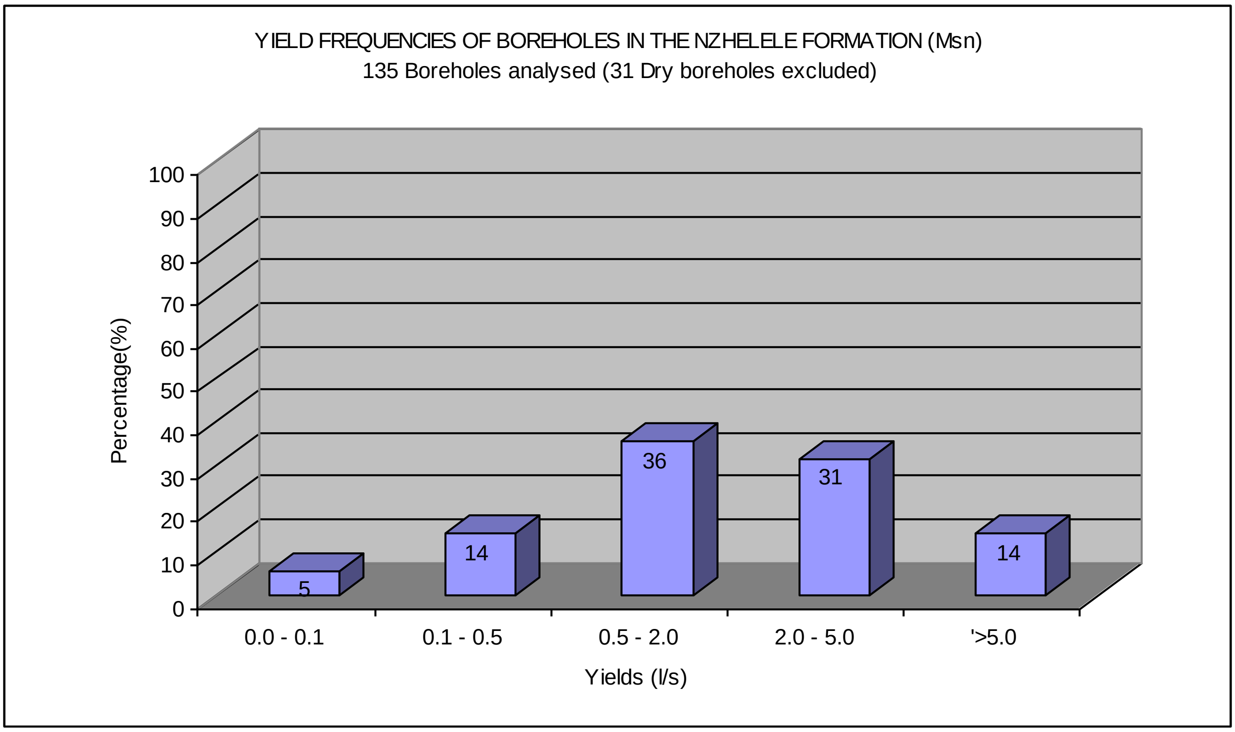

Figure 29: Yield frequency for fractured aquifers of the Nzhelele Formation (Msn)

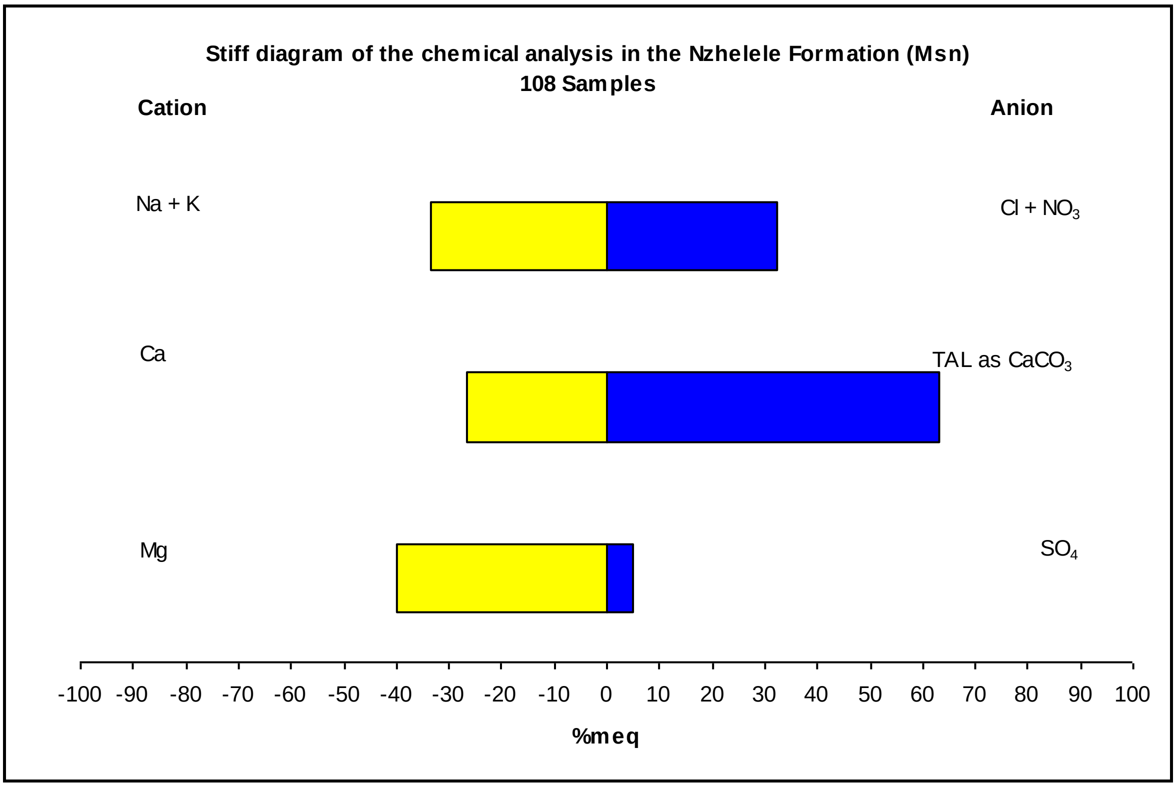

Figure 30: Stiff diagram representing chemical analysis of the Nzhelele Formation (Msn)

7.2.1.7.2 WYLLIES POORT FORMATION (Msw).

The Wyllies Poort Quartzite Formation has a maximum thickness of 4000m in the Thengwe and Ha-Makuya area and decreases considerably to the east and west. It is almost entirely arenaceous and underlies the major part of the more mountainous part of the Soutpansberg. The Formation consists predominantly of coarse-grained purple or reddish sandstone and a medium-to fine-grained pink or whitish quartzite or quartzitic sandstone. Locally thin lenses of grit or conglomerate occur within the sandstone. Red and brown sandy shale, shaly micaceous sandstone and minor siltstone form a few lenticular bands of limited extend nowhere exceeding a thickness of 10m (Brandl, 1981, 2002).

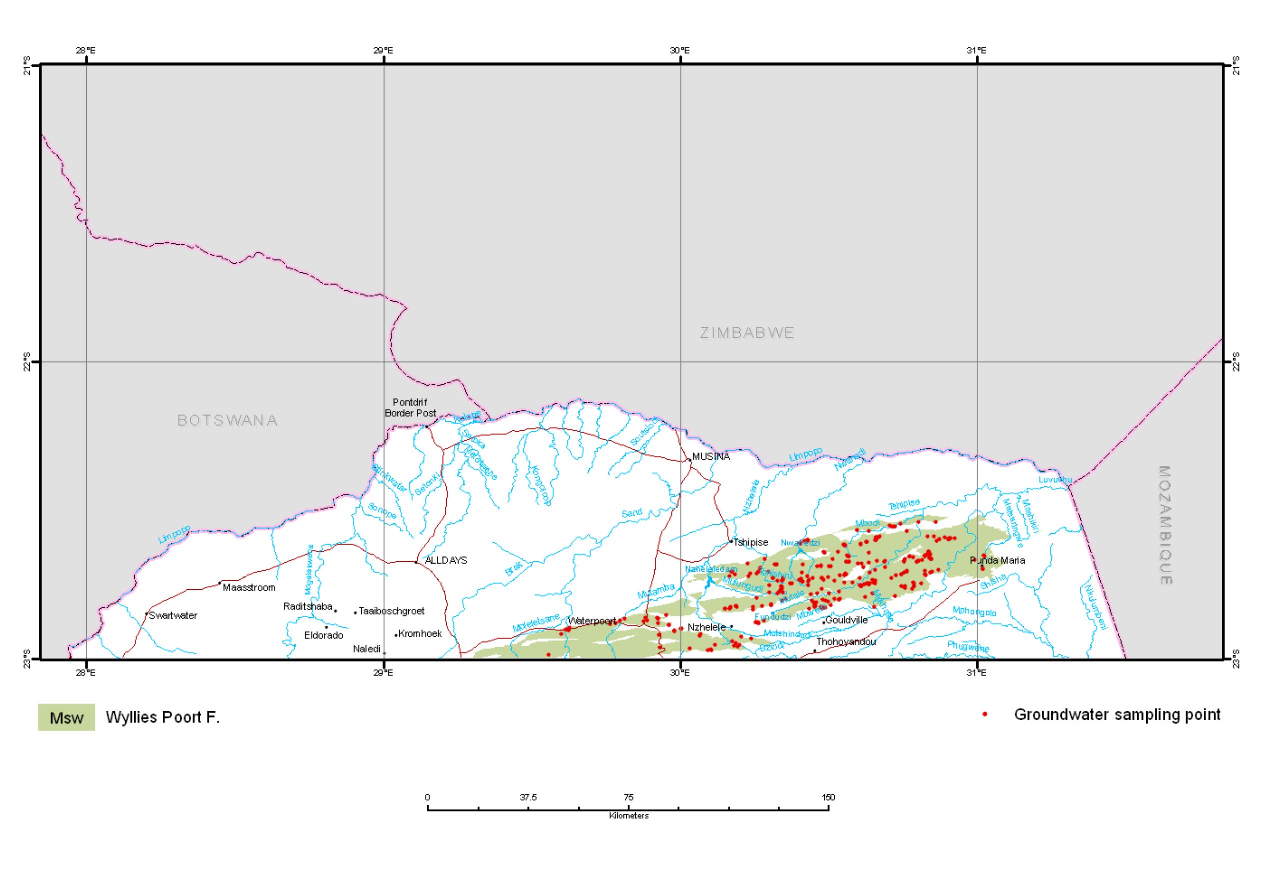

Figure 31: Geographical distribution of the Wyllies Poort Formation (Msw) and the associated groundwater sampling points.

Primary porosity is almost zero within the Formation making the occurrence of secondary fractures and fissures the determining factor in finding water. Water bearing formation (weathered and fractured zones) is limited to a depth of 100m (Du Toit, 1998). The low potential of the rock mass is evident in the high number (18%) of dry boreholes drilled in the formation. Secondary fractures relate to the numerous faults transecting and bordering the formation, diabase sills and dykes and jointing. The east-west trending fault zones are in cases associated with steep, almost polished rock faces on the southern slope of mountains. Access for drilling rigs can be a problem as the faults are steeply dipping and the drill rig must be positioned as near as possible to the fault plane. The faults and dykes oblique to strike give rise to narrow valleys. These are good targets to investigate in the search for groundwater. In the southern part of the map area where the average rainfall is higher, small streams flow for long periods in these valleys. The first strikes can relate to deep colluvium formed in these valleys with the second strike related to the geological lineament.

In the dryer northern part with less vegetation cover, white quarts crystals or recrystallisation intergrowths in the purple sandstone or quartzitic sandstone mass can indicate the presence of a fault zone.

The use of scientifically proven methods is recommended in the development of production boreholes, as the groundwater potential for this formation is poor to average. Statistics indicate that 65% (Figure 32) of the successful boreholes yield less than 2*l/s*. 18% of the successful boreholes yield more than 5*l/s*.

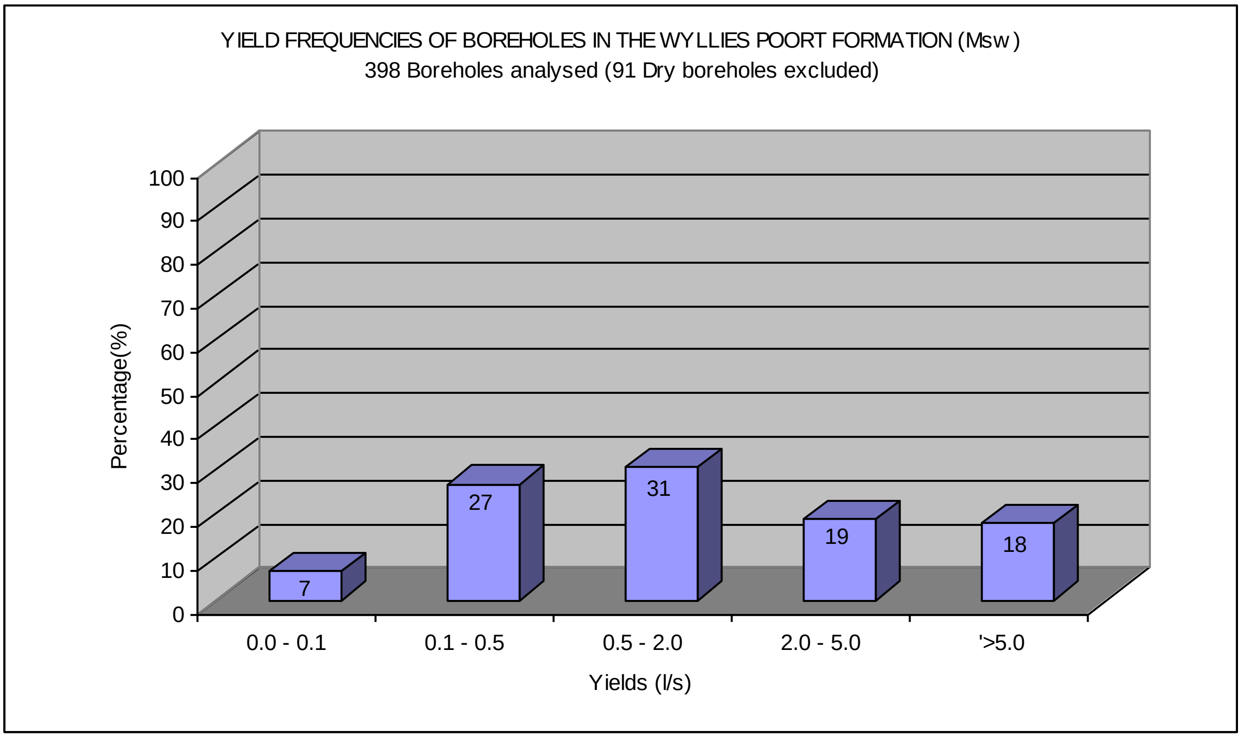

Figure 32: Yield frequency for fractured aquifers of the Wyllies Poort Formation (Msw)

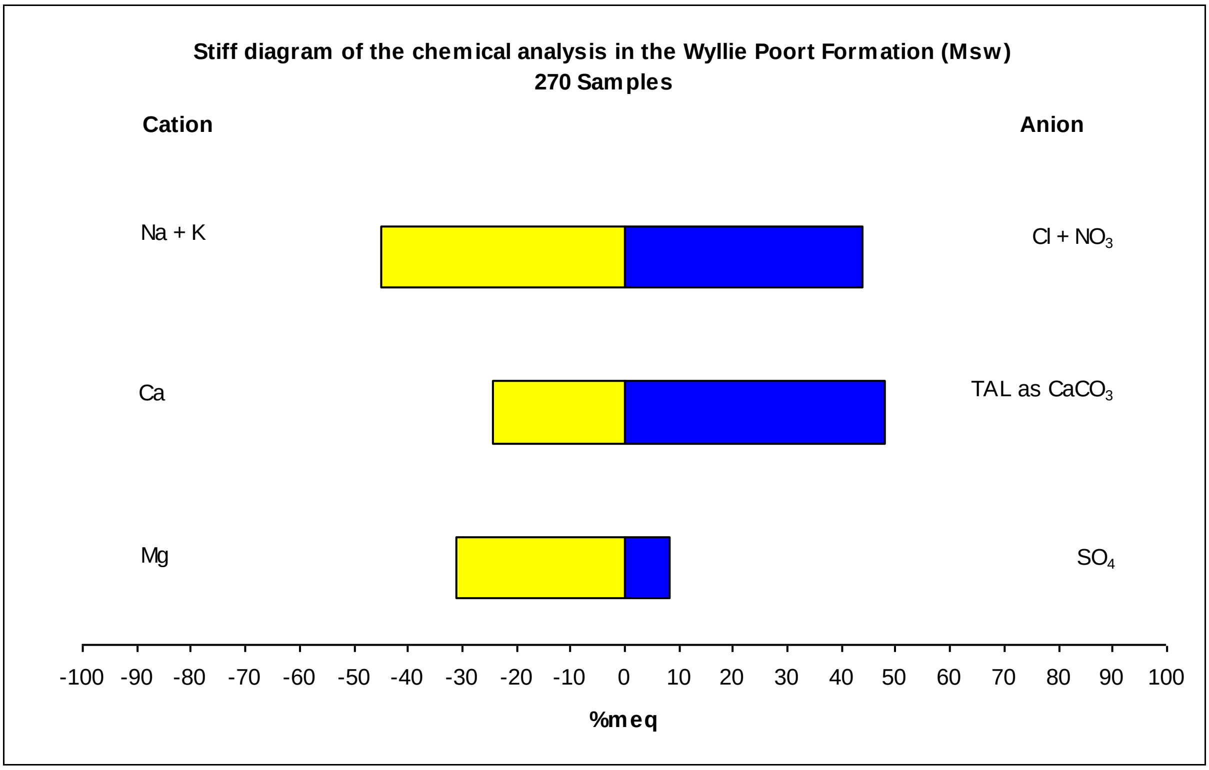

Figure 33: Stiff diagram representing chemical analysis of the Wyllies Poort Formation (Msw)

The stiff diagram (Figure 33) shows the broad classification according to anions and cations. The water exhibits a sodium-magnesium-calcium-bicarbonate-chloride character. The bicarbonate type of water is generally associated with movement of groundwater from recently recharged areas and indicates a cation exchange process. It is difficult to explain the Chloride character. The water quality is ideal to acceptable in approximately 90% of the sampled sources. EC values ranges from 3 – 912mS/m, with the harmonic mean calculated as 18mS/m. The chemical results from groundwater sampled in the unit do not show significant quality problems. In 85.6% of the sampled boreholes used in the analyses, the concentration of Chloride falls within the Ideal Class (Cl < 100mg/l). In 92% of the samples, nitrate and nitrite (presented as N) and fluoride concentrations falls within the ideal domestic water class (N < 6mg/l), (F < 0.7mg/l). Seven or 0.2% of the samples exceeds the acceptable limit (N > 10mg/l). The samples with poorer water quality is located near villages showing that poor sanitation practices combined with a shallow sandy overburden and open fractures in the sandstone/quartzite might contribute to the higher concentrations.

The Wyllies Poort Formation occurs mainly in moderately populated rural areas as well as the northern part of the Kruger National Park. Groundwater is abstracted to supply in the domestic and agriculture demand of small to medium villages as well as for the nature reserve. In the south-western part of the formation, groundwater is utilized in periods of drought for avocado and nut orchards.

7.2.1.7.3 FUNDUDZI FORMATION (Msf).

The Fundudzi Formation has a maximum thickness of 2800m in the vicinity of Lake Fundudzi thereafter it decrease rapidly to the west. The Formation consists of arenaceous and argillaceous rocks with intercalated bands of lava. The arenaceous rocks consist of white, pink or purple sandstones, locally quartzitic and in places well laminated. Grain size varies from fine to very coarse grading in places into conglomerate. The argillaceous sediments are interbedded within the sandstone consisting of brownish or purple micaceous sandy shale, grey or dark-red shale and thinly laminated, dark-grey siltstone (Brandl, 1981, 2002).

The water bearing formation (weathered and fractured zones) is limited to a depth of 60m. The groundwater exploration potential in this formation is considered low to very low. One of the conclusions reached from groundwater studies done in the Kruger National Park is that the transmissivity in the Fundudzi Formation decreases with depth. Occurrence of groundwater in this Formation is limited to secondary openings associated with geological structures such as faults, shear zones, dykes and sills. It is considered a double porous medium. The water is typically stored within the rock matrix, with the fractures (if present) as the water carrying medium. Due to the low transmissivity of the Formation groundwater potential is very low unless secondary fractures and fissures are present (Du Toit, 1998).

The sedimentary rocks of this Formation have low to very low primary permeability with low storage potential. The results of the yield frequency diagram show a positive tendency to the higher yields that is contradictive to studies done. This can be attributed to the use of scientific approved methods in the search for groundwater over the past years that specifically targeted geological lineaments. The statistics indicate that 40% (Figure 35) of the successful boreholes yield more than 2ℓ/s, 42% yield between 0.5-2ℓ/s and 18% is less than 0.5*l/s*. 11% of the boreholes were drilled dry.

The stiff diagram (Figure 36) represents 135 groundwater samples. The water exhibits a magnesium-calcium-sodium-bicarbonate-chloride character. Water is abstracted mainly for rural domestic supplies, livestock watering and in the Kruger National Park for game watering and domestic use. The quality of the water is generally very good with 92% of the samples having EC values less than 150mS/m. (Harmonic mean for unit = 22.8mS/m). The water quality is ideal to acceptable in approximately 90% of the sampled sources.

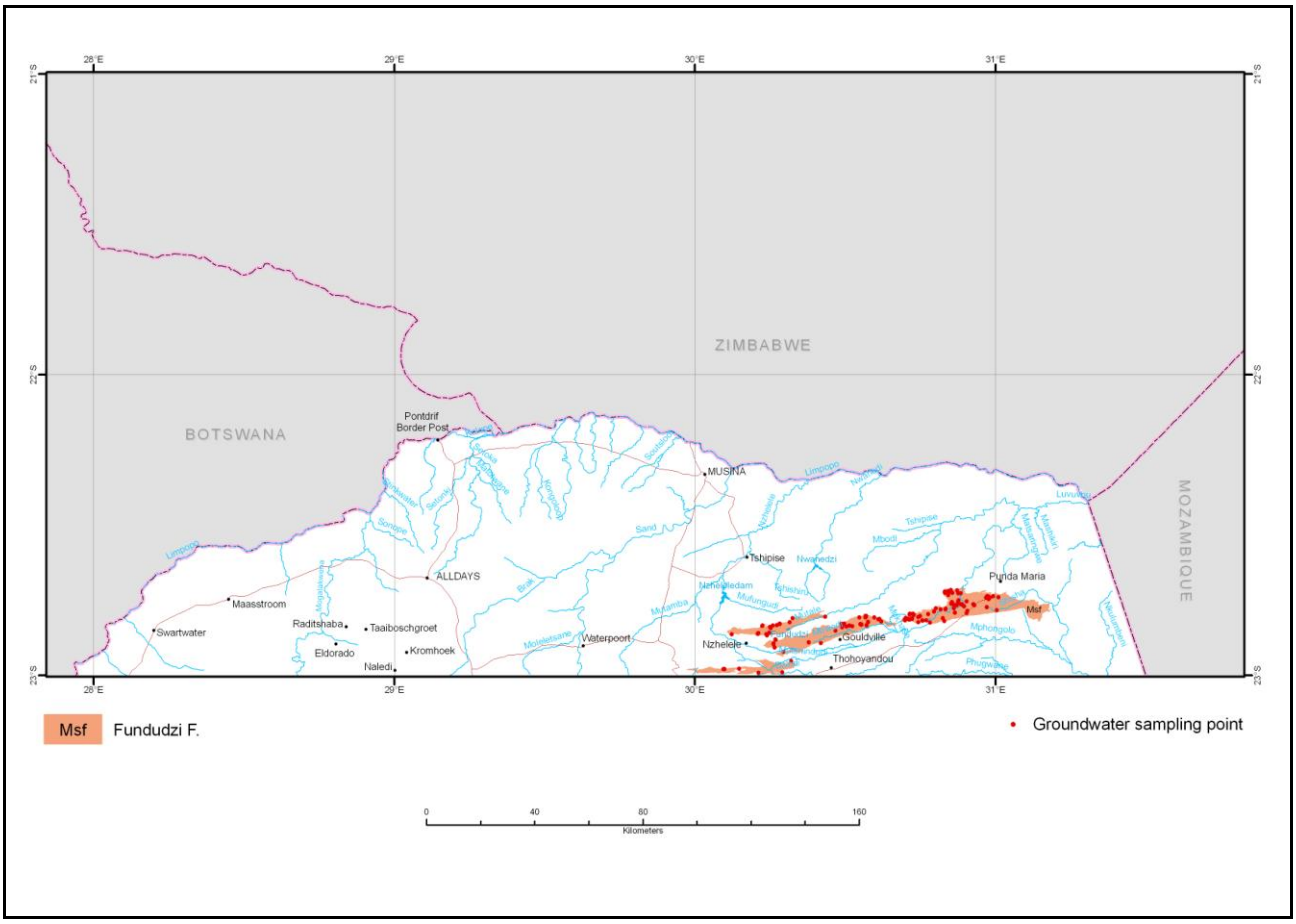

Figure 34: Geographical distribution of the Fundudzi Formation (Msf) and the associated groundwater sampling points

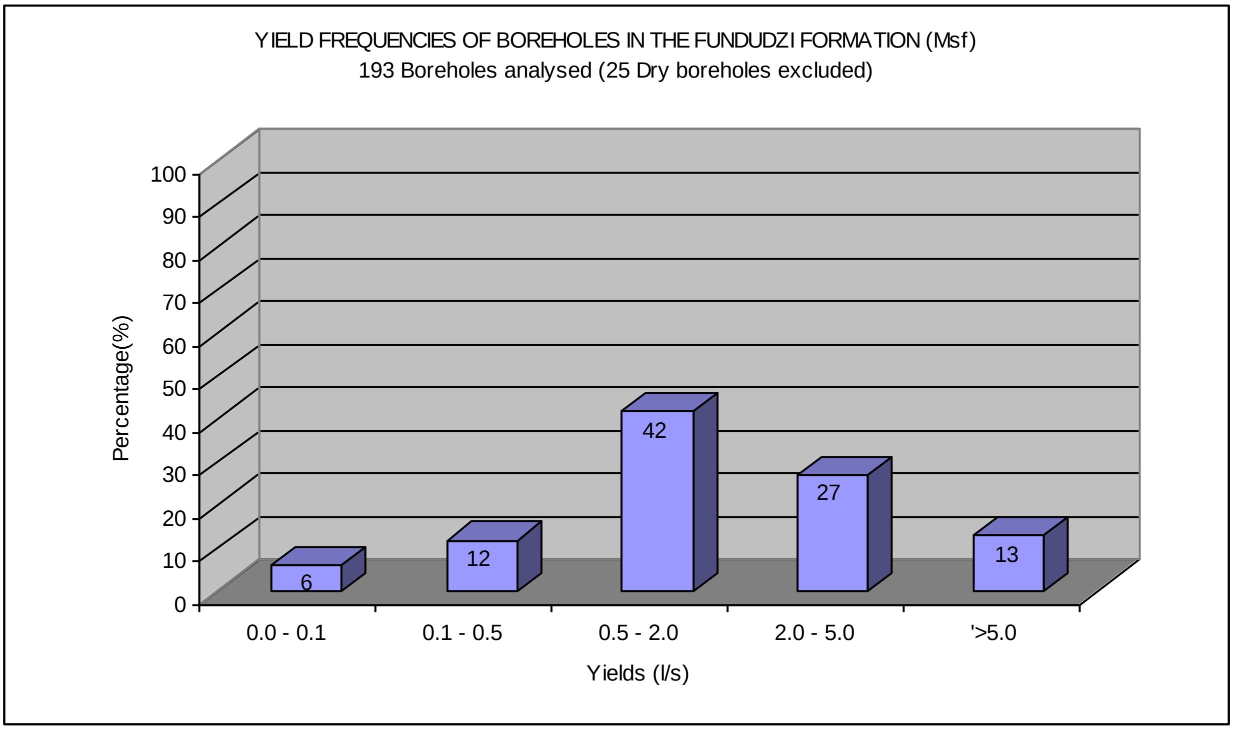

Figure 35: Yield frequency for fractured aquifers of the Fundudzi Formation (Msf)

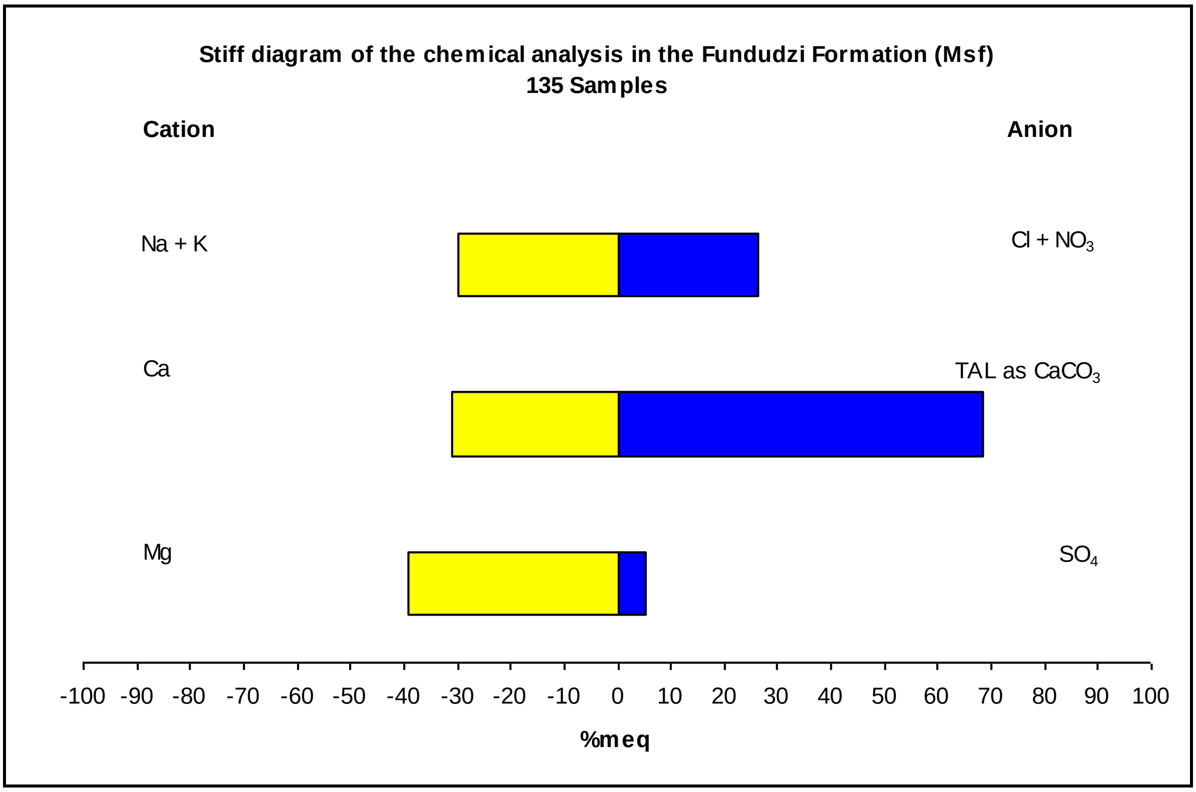

Figure 36: Stiff diagram representing chemical analysis of the Fundudzi Formation (Msf)

7.2.2 CATEGORY C: KARST AQUIFERS.

No karst aquifers occur within the map area and therefore not further discussed.

7.2.3 CATEGORY D: INTERGRANULAR AND FRACTURED AQUIFERS.

- Lebombo Group (Jl)
    - Letaba Formation
- Dolerite (Jd)
- Clarens Formation (Trc)
- Diabase (N-Zd)
- Soutpansberg Group (basalt) (Ms)
    - Sibasa Formation (Mss)
    - Stayt Formation (Msa)
- Bulai Gneiss (Rbu)
- Hout River Gneiss (Rho)
- Sand River Gneiss (Zsa)
- Alldays Gneiss (Zal)
- Messina Suite (Zbm)
- Madiapala Syenite (Zma)
- Goudplaats Gneiss (Zgo)
- Beit Bridge Complex (Z)
    - Gumbu Group (Zbg)
    - Malala Drift (Zba)
    - Mount Dowe Group (Zbo)

Intergranular and fractured aquifers cover approximately 70.29% of the total map area. Figure 37 shows the Geographical distribution of the intergranular and fractured aquifers.

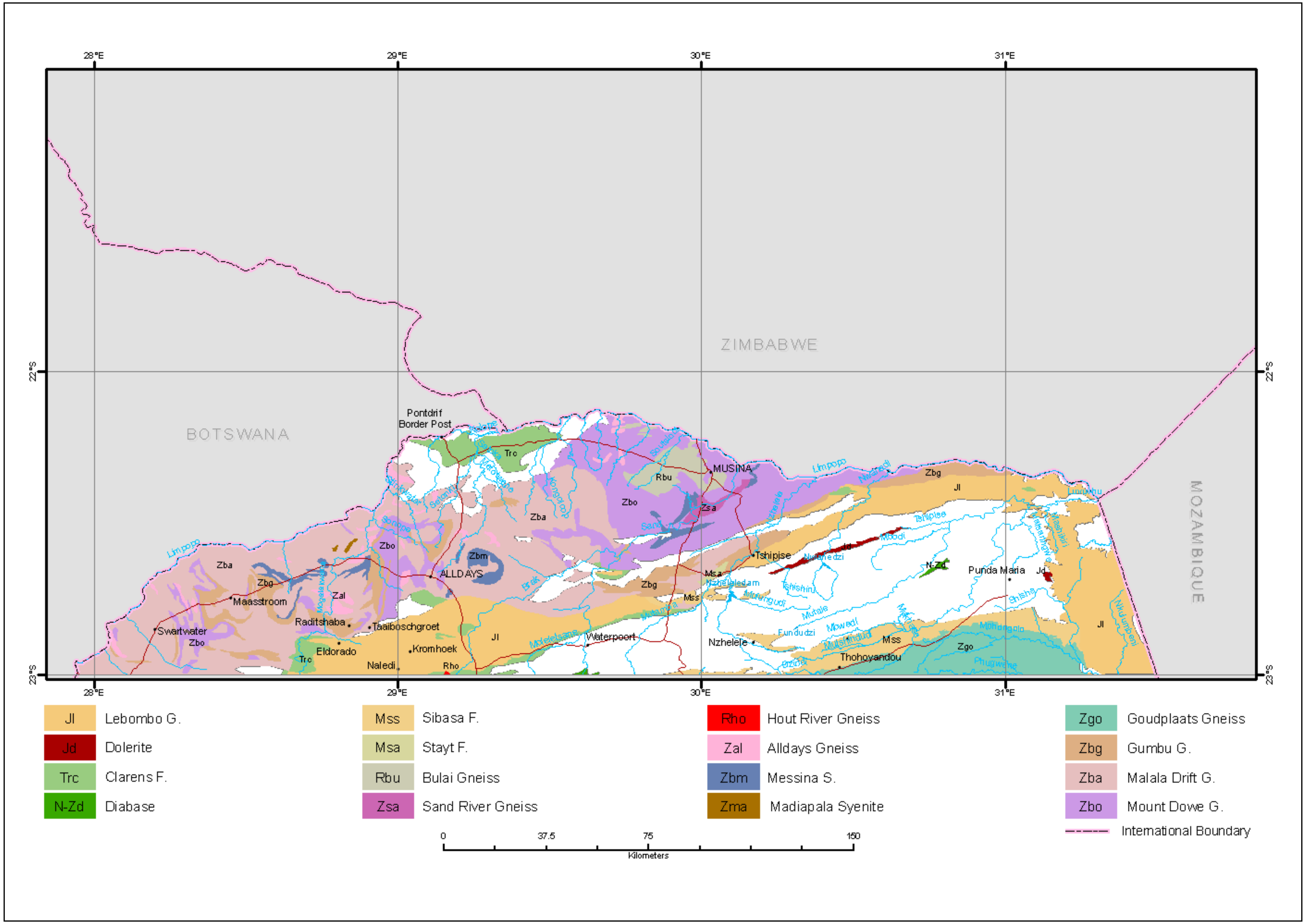

Figure 37: Geographical distribution of the intergranular and fractured aquifers

7.2.3.1 LEBOMBO GROUP (Jl)-Letaba Formation.

The outpouring of lava marked the end of the sedimentary deposits of the Karoo Supergroup. Two Formations of the Lebombo Group occurs within the map sheet. The youngest, the Jozini Formation occurs in a very small area in the eastern part of the map sheet and is discussed in section 5.1.1.1. It overlays the Letaba Formation a name applied to all basaltic lava of Karoo age in the Limpopo Province. In the Tuli basin, the unit is represented by isolated remnants (not shown) while it is more representative and wide spread in the Tshipise and Lebombo basins (Figure 38). It covers approximately 16.1% of the map area and is an important aquifer in the Tshipise basin in the sense that groundwater is abstracted for irrigation and regional supply from fault zones delineating the northern (Tshipise fault progressing into the Taaibos fault) and the southern boundary (Bulkop, Senotwane and Phareng faults) of the basin respectively. Deep boreholes (100-300m) targeting deep secondary fracturing within the basalt and sandstone of the underlying Clarens Formation also yielded good success. The Clarens Formation is conformably overlain except south of Punda Milia where the Letaba Formation directly overlays rocks of the Soutpansberg Supergroup or basement gneisses (Schutte, 1986). Areas underlain by this Formation characteristically consists of flat terrain with poor outcrop and a black clayey soil "turf" overburden. The basalt is massive, fine-grained, dark-grey with minor amygdales (pine-like cavities of gas chambers) of zeolite, quarts, calcite and chalcedony or chert that occurs in thin intercalated flows. In the Tuli basin the absence of pyroclastic material and the lack of evidence of violent eruptions indicate that the lava was of the non explosive, fissure-flow type (Brandl, 2002).

The potential of the formation itself is considered low to average. Studies done in the Lebombo basin found that in the absence of geological lineaments and where the formation is too thick to encounter the underlying Clarens Formation, the recommended targets for groundwater strikes relate to weathered and fractures zones within the Basalt. With a decreasing transmissivity with depth within this Formation borehole yields decreases with depth. It is recommended that a maximum of 80m to 90m should be drilled for groundwater exploration purposes (Du Toit, 1998). An interesting phenomenon was found in some holes drilled near Sigonde, a village within the Tshipise basin where the underlying Clarens formation is considered too deep to explore with normal groundwater projects. It was found that some boreholes encountered highly fractured basalt but were dry or almost dry (muddy) during drilling. Pumping tests during the DWA GRIP project were done on these boreholes with constant tests up to 8*l/s* completed (Lubbe, personal communication, 2011).

In a study carried out on the farm Kromhoek 438MS to determine the groundwater potential of the **Tshipise sandstone underlying the Letaba Basalts** it was determined that the basalt has no primary permeability, but when fracturing/jointing occurs as a result of localised stress releases or minor faulting followed by hydro-chemical weathering (in varying phases) a high degree of secondary permeability of several orders higher than the primary basalt rock can develop. The effect of the hydro-chemical weathering process of the basalt tends to go through different phases (from a slightly fractured to blocky, jointed and finally to a soft decomposed clayey residue/soil). The most promising phase in terms of permeability and storage is where the basalt portrays a blocky and jointed (micro-fractured) appearance. Once the hydro-chemical weathering process has commenced, the basalt tends to weather as deep as between 15 to 25m from surface. Where secondary structures and probably the most recently larger fracture/fault zones are present weathering may develop as deep as 95 m below surface. Differential weathering of the basalt, however, has resulted in secondary mineralization and subsequent sealing of many of the secondary fractures/joints. The thickness of the basalt in the Kromhoek study area varies from 99m to 202m. The hydrochemistry of the basalt is influenced by a natural built-up of nitrate either due to nitrification enhanced by the Acacia trees or the heavy decomposition of the basalt or both. Nitrate (NO_2 + NO_3 as N) concentrations in the order of 15 – 21mg/l have been recorded in the Kromhoek 438MS study area during sampling (IAEA study, 1999-2003).

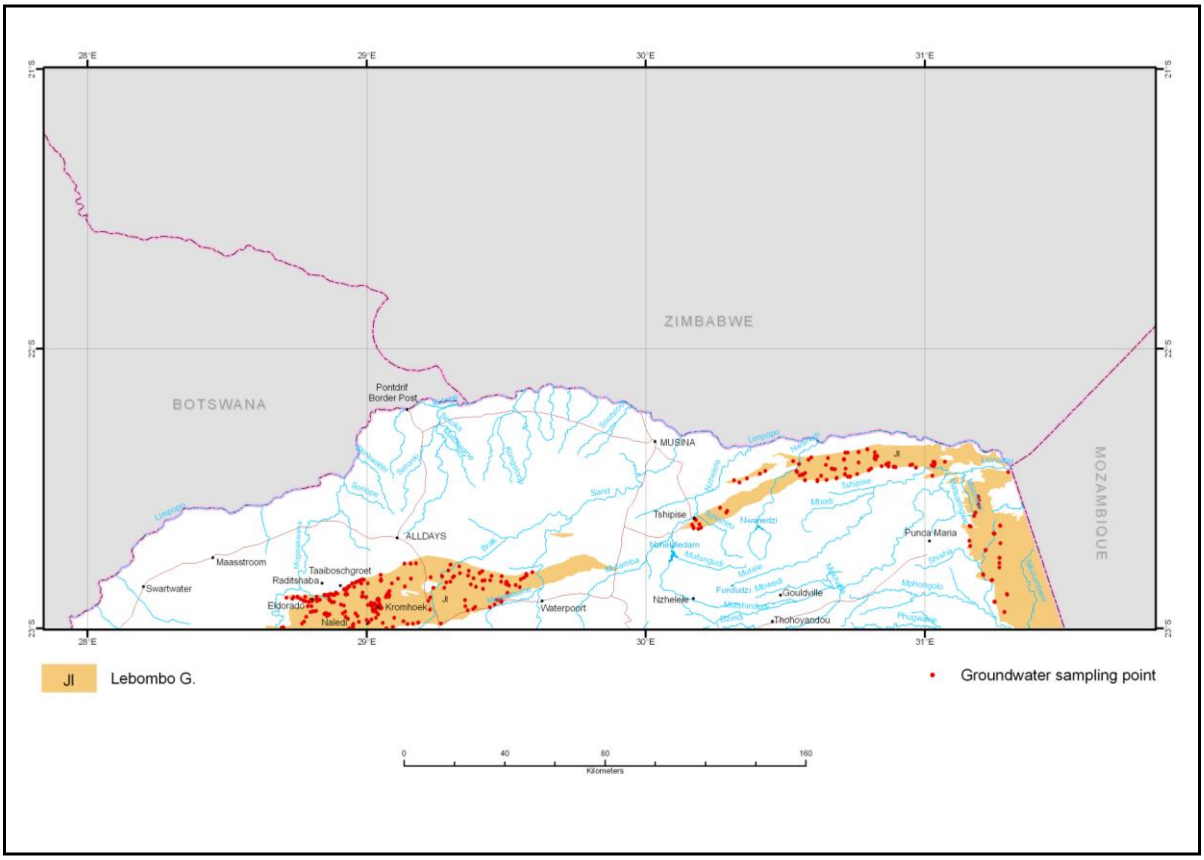

Figure 38: Geographical distribution of the intergranular and fractured aquifers of the Lebombo Group (Jl) and associated groundwater sampling points.

Statistics revealed that 30% (Figure 42) of the successful boreholes yield between 0.5 and 2*l/s* with 47% yielding more than 2*l/s*. Low yielding boreholes less than 0.5*l/s* is 23% with 8% recorded as dry. The depth to groundwater level varies between 10 and 40mbgl.

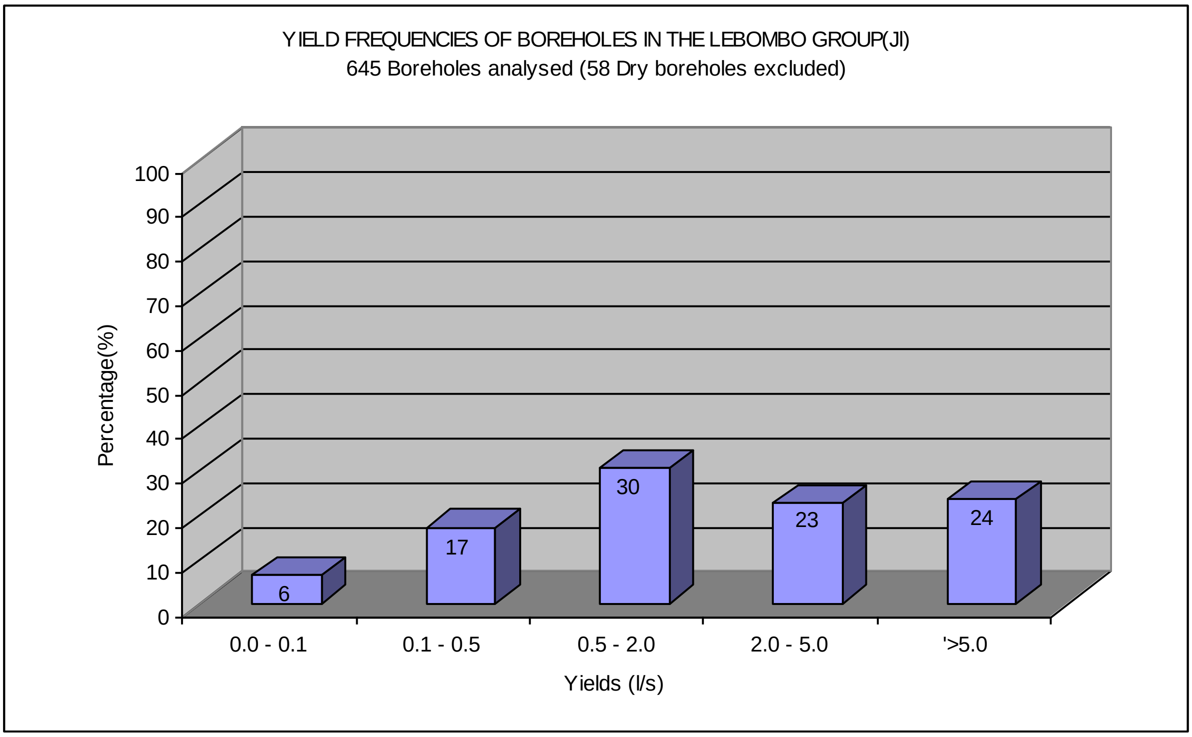

Figure 39: Yield frequency for the intergranular and fractured aquifers of the Lebombo Group (Jl)

Groundwater abstraction includes agriculture uses (livestock and irrigation), single village and regional village domestic water supply as well as for conservation purposes in the Kruger National Park. In many places it is the only source of water despite the elevated **nitrate (N)** concentration which is evenly distributed throughout the unit.

97.5% of the reported EC values (EC <150mS/m) falls within the ideal to maximum allowable limits (EC < 370mS/m) for domestic use. The chemical analysis available for nitrate and nitrite concentrations (reported as N), shows that 55.8% falls within the ideal to acceptable range (N < 10mg/l) and 19.2% outside the maximum allowed limit (N > 20mg/l). The concentration for (N) varies between 0.02 to 108mg/l with a harmonic mean of 0.41mg/l and an arithmetic mean of 12mg/l for the unit. The general water type can be described as a sodium-bicarbonate and chloride water with elevated calcium concentrations possibly related to reverse ion exchange (replacement of Na^+ with Ca^{2+} and Mg^{2+}). Elevated fluoride, chloride, and sodium concentrations occur in samples near the Tshipise hot water spring. Sources with elevated fluoride are also more dominant in the Lebombo Basin while sources with elevated magnesium concentrations occur randomly. Although the groundwater is rated as hard to very hard it is considered good potable quality (all constituent levels within the maximum allowable limits) with the exception of the nitrate levels. This is typical of groundwater contained in basalt aquifers.

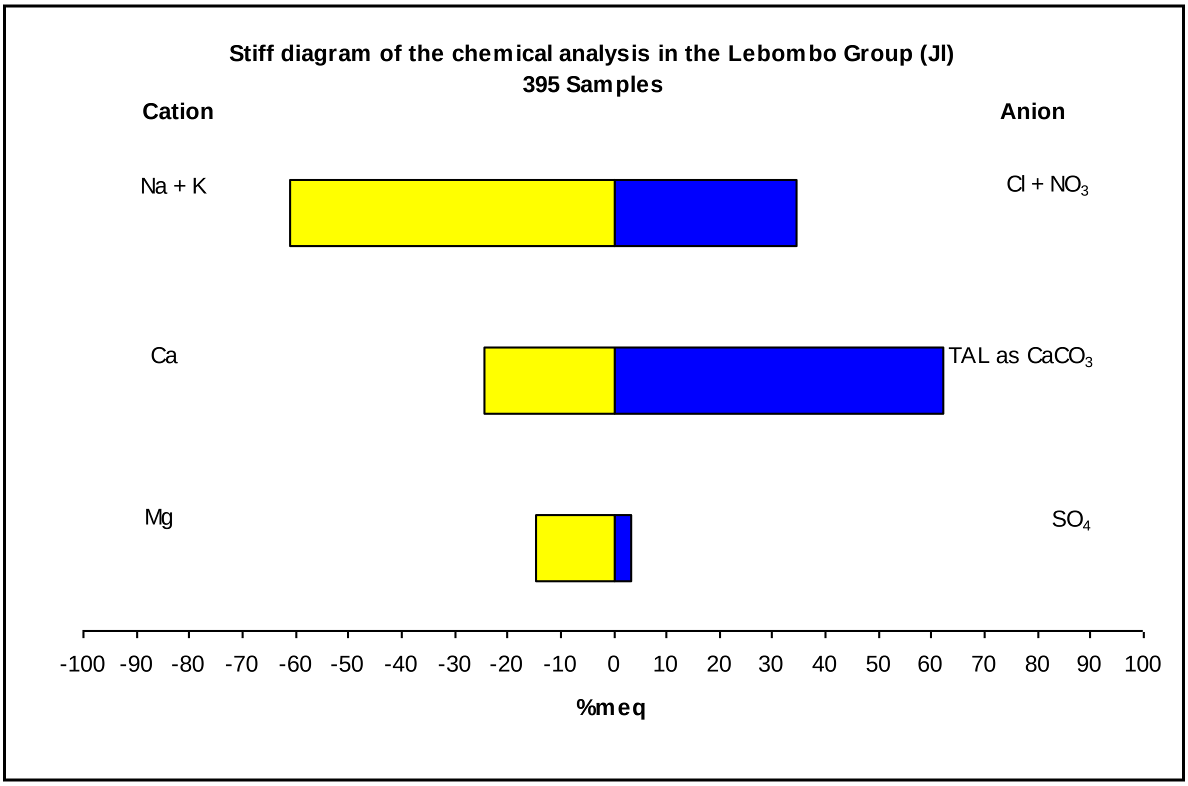

Figure 40: Stiff diagram representing chemical analysis of the fractured and intergranular aquifers of the Lebombo Group (Jl)

7.2.3.2 DOLERITE (Jd)

The most widespread intrusive rock of post-Karoo age is dolerite occurring as sills and dykes. The scale of the maps prohibits the inclusion of all dyke intrusions and only the prominent sills are shown on the map (Figure 41).

Within the Tshipise basin dolerite intrusions generally form thick semi-concordant to concordant sheets (up to 200m) in the argillaceous sediments beneath the Solitude Formation in the area north of the Klein Tshipise fault. The rock is generally fine grained to aphanitic of lustrous black colour (Brandl, 1981). Outcrop is usually easily identified within the soft sediments. The occurrence of these sills are indicated by a perpendicular cross section to regional strike of the geology on an inset map included on the 1:250 000 geological map sheet, 2230 Messina. The sills are shown as parallel intrusions between the lower formations of the Karoo Supergroup dipping moderately to the north. In the south-western part of the basin dolerite sills overlay all the sedimentary formations of the Karoo Supergroup. Dolerite dykes in the south-western part of the Tshipise basin trend easterly and some slightly more north or southerly. Within the north-eastern part of the basin the dykes do not exhibit a dominant trend as it strikes in almost all the directions.

Within the Lebombo basin one prominent sill is depicted on the map near the border with the National Kruger Park in the east (Figure 41). In the southern part of the basin fewer dykes are indicated on the 1:250 000 geological map sheet, 2230 Messina, although east to west trending geological lineaments occur that are most probably related to dolerite intrusions. Towards the northern part of the basin dykes with a more dominant north-northwest trend were observed.

In the Tuli basin, dykes are abundant in the area close to the confluence of the Limpopo and Shashi Rivers and may be classed as a dyke swarm (Chidley, 1985). The major trend of dykes is east-west with a subordinate northeast/southwest trend.

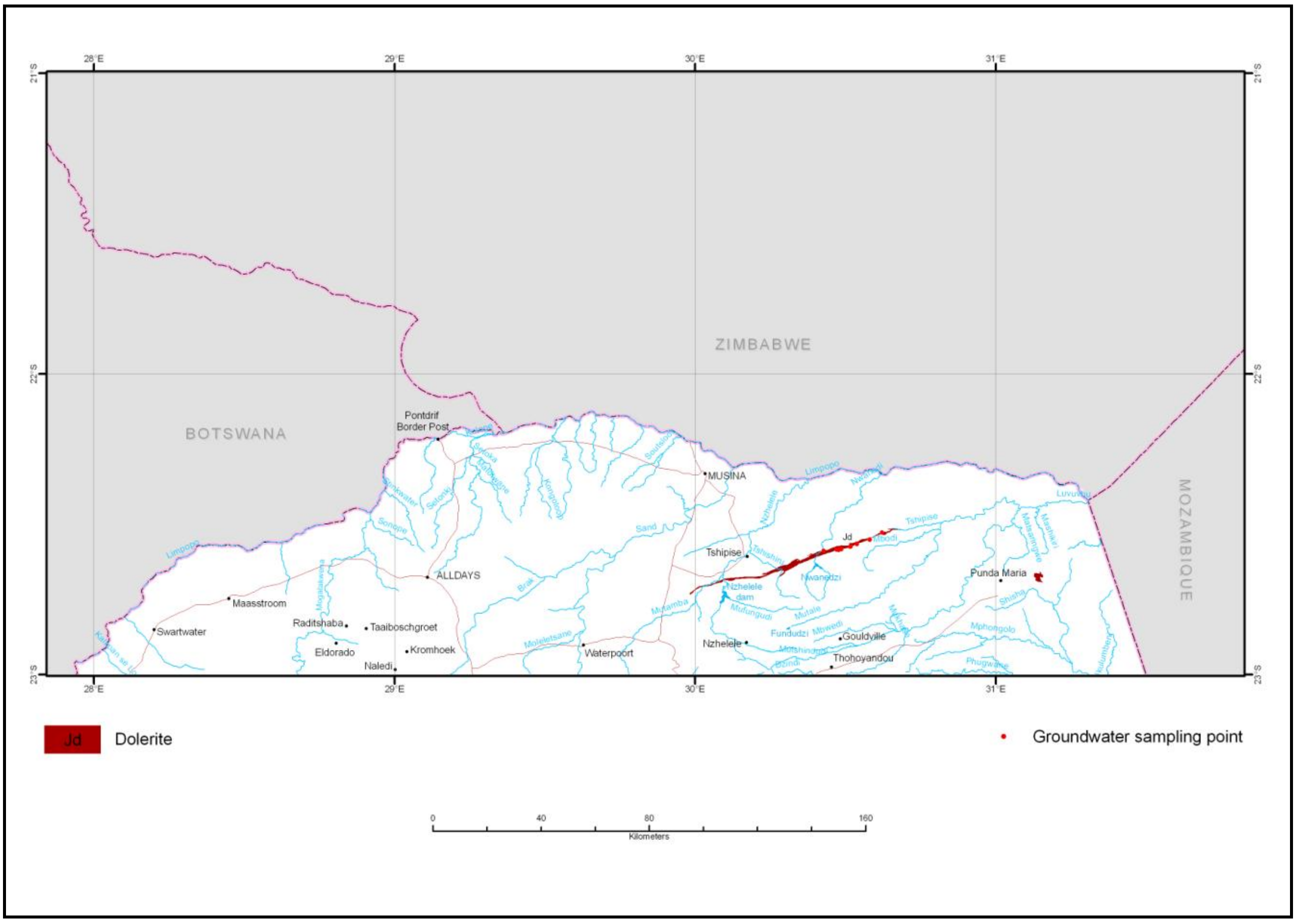

Figure 41: Geographical distribution of the intergranular and fractured aquifers of the Dolerite Intrusions (Jd) and associated groundwater sampling points

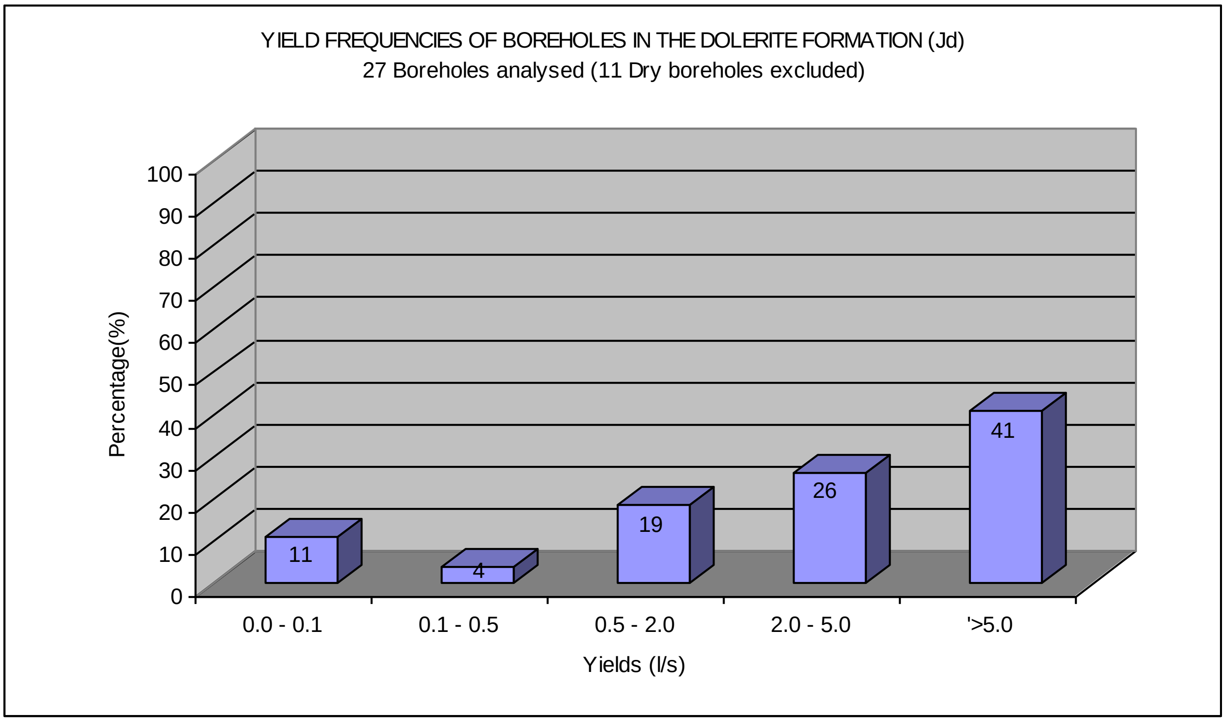

Figure 42: Yield frequency for the intergranular and fractured aquifers of the Dolerite Intrusions (Jd)

Statistics indicate that 41% of the successful boreholes yield more than 5*l/s* with 45% yielding between 0.5 and 5*l/s*. It appears from the yield frequency that the groundwater potential is good within this unit with a more than average change of striking a borehole with a high yield. 29% of the holes are dry indicating that scientific methods should be employed to locate drilling sites.

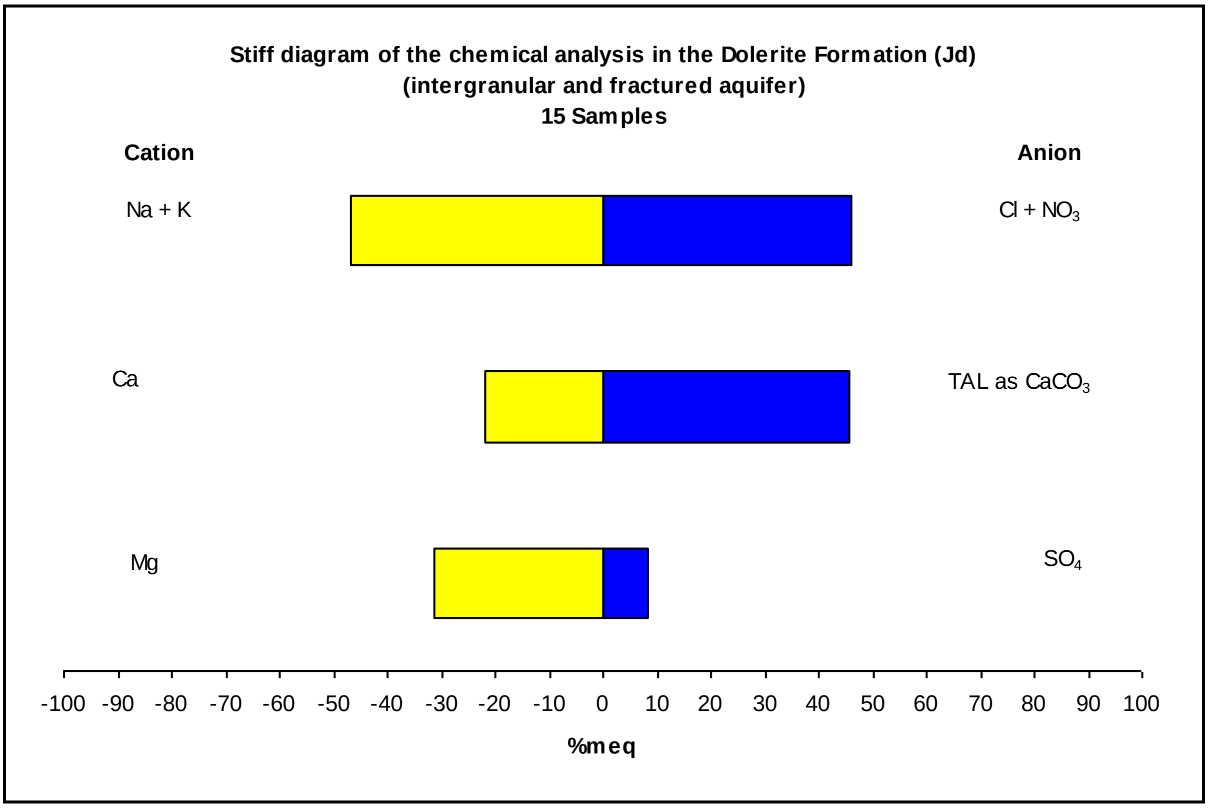

Figure 43: Stiff diagram representing chemical analysis of the fractured and intergranular aquifers of the Dolerite Intrusions (Jd)

Figure 43 shows the broad classification according to anions and cations of the unit. The water displays a sodium-magnesium-calcium-bicarbonate-chloride character. The quality of the water is generally good to moderate as all the EC values falls under the maximum allowable limit (EC < 370mg/l) with 73.3% within the ideal to acceptable range (EC < 150mS/m). No fluoride, sodium, potassium, sulphate and calcium concentrations exceed the maximum allowable limits for drinking water. Unacceptable high concentrations of Magnesium occur in 20% of the samples (Mg > 100mg/l), Nitrate (N > 20mg/l) in 14.3% of the samples and Chloride (Cl > 600mg/l) in 6.7% of the samples. Slightly higher than average fluoride concentrations occurs in sources near the contact with Letaba Basalt. The other elevated elements occur randomly throughout the unit. The above statistics will differ in each of the major set of dykes as the geological and hydrogeological conditions are different.

7.2.3.3 CLARENS FORMATION (Trc)

The Formation is divided into two members, the **Red Rocks Member** and the overlying **Tshipise Member** which together attain a thickness of approximately 200m in the Tuli and Tshipise Basins.

The Red Rocks Member is generally a very fine-grained to fine-grained, white and pinkish to red, argillaceous **sandstone** with a characteristic mottled appearance. In the Tuli Basin the thickness is more or less 40m and in the Tshipise Basin it has a fairly constant thickness of approximately 100m with a maximum thickness of 150m reported near Tshipise. The thickness of the overlaying Tshipise Member is extremely variable in the Tuli Basin, the contact often sudden, consisting of pinkish sandstone near the base but otherwise homogenous whitish fine-grained sandstone. Outcrop forms flat topped kopjes underlain by Red Rock lithologies forming concave slopes with caves often developed immediately below the contact. In the Tshipise basin the thickness of the Tshipise Member is more constant with thicknesses reported as 100m in the east and 130m in the southwest. It often forms local spectacular topographic features with steep cliffs and rugged hills. It is composed essentially of fine-grained whitish to cream coloured matured sandstone (Brandl, 2002).

In a study carried out on the farm Kromhoek 438MS to determine the groundwater potential of the Tshipise sandstone underlying the Letaba Basalt, it was found that the sandstone aquifer is by far superior in quantity and quality compared to the overlying basalt aquifer. Blow yields of up to 40*l/s* were obtained in the sandstone in the vicinity of Kromhoek 438MS and Terveen 381MS. The boreholes that penetrated the Karoo sandstone below the basalt gave increasing blow yields of good quality water from the first strike down to final depth. The hydraulic conductivity is determined mainly by fracturing of the sandstone but a progressive increase in yield was observed also in a section of sandstone in which no fractures were observed. The aquifer therefore appears to have significant primary porosity. In contrast to the high nitrate concentrations of water in the basalt aquifer several samples taken from the much deeper seated and probably wider recharged Tshipise Sandstone show a much better water quality (N < 5mg/l), (IAEA study, 1999-2003). The above characteristics were also found in groundwater development projects for various farmers and villages in the rest of the Tshipise basin from north of Vivo to the far north-eastern Vhembe District.

Plate 5: Mapungubwe Hill, a world famous archaeological site, artifacts found includes a golden rhinoceros. The hill consists of sandstone belonging to the Clarens Formation. The locality is within the Thuli Basin near the confluence of the Shashi and Limpopo Rivers. The photo is from Google images, unknown photographer (Photo obtained January 2011).

Plate 6: Aventura Holiday Resort at the Tshipise hot spring. The photo is from the northeast. The mountain on the horizon is the northern slope of the Soutpansberg Mountain range (Wyllies Poort Formation), the low area is the Tshipise basin underlain by rocks of the Karoo Supergroup with the first small ridge north of the Soutpansberg formed by outcrop of the Clarens Formation, and the next low area is underlain by basalt of the Letaba Formation. The high ridge in the foreground at the resort is sandstone of the Clarens Formation and north of the road is granitoid rocks of the Gumbu Group. The Tshipise fault cuts oblique through the road following the northern escarpment of the high ridge in the foreground. (Photo, Aventura Resort web site, photo obtained 2009).

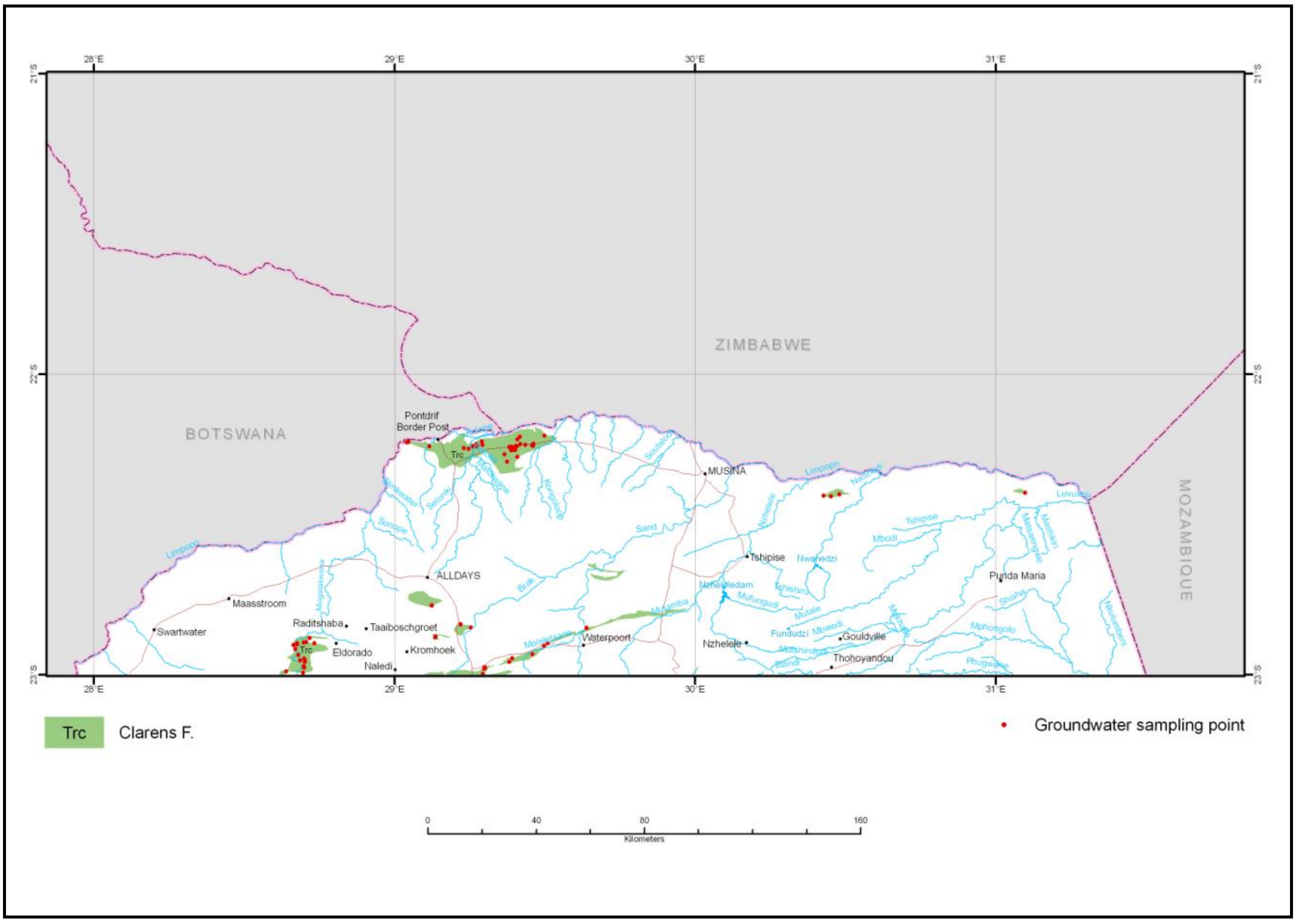

Figure 44: Geographical distribution of the Clarens Formation (Trc) and the associated groundwater sampling points

The contact zone between basalt and sandstone yields varying quantities but are usually < 0.5ℓ/s. Higher yielding water strikes are generally intercepted in the sandstone between 40 and 75m below the main basalt/sandstone contact. The harmonic mean of the reported EC values in Table 6 does not show that the sandstone (EC = 90mg/l) has a better quality than the overlaying basalt (EC = 86.1mg/l), field research established that the quality improve if water strikes are encountered in the underlying sandstone.

The groundwater potential in the Clarens Formation is considered moderate to good, although the primary permeability and storage potential is low. It seems that the depth of the weathered and broken zones within the Formation is playing an essential role in the potential yield of the borehole. The Formation bears a residual primary water bearing character as in progressively increasing yield with depth of weathering. Geological structures like faults and dolerite intrusions are also good targets for ground water exploration within this Formation (Du Toit, 1998). The unit covers approximately 3% of the total map area.

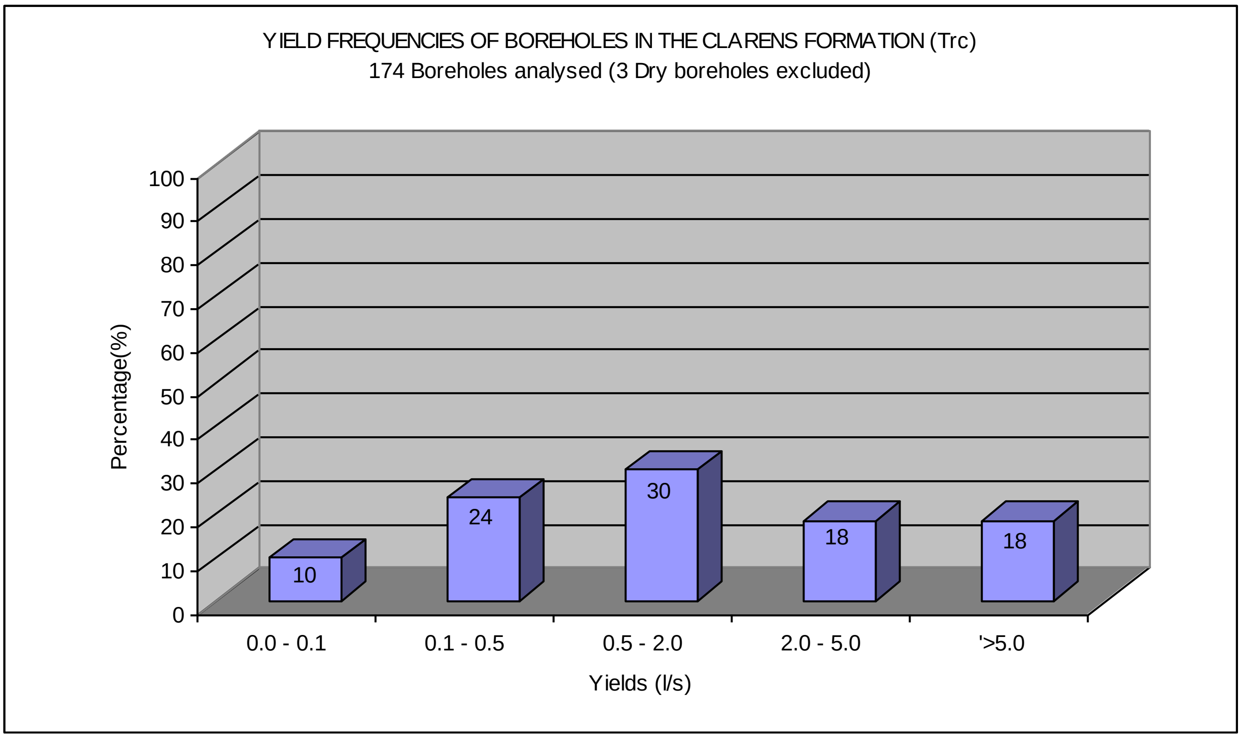

Figure 45: Yield frequency for the intergranular and fractured aquifers of the Clarens Formation (Trc).

Statistics reveal that 64% (Figure 45) of the successful boreholes yield less than 2ℓ/s. The contact zone with the overlaying basaltic rock yield water of varying quantity. Dolerite intrusions in the form of dykes and sills are targeted as it created secondary fractures and joints at the contact with the host rock. High yielding boreholes occurs in fault and deep fracture zones. The static water level varies between 10 and 30mbgl.

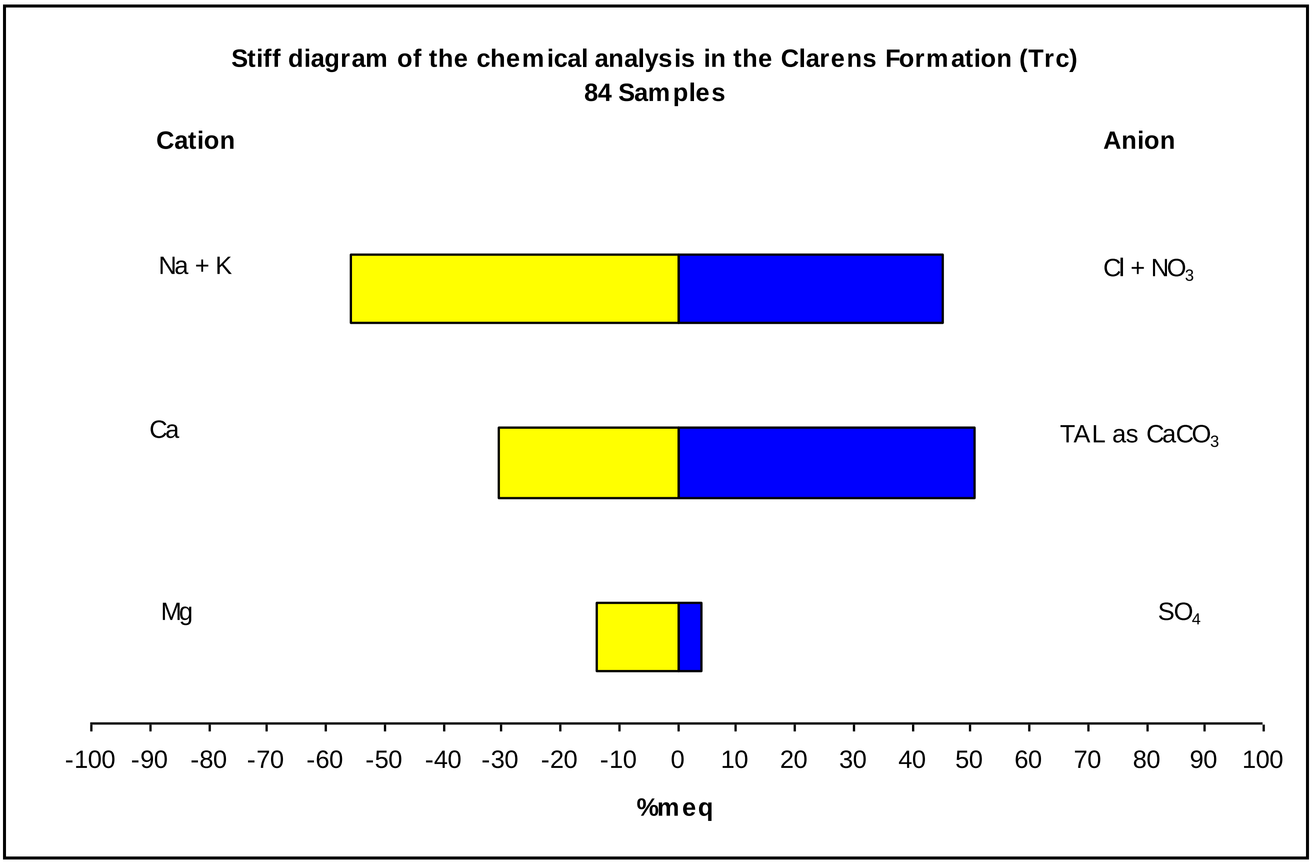

Figure 46: Stiff diagram representing chemical analysis for the fractured and intergranular aquifers of the Clarens Formation (Trc)

Water is abstracted from this unit for domestic use, nature conservation and livestock watering in the central and eastern part of the Tshipise basin with abstraction for irrigation more to the south-western part of the basin. 67.9% of the samples have EC values less than 150mS/m (harmonic mean for the unit is 90mS/m) and 7% with values exceeding the maximum allowable limit (EC > 370mS/m). 12.5% of the samples is unacceptable due to concentrations exceeding the limits for fluoride (F > 1.5mg/l), 13.1% for chloride (Cl > 600mg/l), 8.3% for magnesium (Mg > 100mg/l), 11.9% for sodium and 16.9% for nitrate and nitrite (reported as N), (N > 20mg/l). The sources with problematic chemistry are more or less occurring in clusters, one of these is in the Tuli Basin between Weipe and the farm Cerberus where intensive irrigation occurs. The groundwater in the unit is a sodium-calcium-bicarbonate-chloride water type (Figure 46).

7.2.3.4 DIABASE (N-Zd)

This unit consists of Diabase intrusions that includes sills and dykes that occur in almost all the pre-Karoo formations in the area. The scale of maps prohibits the inclusion of all dyke intrusions (Figure 47).

Within the Beit Bridge gneisses the dominant strike of dykes is east-northeast, with less prominent northeast and east-west trends. Within the Goudplaats gneiss the dominant strike is also east-northeast. Dykes tend to give rise to high narrow ridges in all the older rocks. Sills within the older gneisses are concentrated more or less northeast of Alldays around Venetia mine. The outcrops form almost continuous semicircular morphological structures consisting of at least two concentric inward-dipping rigs (Brandl, 2002).

Within the Soutpansberg Group dykes form negative features. Preferred orientation is east-northeast and less prominent west-northwest. The sills may be several hundred metres thick and are usually found at the interface of lava and sediment or between shale and sandstone. The diabase is generally medium- to coarse-grained dark grey to black rock with greenish to grey colours restricted to diabase within the Soutpansberg strata.

Figure 47 is a poor reflection of the real situation due to inadequate sample representation. The samples grouped under this unit only reflect data from a sill in the Soutpansberg Supergroup as the scale and the GIS method of choosing holes to represent the unit cannot distinguish boreholes drilled along dykes. Six boreholes were available for analysis with three of them dry, thus making an analysis of the unit from this data meaningless. Secondary fractures associated with diabase dykes are good groundwater targets in rocks of the Soutpansberg Supergroup. Dykes occurring within the rocks of the Goudplaats gneiss and Beit Bridge Complex are not regarded as the first priority when exploring for groundwater. South of the map sheet in the Giyani area dykes and contact zones tend to be more fractured and are therefore more successfully developed as groundwater sources. In areas with good outcrop, dykes are more successfully targeted using geophysical methods combined with the visual observation of the dyke and the contact zone. The elimination of non-fractured dykes or anomalies related to amphibolite or greenstone remnants is therefore possible. Within most of the areas secondary fracturing related to faults or joints are the preferred target followed by deep weathering, pegmatite zones and sedimentary transition/contact zones. If the above targets are not found within the area earmarked for a groundwater source, the final drilling position usually relates to a dyke intrusion.

Important detail to consider when choosing a drilling site in the vicinity of a dyke intrusion is width, geological setting, 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 and maps, dykes are usually targeted on the ground in areas along the strike where there is possible weathering (magnetic background data lower) or where joints or fracture zones transect the dyke (bends, discontinuous data). Sills are usually more difficult to drill successfully as the thickness is not always known. Targets associated with sills is the contact with the host rock, deeper than average weathered and fractured zones within the sill, younger intrusions within the sill or the lower contact zone if the sill is not too thick. The above is a general approach and depends on the geological, hydrogeological and physiographical settings of the target area.

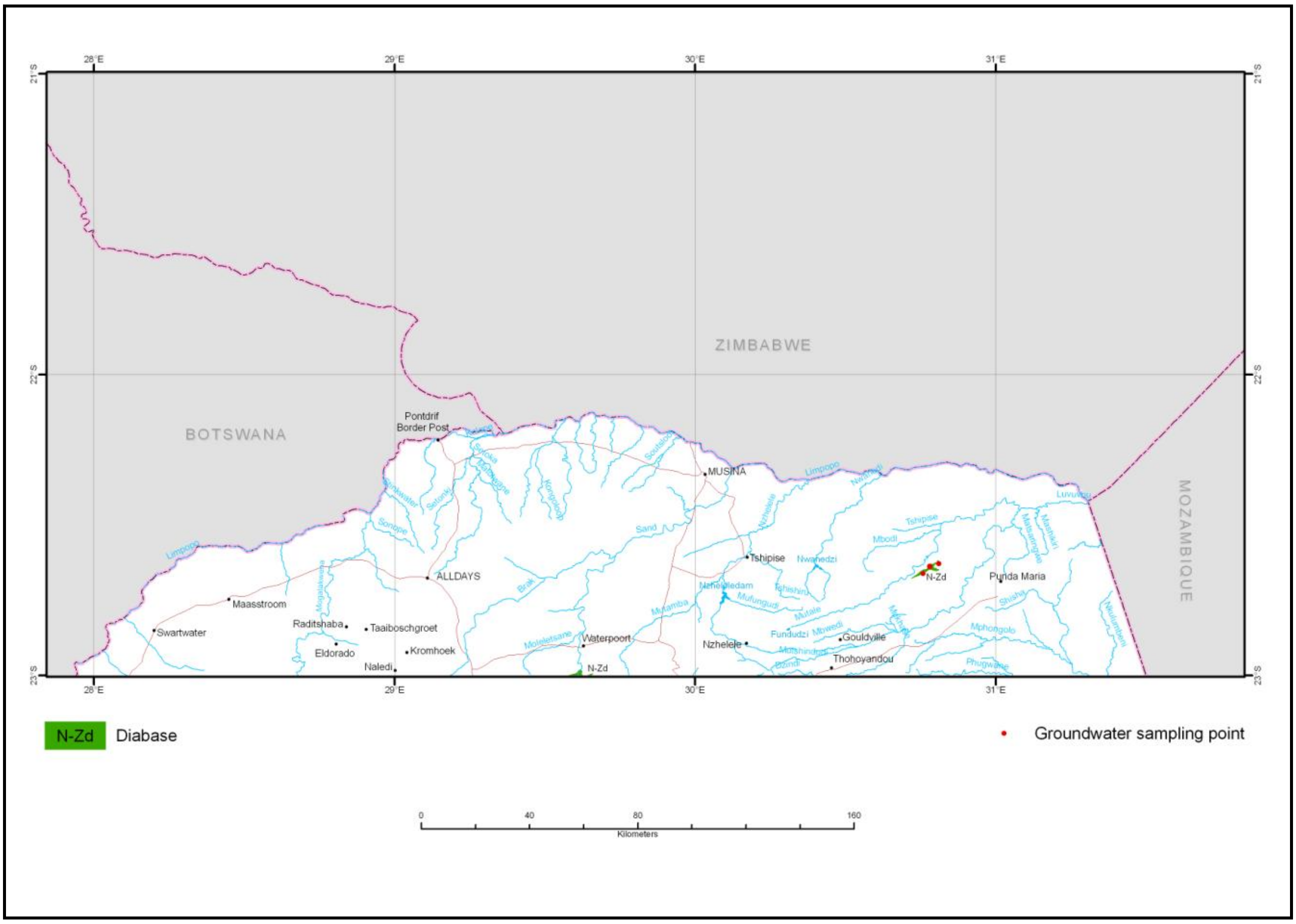

Figure 47: Geographical distribution of the Diabase Intrusions (N-Zd) and the associated groundwater sampling points.

6 Groundwater samples were available and included samples from the 'dry' boreholes. The quality of the water is generally very good. No chemical element exceeded the maximum allowable value in the 6 available samples. EC values range from 32-100mS/m with a harmonic mean value of 51.6mS/m. Figure 49 shows the dominant anions/cations present. The water exhibits a sodium-magnesium-bicarbonate-chloride water type. With more representative samples covering the whole of the map area the analysis might differ due to geological and hydrogeological conditions.

Plate 7: Younger dyke (possible dolerite) intrusion into a very wide diabase dyke in the Pontdrif area. The diabase exhibits typical spheroidal weathering, caused by water promoting chemical weathering within cooling joints. The younger dyke exhibits typical closely spaced jointing, most likely cooling joints where the joints are formed perpendicular to the cooling surface by thermal contraction. If this jointing results in the rock breaking into small 'cube like' fragments it is locally called ''blokkiesklip''. Drilling can be difficult in these dykes as they are highly collapsible but high blow yields are usually obtained (Photo, H. Verster, 2010).

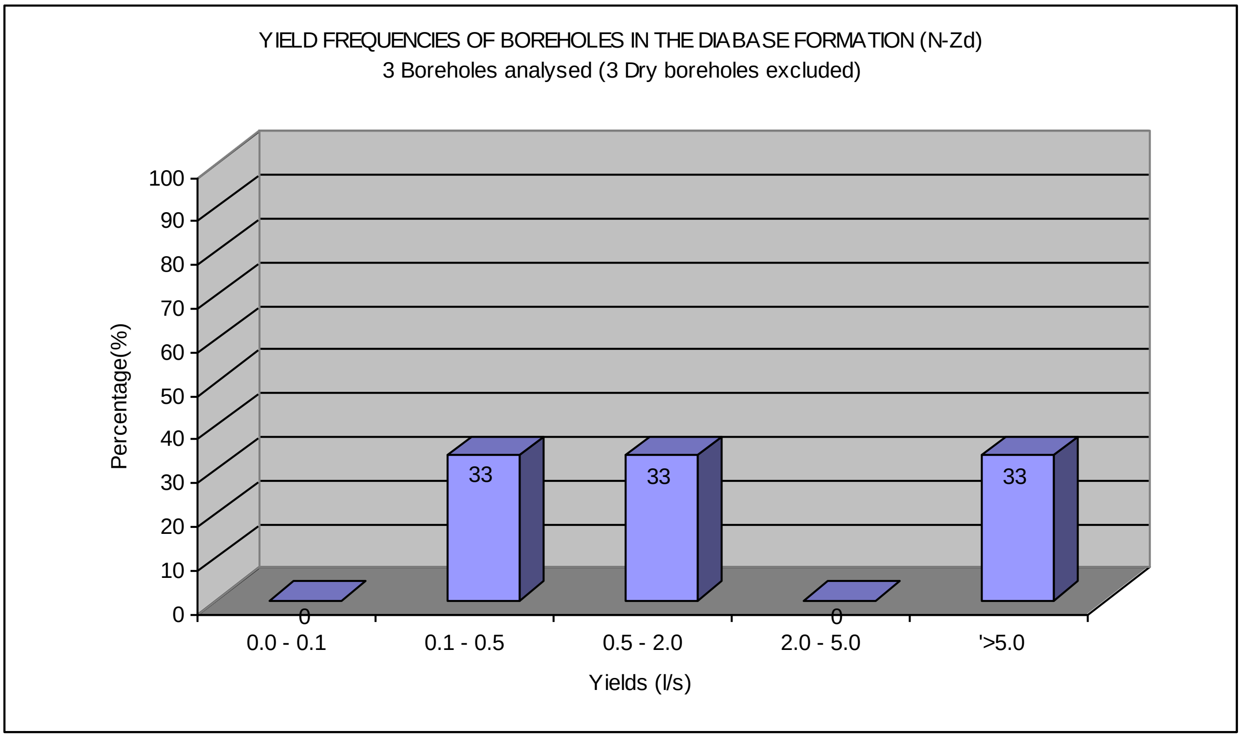

Figure 48: Yield frequency for the intergranular and fractured aquifers of the Diabase Intrusions (N-Zd)

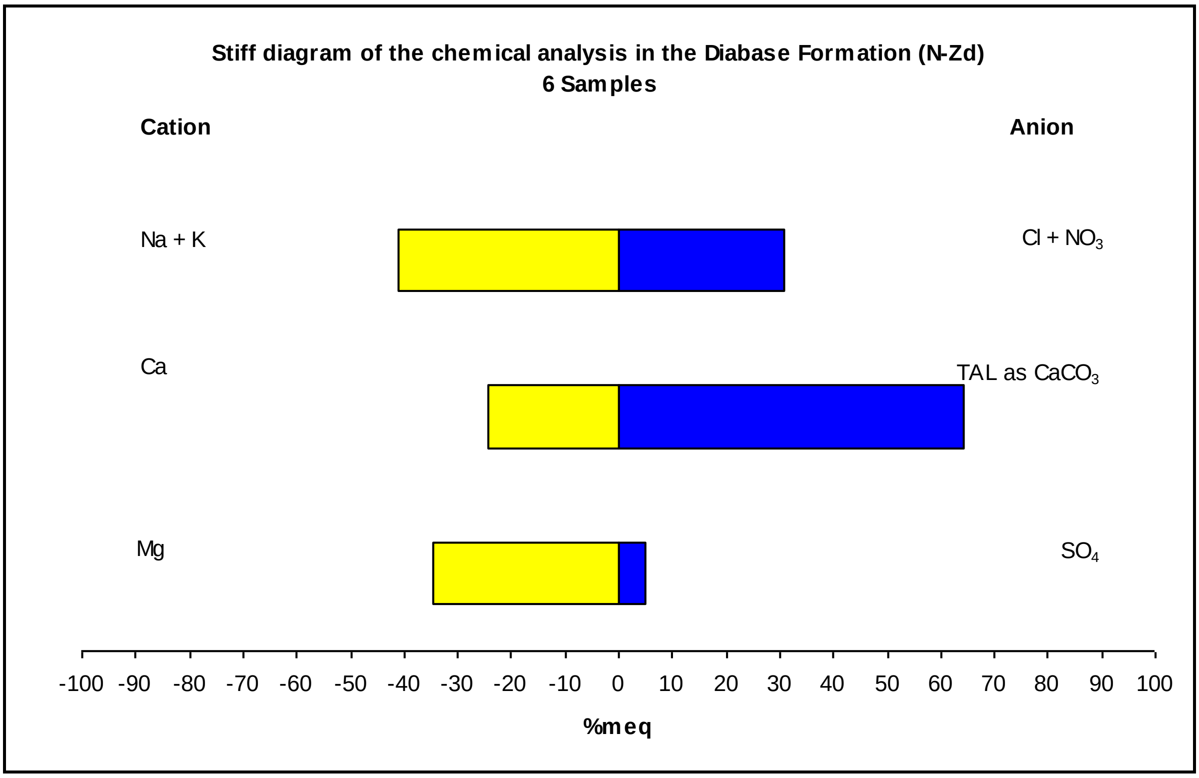

Figure 49: Stiff diagram representing chemical analysis of the Diabase Intrusions (N-Zd)

7.2.3.5 SOUTPANSBERG GROUP (Ms)

The Soutpansberg Group comprises a volcanic and sedimentary rock succession, laid down in an elongated fault-bounded depression. A major centre of volcanic activity was probably located in the Sibasa area and a minor one east of Klein Tshipise. The fractured and intergranular hydrogeological unit of the Soutpansberg group comprises the Sibasa and Stayt Formations.

7.2.3.5.1 SIBASA FORMATION (Mss).

The Sibasa Formation has a maximum thickness of 3300m in the Sibasa area but decreases to the east, west and northwest. The Formation consists predominantly of lava flows with minor intercalations of sedimentary and tuffaceous rocks. The lava is generally aphanitic to fine grained with medium-coarse grained varieties occurring occasionally. The colour varies from blackish to light green. The upper part of the Formation can consist of amygdaloidal varieties with the vesicles filled with quartz, chalcedony, agate or chloride. Lenticular layers and lenses of Tuff and in places agglomerate up to 200m thick occur. The sedimentary rocks tend to be more persistent along strike in the upper part of the succession. The arenaceous rocks reach a maximum thickness of 400m consisting of white, greenish, grey or pink quartzitic sandstone, quartzite, gritty quartzite and conglomerate. The argillaceous sediments do not exceed a thickness of 30m and consist of red and purple micaceous shale's grading locally into whitish sandy shale and minor greyish siltstone (Brandl, 1981).

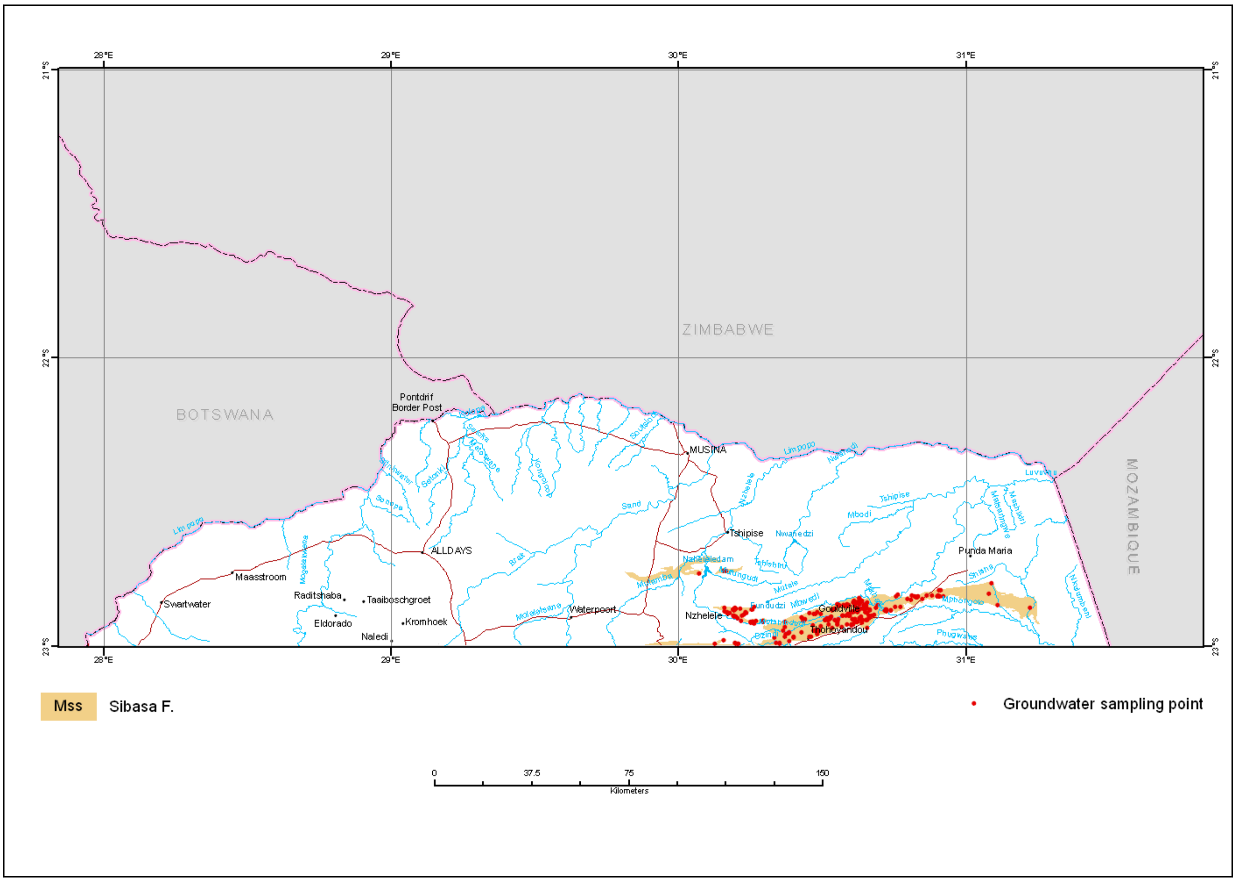

Figure 50: Geographical distribution of the intergranular and fractured aquifers of the Sibasa Formation (Mss) and the associated groundwater sampling points

Numerous faults cut through the formation which is 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 fresh 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. Water is also obtained on the contact between the basalt and the overlaying sandstone. However, due to the mountainous topography this option is not always feasible (Du Toit, 1998). The depth to groundwater level is generally <25m.

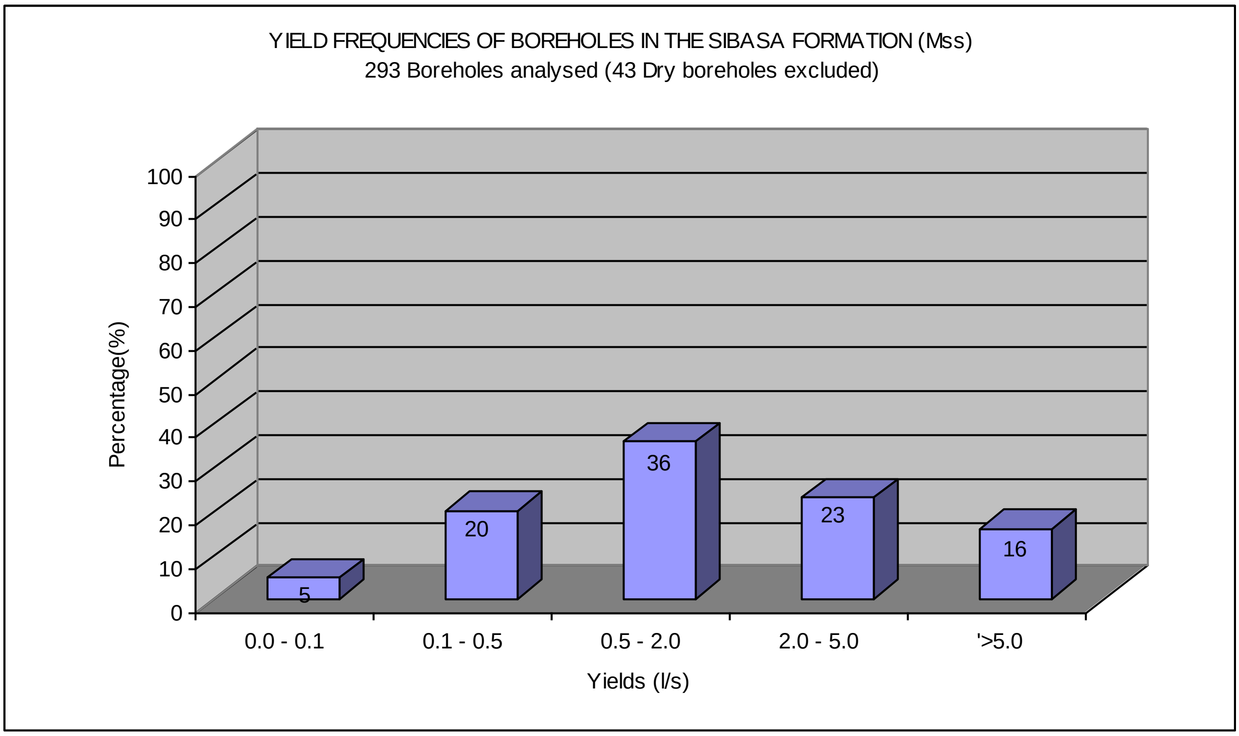

Figure 51: Yield frequency for the intergranular and fractured aquifers of the Sibasa Formation (Mss)

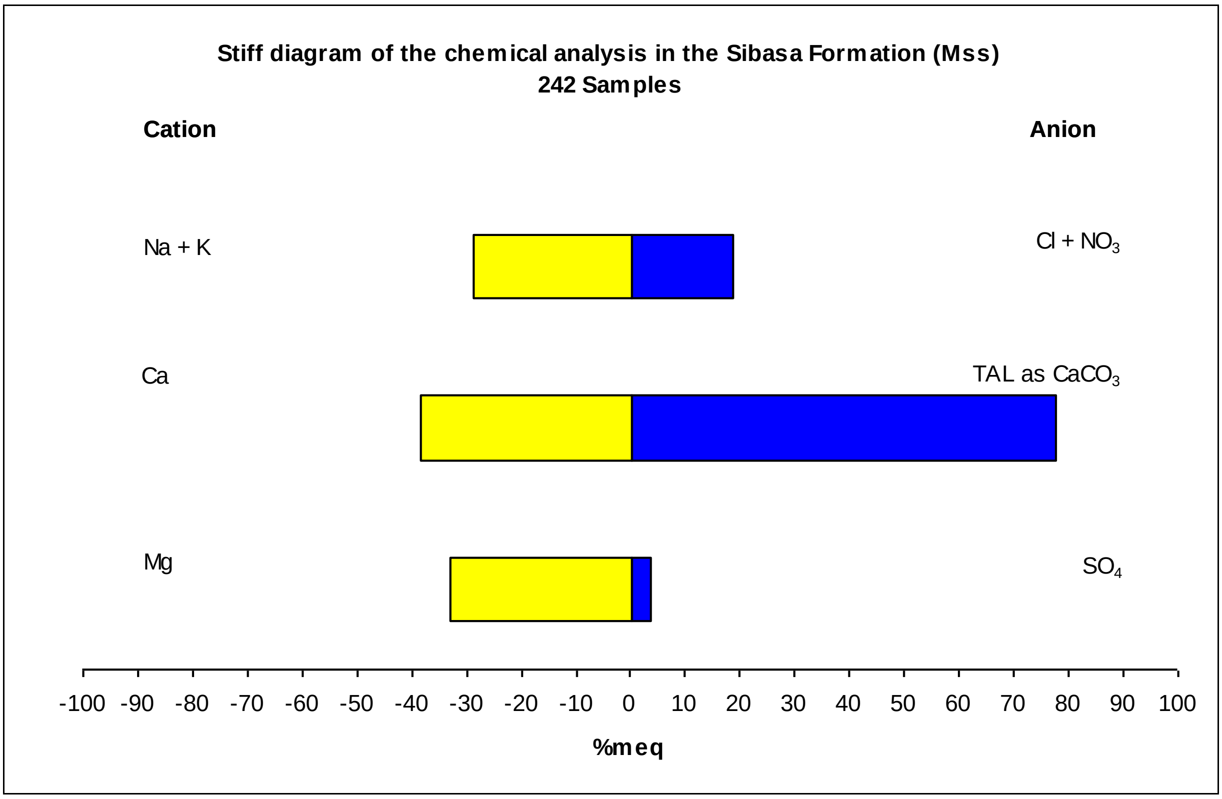

Figure 52: Stiff diagram representing chemical analysis of the Sibasa Formation (Mss)

Figure 51 shows the yield frequency of the Sibasa Formation. The unit occurs in a high rainfall zone that contributes to the 39% boreholes with a yield exceeding 2l/s. Distribution of data points is moderate to good over the unit aerial extend (Figure 50). 18% of the boreholes are dry and 61% of the successful boreholes yield less than 2l/s, indicating that drilling sites must be carefully selected. Groundwater supplies in the domestic, livestock and irrigation needs of small to medium size villages.

Chemical data for the unit is presented in a stiff diagram (Figure 52). The water exhibits a calcium-magnesium-sodium-bicarbonate water type with elevated chloride concentrations. EC values range between 3mS/m and 150mS/m. The calculated Harmonic mean is 34.8mS/m and the arithmetic mean is 56mS/m. The water is dominantly of an ideal water quality as 100% of the fluoride and sulphate, 96.3% of the chloride and 69.1% of the nitrate and nitrite (reported as N) concentrations fall within the ideal class. 3.8% or 9 sampled boreholes exceed the maximum allowed concentration for nitrate (N > 20mg/l) when evaluating it for domestic use. These sources occur within or near villages. In one sample, the pH value exceeded the maximum acceptable alkalinity. (pH > 10) In another three samples, the pH values were inside the acceptable values, but still very high in alkalinity (pH 9.1-10).

7.2.3.5.2 STAYT FORMATION (Msa)

The Stayt Formation forms a small occurrence between the Xmas and Tshipise faults. The maximum thickness is estimated at 1800m (Brandl, 1981). The contact with the underlying Beit Bridge Complex is unconformable. At the base a thin conglomerate is generally developed followed by greenish grey amygdaloidal lava with a thickness of 1000m followed by argillaceous and arenaceous sediments (Meinster, 1974; Sohnge, 1945; Vitry, 1976).

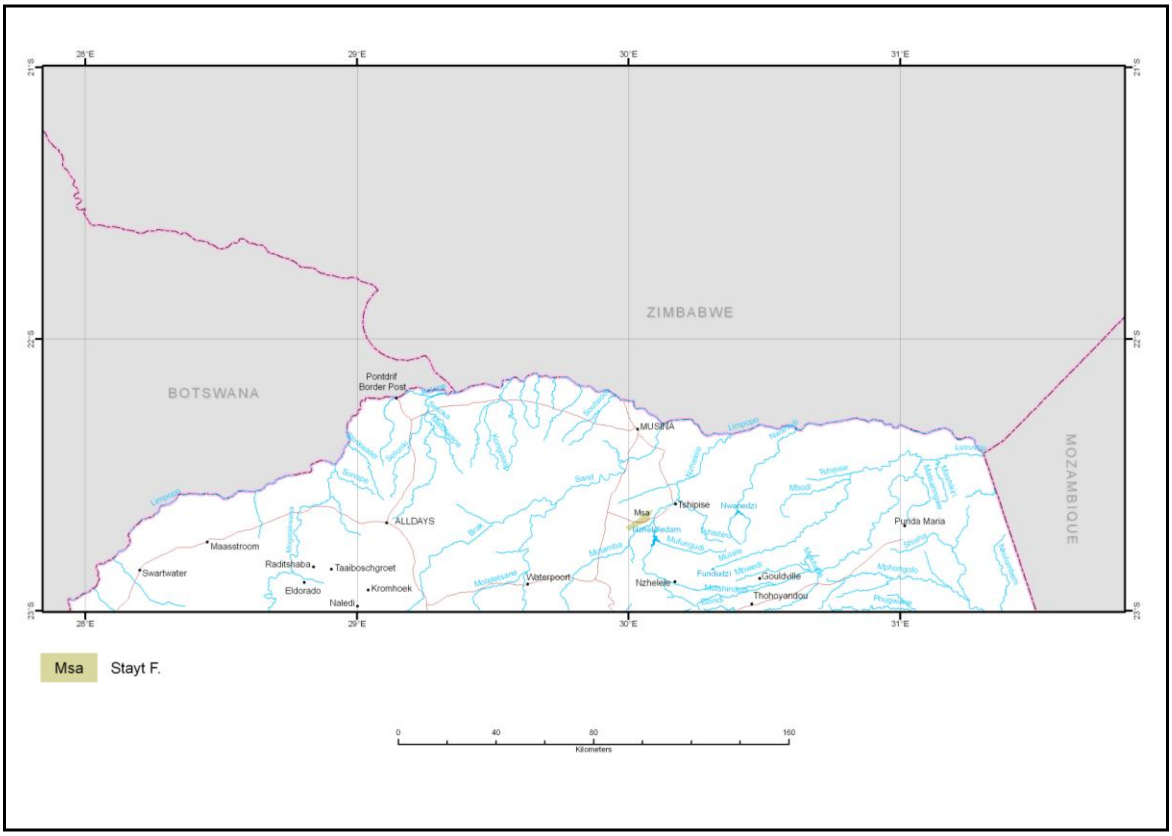

Figure 53: Geographical distribution of the Stayt Formation (Msa) and the associated groundwater sampling points

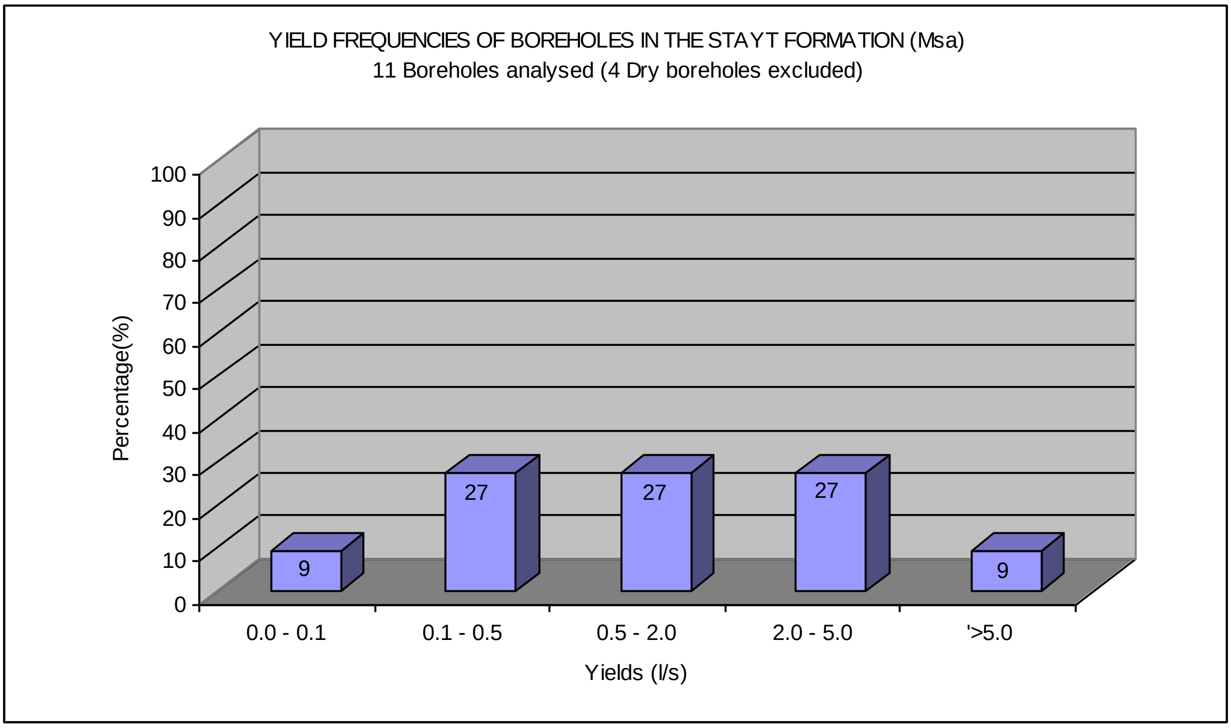

Figure 54: Yield frequency for the intergranular and fractured aquifers of the Stayt Formation (Msa)

The data of 11 successful boreholes were plotted in Figure 54. The groundwater potential within this Formation is considered moderate to poor with 63% yielding less than 2*l/s*. 26% of the boreholes were reported dry. No chemical analyses were available to give an indication of the water quality of unit.

7.2.3.6 BULAI GNEISS (Rbu)

The Bulai Gneiss, a large probably syntectonic batholith intrusion is confined to the northern part of the map occurring just northwest of Musina (Figure 55). Morphologically it is characterised by the development of large flat pavements, barren exfoliation domes and whaleback kopjes. A number of varieties have been recognised within the batholith, with grey to pinkish porphyroblastic gneiss being the most widespread and best exposed variety. It has a monolithic composition and is composed of porphyroblasts of microcline in a groundmass of plagioclase, quartz and biotite. The intrusive nature of the unit is noticeable on a local and regional scale and is further supported by the ubiquitous presence of supracrustal enclaves. Two types of intrusive contacts have been observed; the first exhibits a cross-cutting relationship with no or little structural disturbance of the intruded rocks while the second displays a major deformation of the enclosing gneisses (Watkeys, 1984).

A prominent feature of the Gneiss is the presence of fresh meso- to melanocratic lamprophyric dykes with a frequent width of 30cm, although it can be up to 150cm. They cut across the regional fabric of the host rock. In low-strain areas the dykes are slightly sinuous, trending in northerly or north-easterly direction, but where the strain was more intense they are complexly folded or boudinaged (Brandl, 2002).

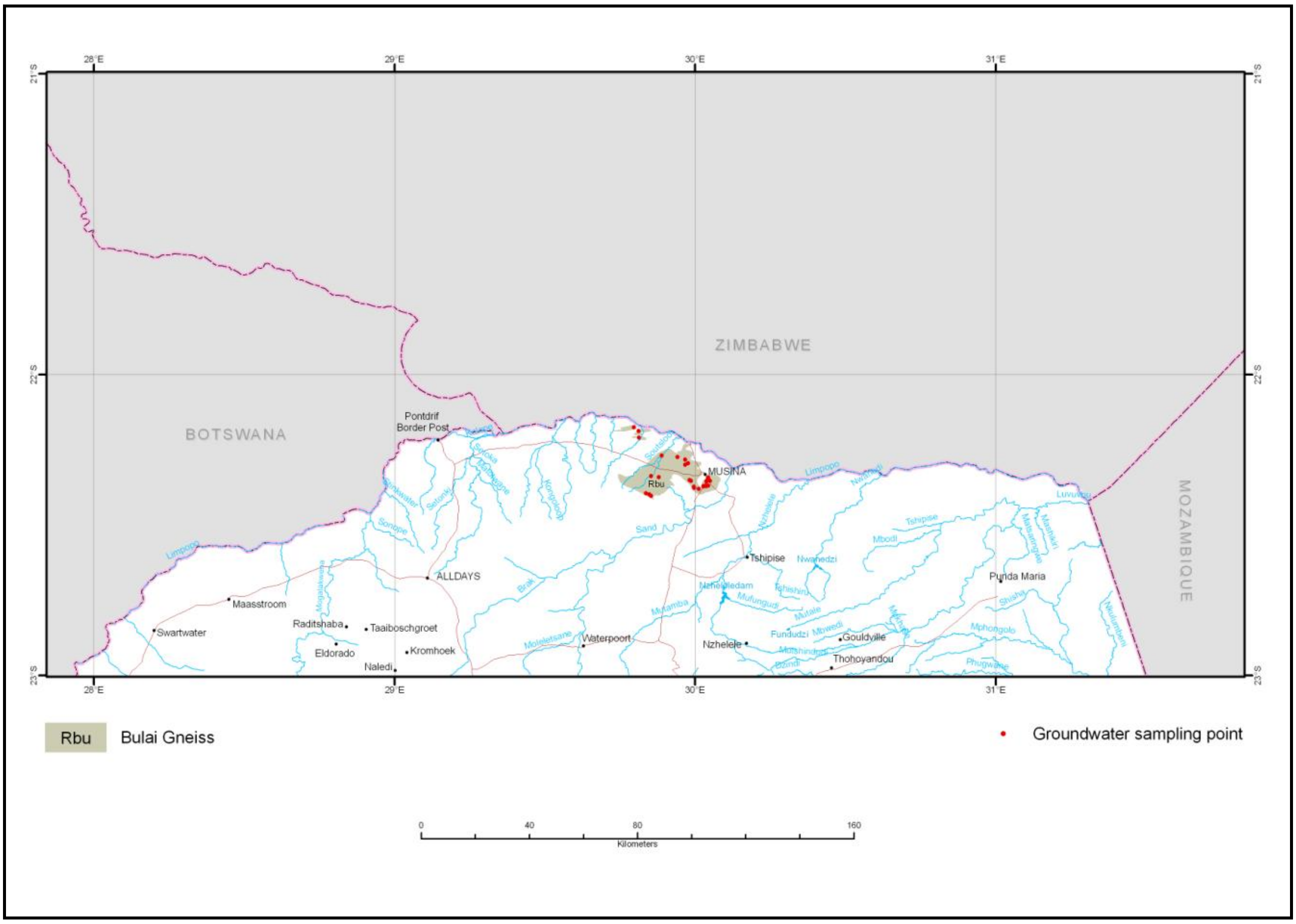

Figure 55: Geographical distribution of the Bulai Gneiss (Rbu) and the associated groundwater sampling points

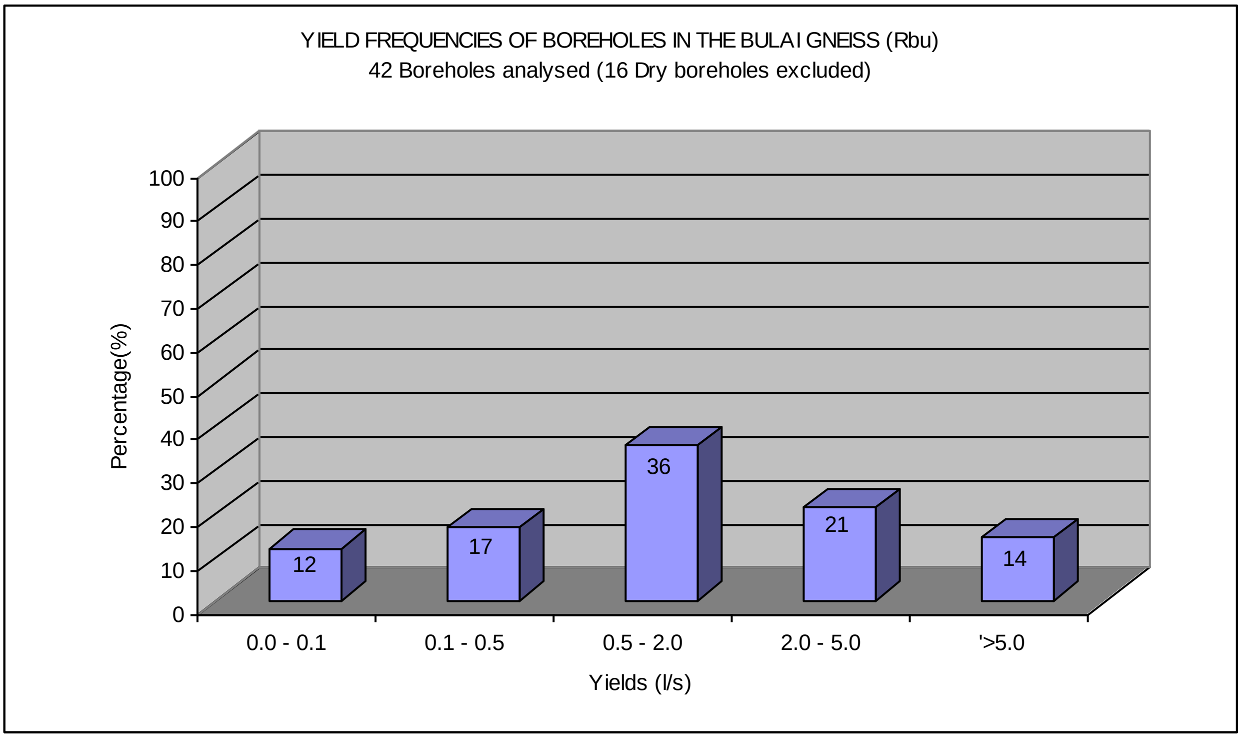

Figure 56: Yield frequency for the intergranular and fractured aquifers of the Bulai Gneiss (Rbu)

The yield frequency distribution diagram in Figure 56 gives a very good indication of the expected groundwater potential. 65% of the successful boreholes are yielding less than 2 ℓ/s, 21% between 2 and 5ℓ/s and 14% yields more than 5ℓ/s. 28% of the boreholes were reported dry.

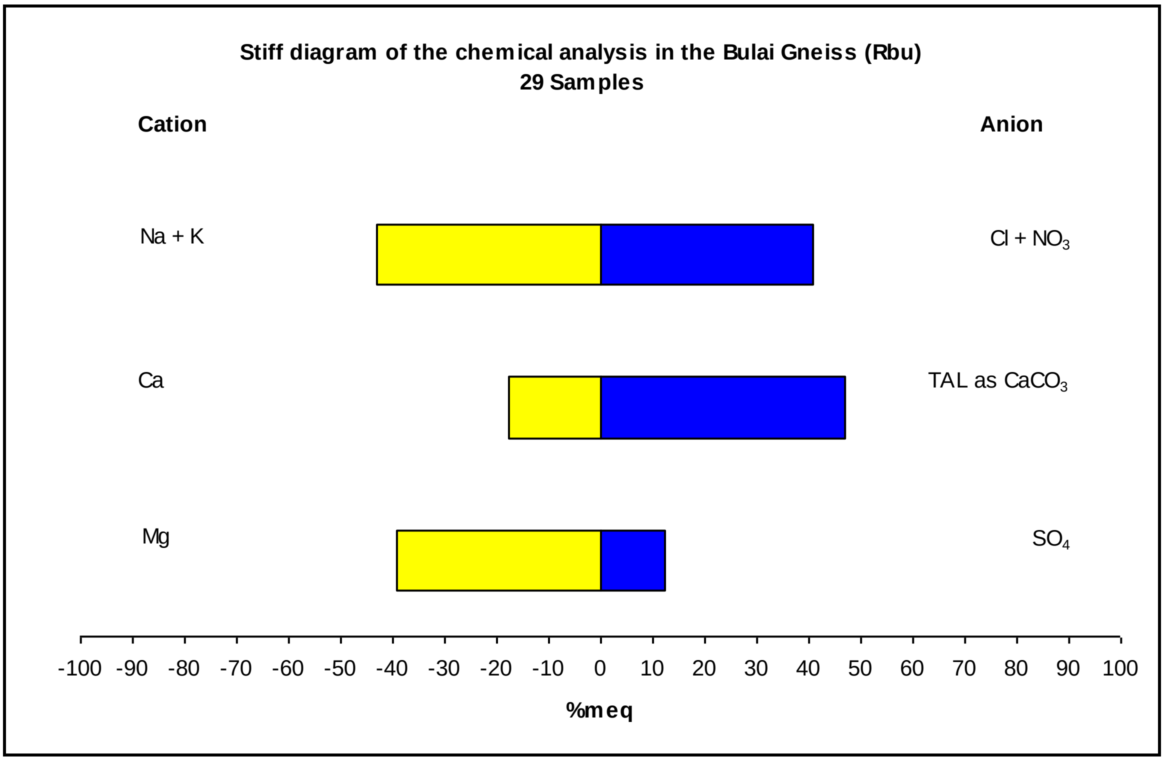

Figure 57: Stiff diagram representing chemical analysis of the Bulai Gneiss (Rbu)

The stiff diagram (Figure 57) shows the broad classification according to anions and cations. The water displays a sodium-magnesium-bicarbonate-chloride character. The water quality is moderate to poor with elevated magnesium, sodium and calcium concentrations. EC values range between 48mS/m and 1139mS/m. The harmonic mean is 151.5mS/m with the arithmetic mean 246mS/m. 17.2% of EC values fall outside the maximum allowed limit (EC > 370mS/m). Nitrate and nitrite (N) problems are reported in 20.7% of the analysis with concentrations exceeding the maximum allowable limit (N > 20mg/l), compared with 24% classed as ideal (N < 6mg/l). Fluoride values exceed maximum allowed limits in 37.9% of the groundwater samples taken in the unit (F > 1.5mg/l). Only 10% of the samples are falling within the Ideal Class (F < 0.7mg/l). Unacceptable chloride concentrations are found in 17.2%, and sulphate in 10.3% (Cl and SO_4 > 600mg/l) of the samples. The water sources with problematic chemistry occur randomly throughout the unit.

7.2.3.7 HOUT RIVER GNEISS (Rho)

The Hout River Gneiss is an important unit on the adjacent Polokwane hydrogeological map sheet but on the Messina map the unit does not outcrop and only occurs on depth in the southern part of the map near Kromhoek. The unit was included on the map sheet as the contact between this unit and the overlaying rocks of the Karoo Supergroup was investigated in various groundwater projects. 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 pegmatite rocks.

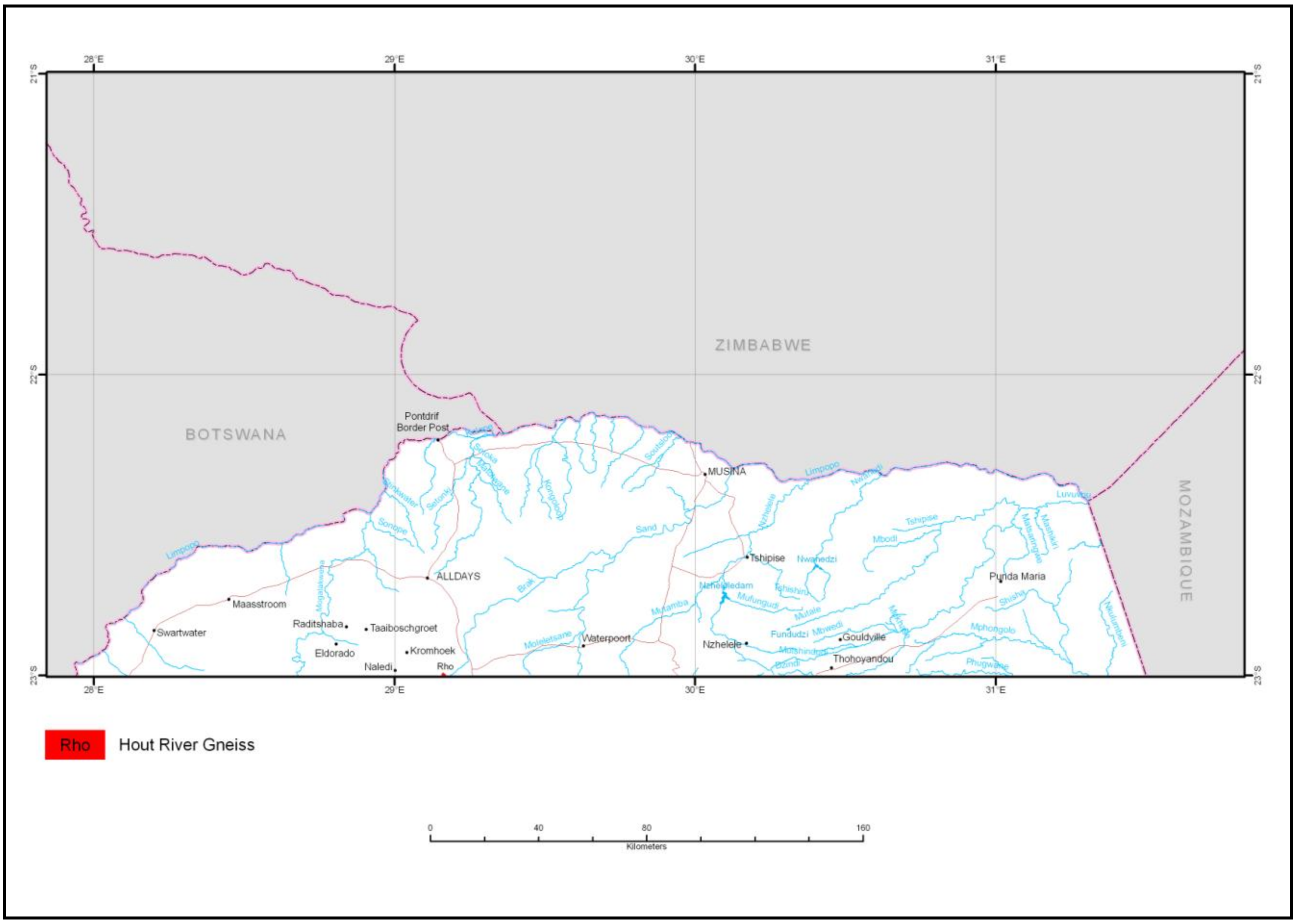

Figure 58: Geographical distribution of the Hout River Gneiss (Rho)

Although no chemical samples are available in this unit of the study area, the characterization of the Hout River Gneiss in the adjacent Polokwane study area can be assumed. The quality of the water is generally good and within acceptable limits for domestic use. Groundwater in this unit is classified as a sodium-magnesium-bicarbonate-chloride water type. The groundwater potential is good.

7.2.3.8 ALLDAYS GNEISS (Zal).

In the central and western parts of the Central Zone (Figure 58), a homogeneous tonalitic gneiss younger than the supracrustal rocks of the Beit Bridge Complex, are well developed (Brandl, 1990). The unit underlies 1.17% of the map sheet.

All greyish, biotite-bearing gneisses occurring in this area have been grouped under the term Alldays Gneiss, except the Sand River Gneiss. The Alldays gneiss occurs in the map area as either large elongate or oval-shaped bodies up to several km across, or more often as concordant sheets which can vary in width from as little as 20 cm to several hundred metres. Characteristic forms of weathering are isolated boulder-strewn hills, large whaleback exposures or smooth pavements near rivers. It consists of medium rarely coarse-grained rock varying from leucocratic, light to dark grey, pinkish grey or pink. Its gneissose structure is defined by the orientation of ferromagnesian minerals (Brandl, 1990).

The presence of remnants of supracrustal gneisses at a number of localities demonstrates that the Alldays Gneiss is an orthogneiss which has an intrusive relationship with the country rocks. Local occurrences of xenoliths (2-5m) of anorthositic gneiss of the Messina Suite in the Alldays Gneiss strongly indicate that the latter postdates the emplacement of the Messina Suite rocks.

Mineralogically the Alldays Gneiss is composed of plagioclase, quartz, K-feldspar, biotite, hornblende and opaque phases, with cummingtonite, pyroxene and garnet occurring only locally. Apatite, zircon and epidote are present as accessories (Brandl, 2002).

Within the Swartwater area the Alldays gneiss appears in two outcrop forms, a homogeneous granular textured type which forms small hills of rounded boulders, and a widespread form which exhibits clear gneissic banding and extensive flat outcrops (Pretorius, 1986).

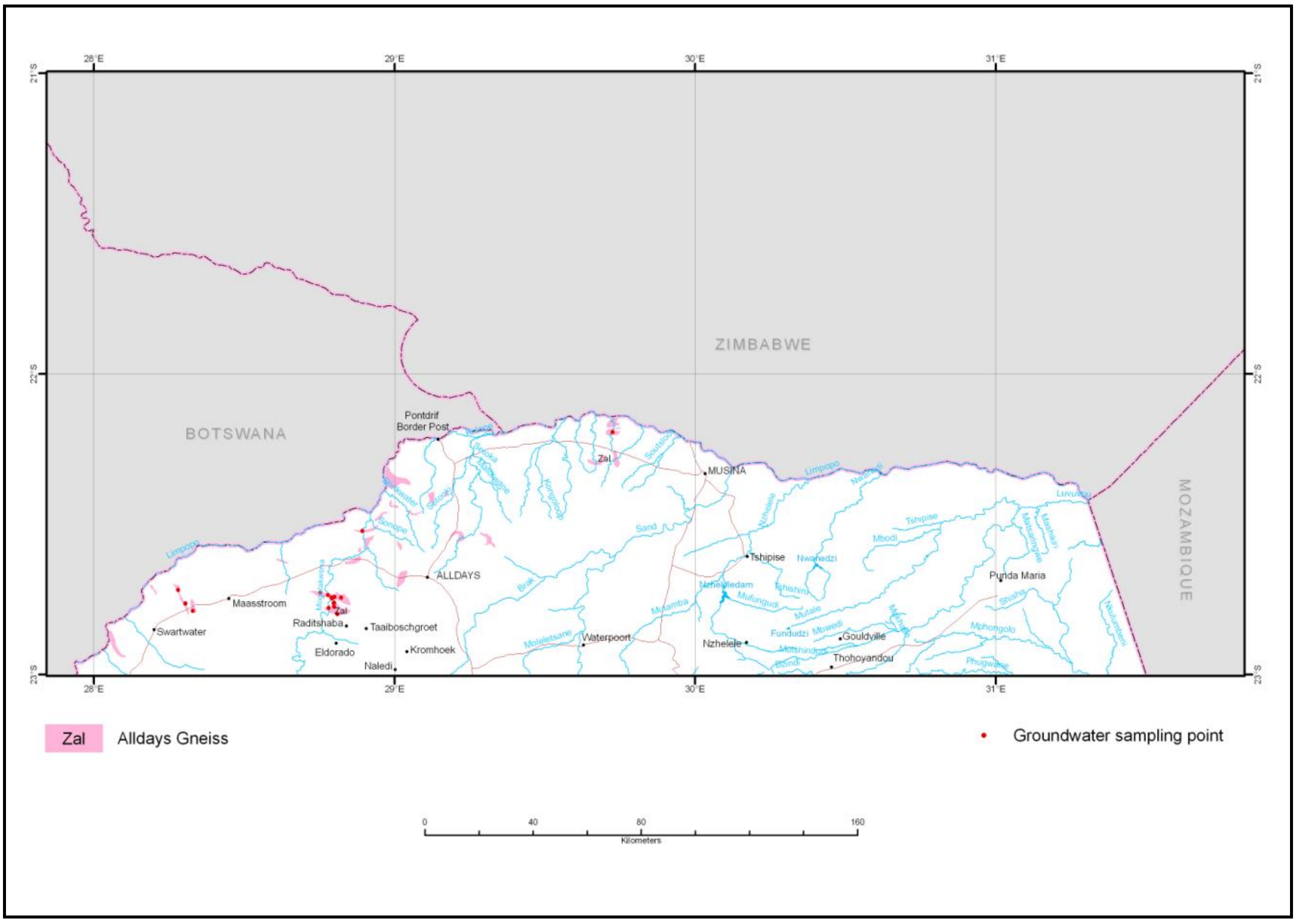

Figure 59: Geographical distribution of the Alldays Gneiss (Zal) and the associated groundwater sampling points

The groundwater potential of the gneisses is moderate to poor with 74% (Figure 60) of the boreholes yielding less than 2ℓ/s and 26% yielding > 2ℓ/s. 74 boreholes plot within the unit with a small percentage (5%) reported to be dry. Statistically the chances of finding a wet borehole within this unit are very good. It is, however, possible that dry yielding boreholes are not well documented on the data base.

Seventeen groundwater samples were available for chemical analysis. Two of these samples have EC values greater than 600mS/m which exceeds the maximum allowed limit (EC >370mS/m). These same 2 samples differ completely from the rest of the samples in the unit as the concentrations of all the chemical elements are 2-5 times higher, except for the fluoride values. Although no explanation could be concluded from the results, these 2 samples, however, do not change the character of the water. Figure 61 shows the broad classification according to anions and cations. Groundwater in this unit has a sodium-calcium-bicarbonate-chloride character. The available samples indicate that 17.7% of the nitrate and nitrite (reported as N > 20mg/l), 11.8% of the sulphate, chloride, magnesium and sodium (Cl and SO_4 > 600mg/l, Mg >100mg/l, Na > 400mg/l) and **52.9% of the fluoride** (F > 1.5mg/l) concentrations exceed the maximum allowed limit for domestic use.

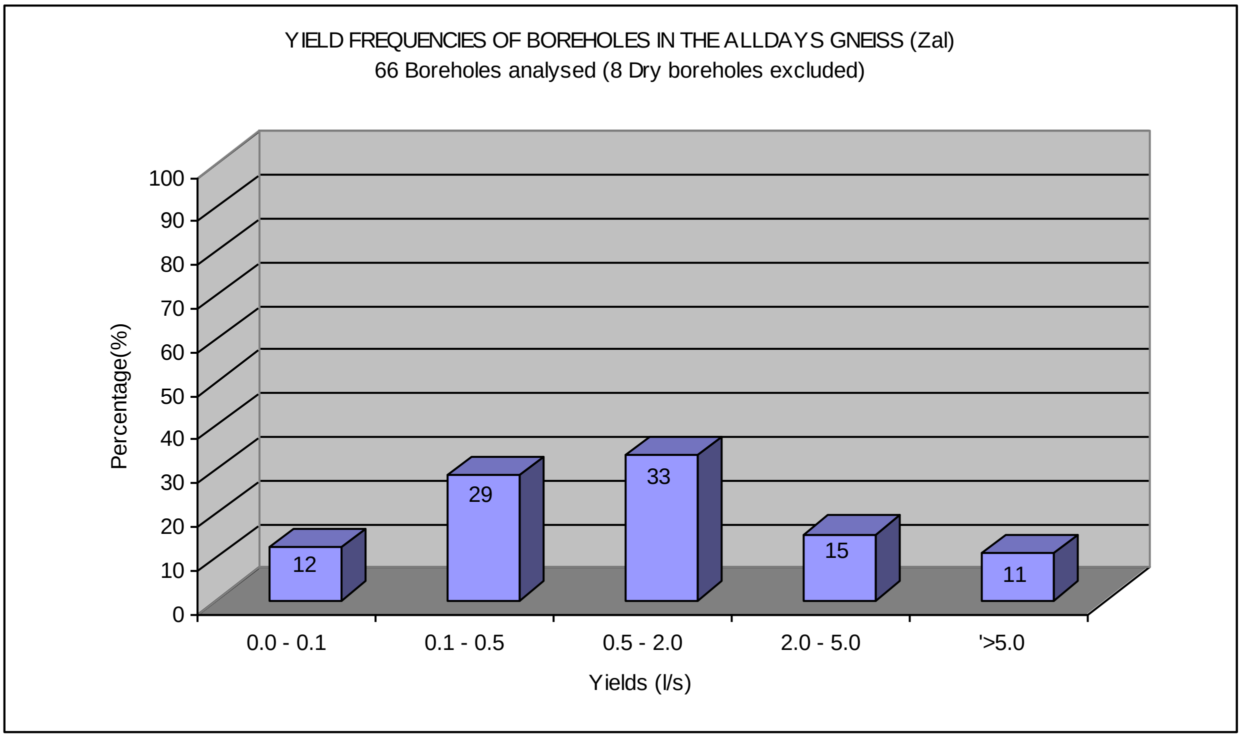

Figure 60: Yield frequency for the intergranular and fractured aquifers of the Alldays Gneiss (Zal)

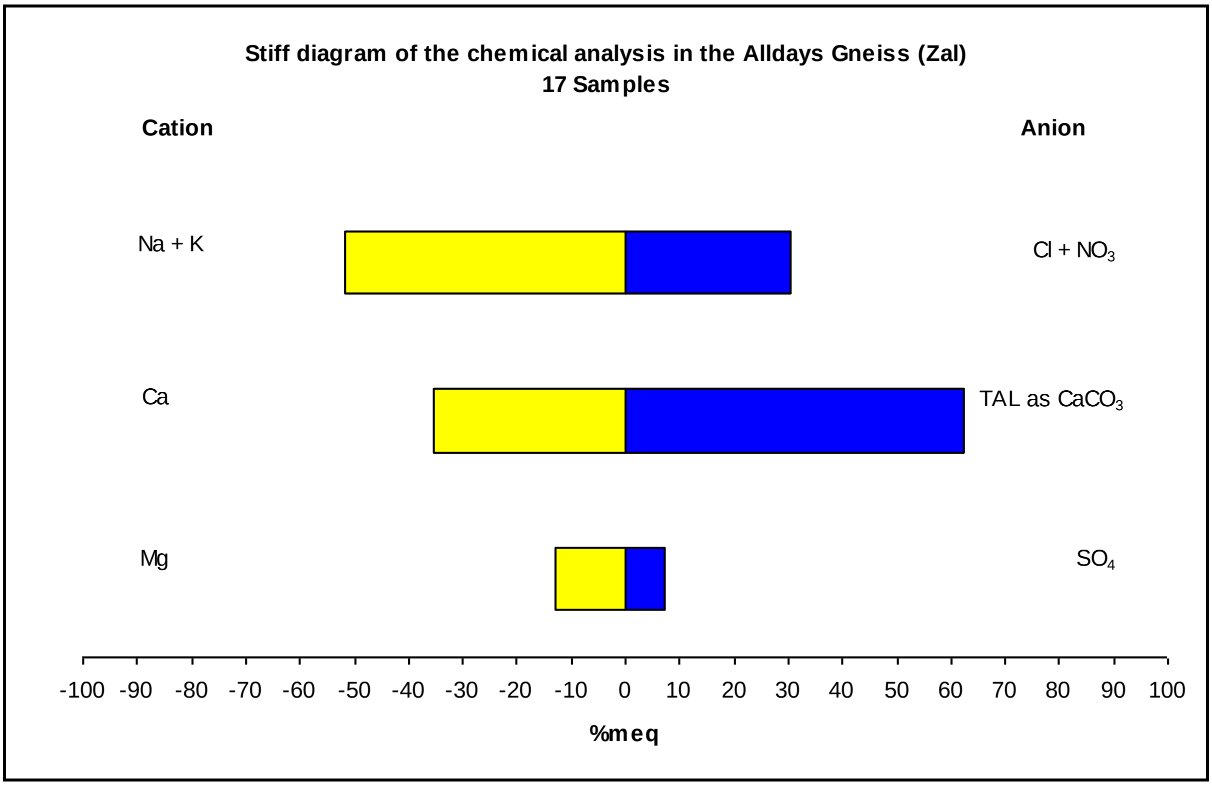

Figure 61: Stiff diagram representing chemical analysis of the Alldays Gneiss (Zal)

7.2.3.9 MESSINA SUITE (Zbm)

The Messina Suite is interpreted as having been emplaced as a sill-like layered igneous body into the supracrustal gneisses of the Beit Bridge Complex, probably at a depth of less than 12km (Barton, et al., 1979). Frequent remnants of supracrustal gneisses in particular metaquartzite and calc-silicate rocks are evidence of the intrusive nature of the Suite. Outcrop generally occurs as elongate layers of considerable outcrop width, which can extend along strike continuously for tens of kilometres (Figure 62). The Messina Suite rocks in the eastern occurrences are mainly associated with metaquartzite, while in the Mogalakwena River area they occur adjacent carbonate rocks (Van der Walt, 1977; Pienaar, 1985).

Rocks of the Messina Suite consist of meta-anorthosite and metaleucogabbro (anorthositic gneiss) together with very subordinate ultramafic rocks. The majority of the anorthositic gneisses seem to be derived from Leucogabbro. On occasion as in the domal structure approximately 10km in diameter near Alldays, metaleucogabbro is seen to grade into thin horizons of metagabbro, now represented by layered hornblende gneiss. This intrusion is surrounded by a characteristic coarse garnetiferous leucogneiss.

The anorthositic gneiss characteristic weathers to large blocks or slabs having a greyish or light-brown skin through which ferromagnesian minerals, and sometimes quartz grains, protrude. Where the rock has the composition of an anorthosite it is fairly massive and slightly speckled, and with an increase of the dark minerals, it becomes streaky or has a banded appearance. In hand specimens the rock, which is medium-grained, is commonly greyish white to bluish grey and only rarely has a greenish tint. The anorthosite is composed principally of plagioclase, together with very subordinate hornblende, pyroxene, quartz and biotite. Accessories include sphene, apatite, epidote, allanite and opaque.

The ultramafic rock is quite rare in the map area and therefore not indicated on the 1:250 000 geological map sheet 2228, Alldays. It includes metaperidotite, metapyroxenite, hornbendite and serpentinite (Brandl, 2002).

The results of four chemical analyses were available for analysis. The stiff diagram representing the chemistry of the unit (Figure 63) shows the broad classification according to anions and cations. With the results of only four boreholes, it is not possible to perform a valid assessment of expected yield and chemistry. The diagram shows the water to exhibit a sodium-calcium-magnesium-chloride-bicarbonate character. High fluoride (F > 1.5mg/l) and nitrate and nitrite (reported as N > 20mg/l), concentrations are found in 50% of the samples. High chloride (Cl > 600mg/l) and magnesium (Mg > 100mg/l), concentrations is found in 25% of the samples. More samples are required to validate the interpretation.

The yield frequency diagram (Figure 64) was compiled using the data of 79 successful boreholes plotting within the Messina Suite. Only 1 borehole is reported as dry on the data base. This is an understatement as work done for farmers in the Alldays area underlain by this unit give a picture of a high percentage of dry boreholes. From the graph and field notes, the groundwater potential generally low as approximately 93% of the successful boreholes yield less than 2ℓ/s.

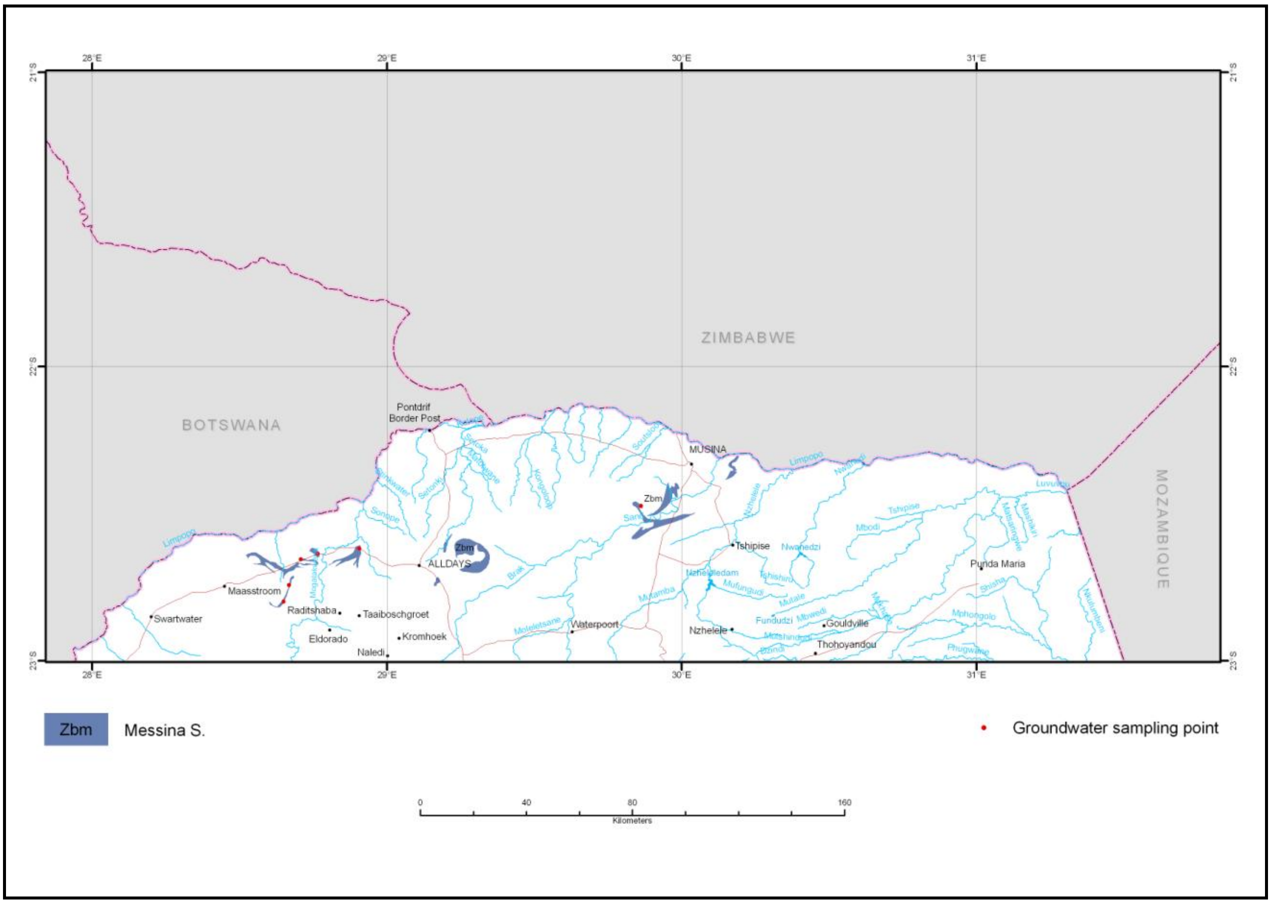

Figure 62: Geographical distribution of the Messina Suite (Zbm) and associated groundwater sampling points

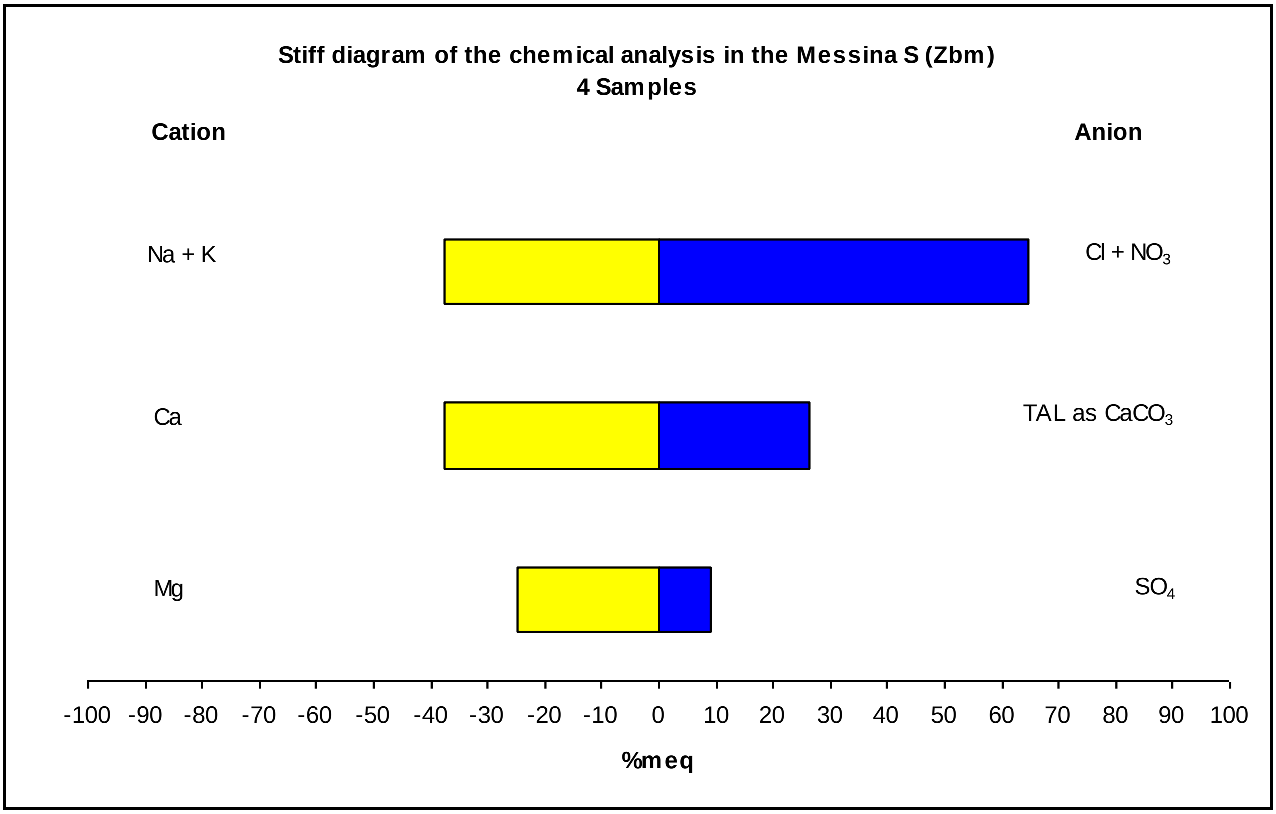

Figure 63: Stiff diagram representing chemical analysis of the Messina Suite (Zbm)

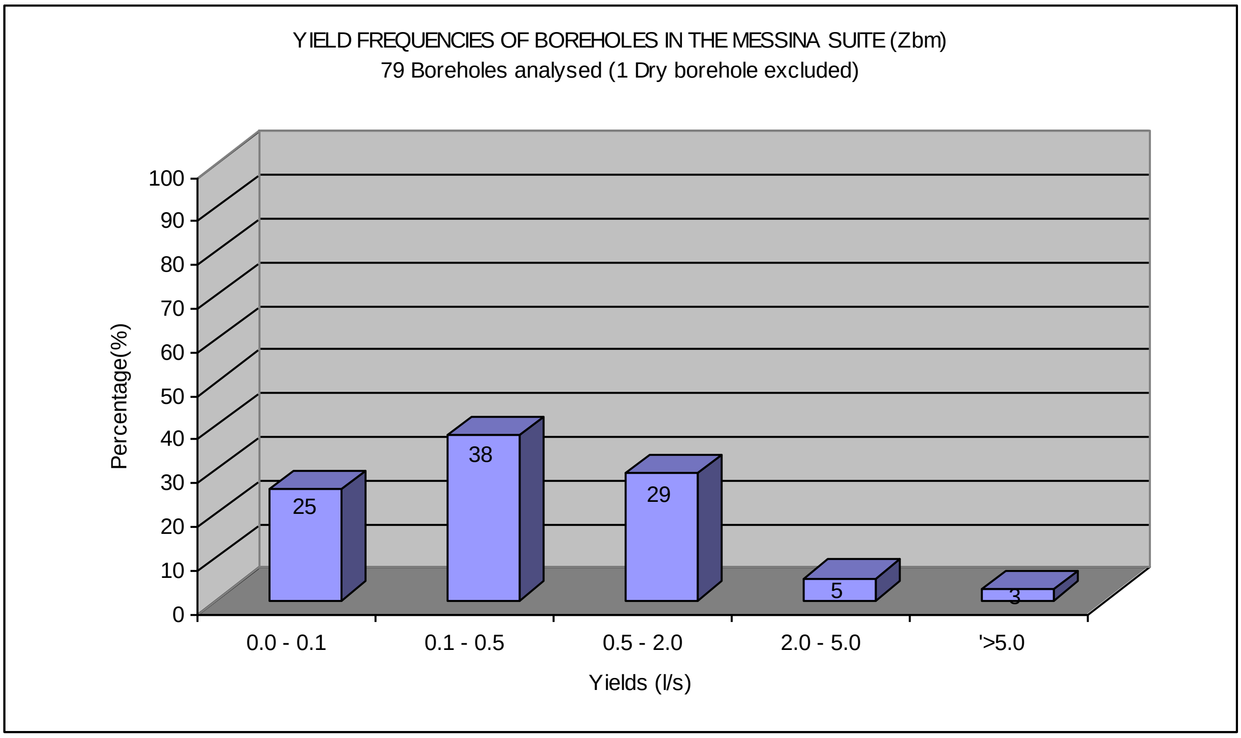

Figure 64: Yield frequency for the intergranular and fractured aquifers of the Messina Suite (Zbm)

7.2.3.10 MADIAPALA SYENITE (Zma).

The Madiapala metasyenite occurs as a seemingly closed elongated structure in the north-western part of the map sheet (Figure 65). Small nearby satellite bodies are not indicated. The metasyenite is resistant to weathering giving rise to a prominent steep-sided ridge. It appears that two main varieties of metasyenite are present. The first is pinkish grey and homogeneous and the second is irregular dark-grey and pink bands. The rock exhibits strong fabric, although in places cross-cutting veins of a pinkish material have also been observed (Brandl, 2002).

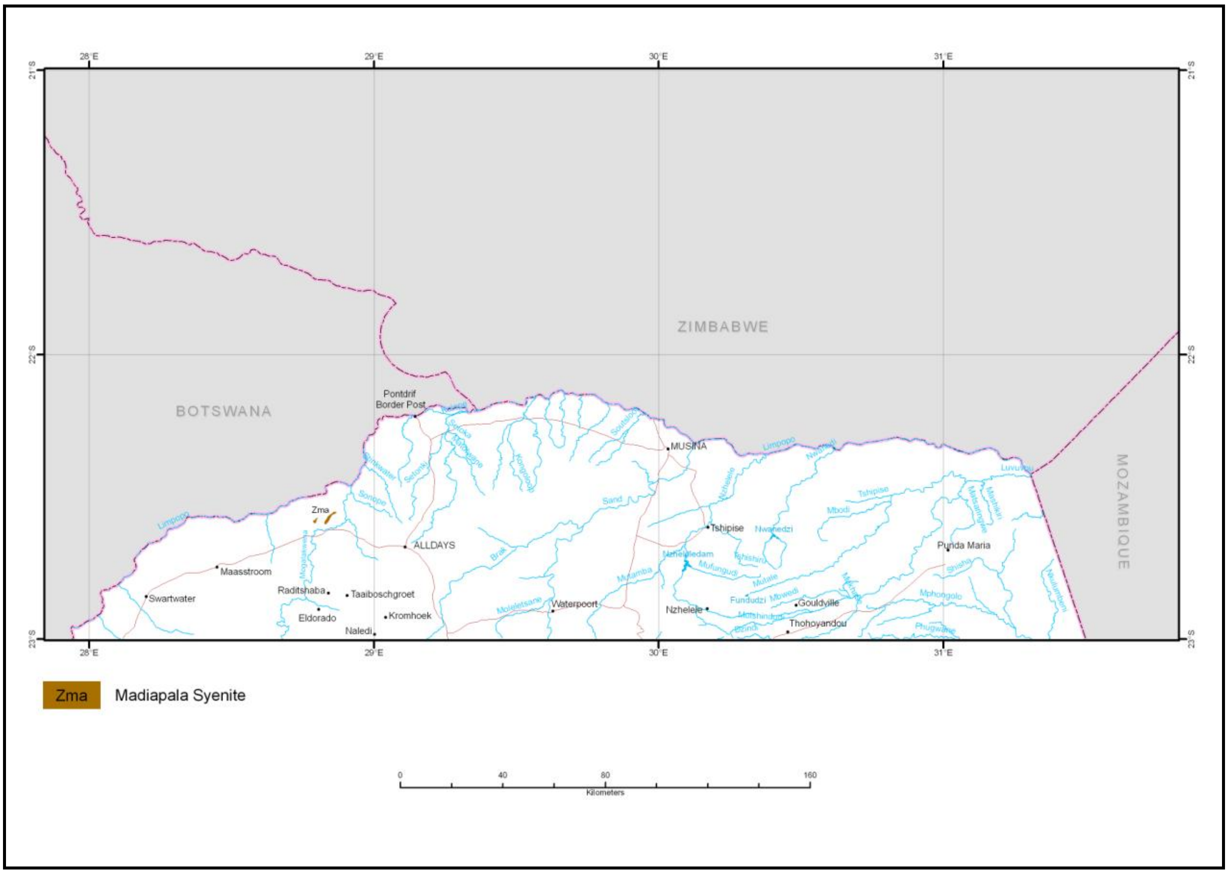

Figure 65: Geographical distribution of the Madiapala Syenite (Zma)

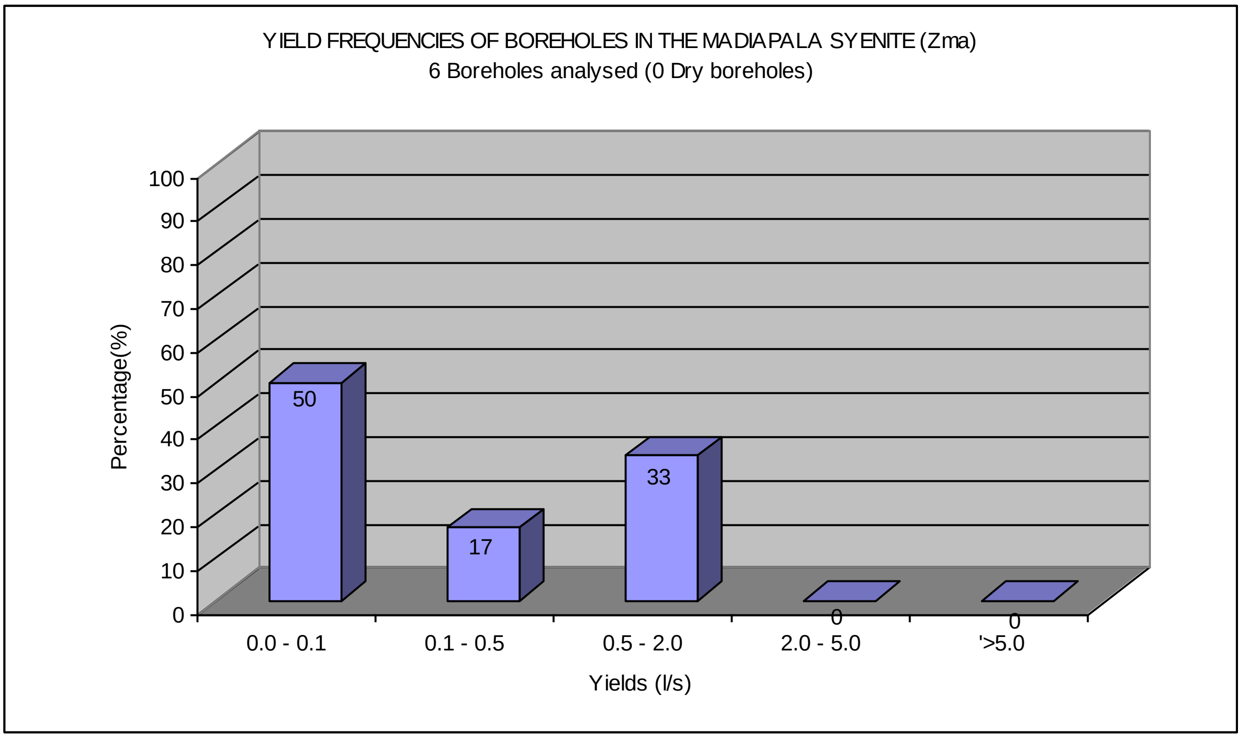

Figure 66:Yield frequency for the intergranular and fractured aquifers of the Madiapala Syenite (Zma)

The yield frequency distribution diagram in Figure 66 gives an indication of the expected groundwater potential although only 6 data points were available. All of the successful boreholes are yielding less than 2 ℓ/s. No dry boreholes were reported and no chemical data was available to determine the nature of the groundwater chemistry for this unit.

7.2.3.11 SAND RIVER GNEISS (Zsa).

The Sand River Gneiss occupies a fairly large area southeast of Messina where it forms spectacular outcrops on rock pavements in the bed of the Sand River (Figure 67).

The Sand River Gneiss consists of alternating layered bands of grey gneiss, leucocratic and magmatic gneiss. The varieties occur intimately intermingled with each other and are strongly folded together. The grey layered gneiss variety seems to be the oldest, as it forms rotated boulders within the leucocratic gneiss. The youngest phase appears to be the dark grey variety (Brandl, 1981, 2002).

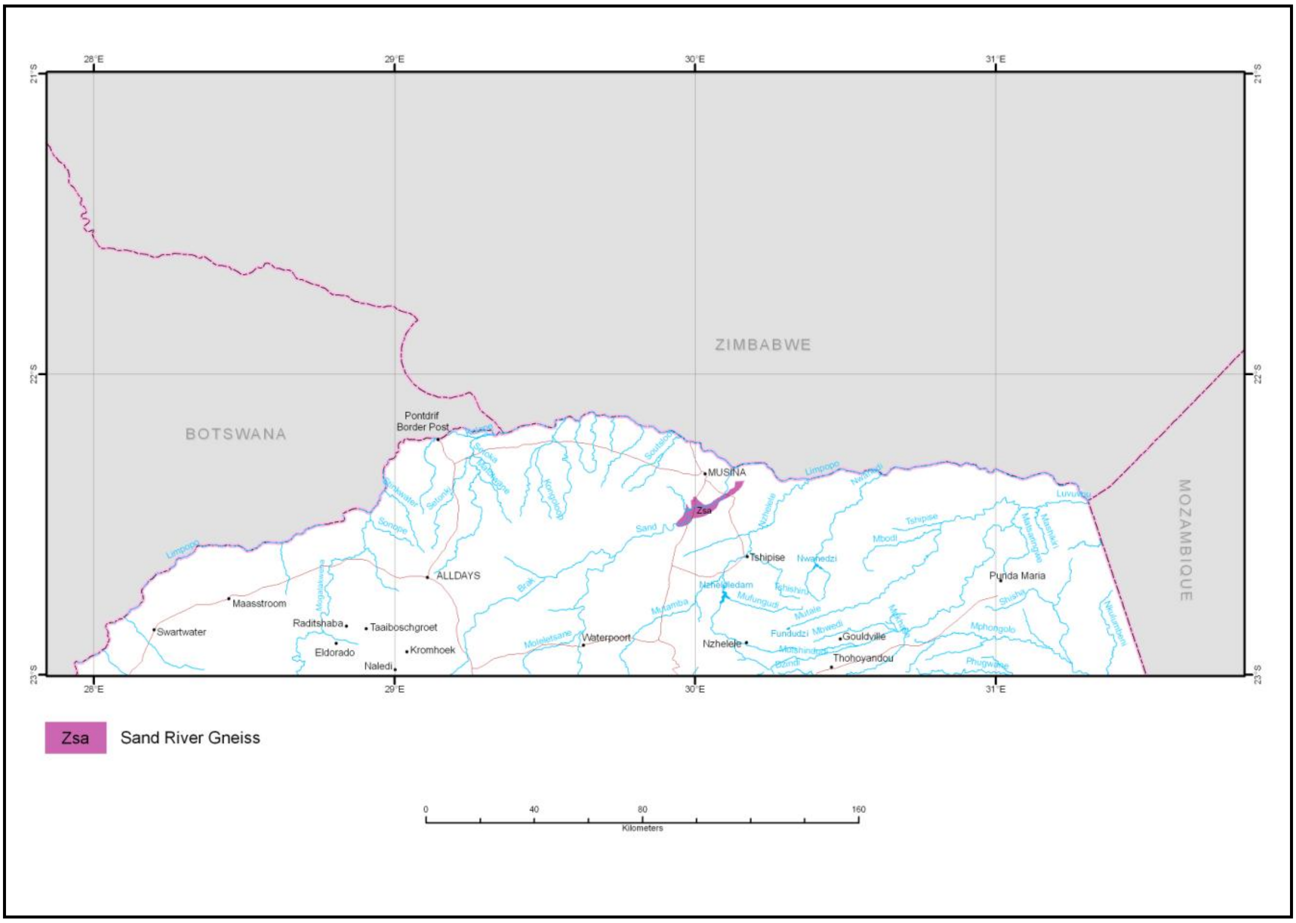

Figure 67: Geographical distribution of the Sand River Gneiss (Zsa) and the associated groundwater sampling points

Due to a lack of data no quality and quantity assessment could be done. The unit underlies 0.36% of the total map area.

7.2.3.12 GOUDPLAATS GNEISS (Zgo)

The Goudplaats Gneiss underlies the south-western part of the map sheet (Figure 68) and covers 4.22% of the total map area. It consists of leucocratic biotite gneiss, leucocratic granite and pegmatite, grey biotite gneiss and migmatite. Outcrop can be seen throughout the area in ephemeral stream beds and road cuttings. The gneiss can be large unfoliated masses or can exhibit alternating bands of melanocratic and leucocratic material.

Small scattered enclaves of the Giyani Group are found throughout the gneisses. They include amphibolite, metaquartzite, metapelite and ultramafic rocks. The ultramafic rocks are presented by massive, greyish green serpentinite and greenish black coarsely crystalline metapyroxenite. The amphibolites generally occur as small rafts within the gneiss. Metapelite forms only one outcrop on the map area in contrast with the occurrence within the gneisses on the Polokwane map sheet. The Jerome Granite outcrops within the gneiss clearly show the intrusive nature thereof. The Jerome Granite is fine- to medium-grained greyish, pink or reddish granite (Brandl, 1981). The above xenoliths and intrusions are not seen as good groundwater targets.

Other intrusives include numerous diabase dykes and lesser sills. Dykes have a predominantly northeast to southwest strike. Although these dykes are targeted in the search for groundwater, it is generally not expected to be associated with high yielding boreholes. The occasional 'blokkiesklip' dykes are usually higher yielding. (''Blokkiesklip" is a local name for 'cube like' fragments due to closely spaced joints). A field approach in the search for high yielding boreholes that must still be statistically verified is to target areas where the gneiss exhibits strong gneissose with frequent alternating bands of leucocratic and mesocratic material. Another field observation that has proved on various occasions to lead to high yielding boreholes is to look for areas with big Mopani and Leadwood trees. Additionally the possibility of recharge for the source is important. Water strikes in the area are usually between 20 and 40m relating to deep weathering and fracturing. Drilling using air percussion is usually done without any problems. On occasion highly fractured gneiss or diabase will lead to drill and drive methods. Steel casing to prevent boreholes from collapsing is usually required to be installed to depths between 24 and 48m.

The groundwater potential of the Goudplaats Gneiss is moderate. Due to its location entirely within southern Venda and Malemulele, the groundwater within this unit is widely used for rural village supply, small irrigation and livestock watering purposes. The depth to groundwater level is generally situated between 10-30mbgl. Water strikes are dependant on the depth of the weathered and fractured zone. Limited storage capacity makes the aquifer vulnerable to dewatering. Management in terms of the balance between abstraction and recharge must be controlled to prevent dewatering of the aquifer (Du Toit, 1998).

The yield frequency distribution diagram in Figure 69 gives a very good indication of the expected groundwater potential. 62% of the successful boreholes are yielding less than 2ℓ/s, 27% between 2 and 5ℓ/s and 10% yields more than 5ℓ/s. Approximately 14% of the reported boreholes were dry. 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 strong banding and pegmatitisation.

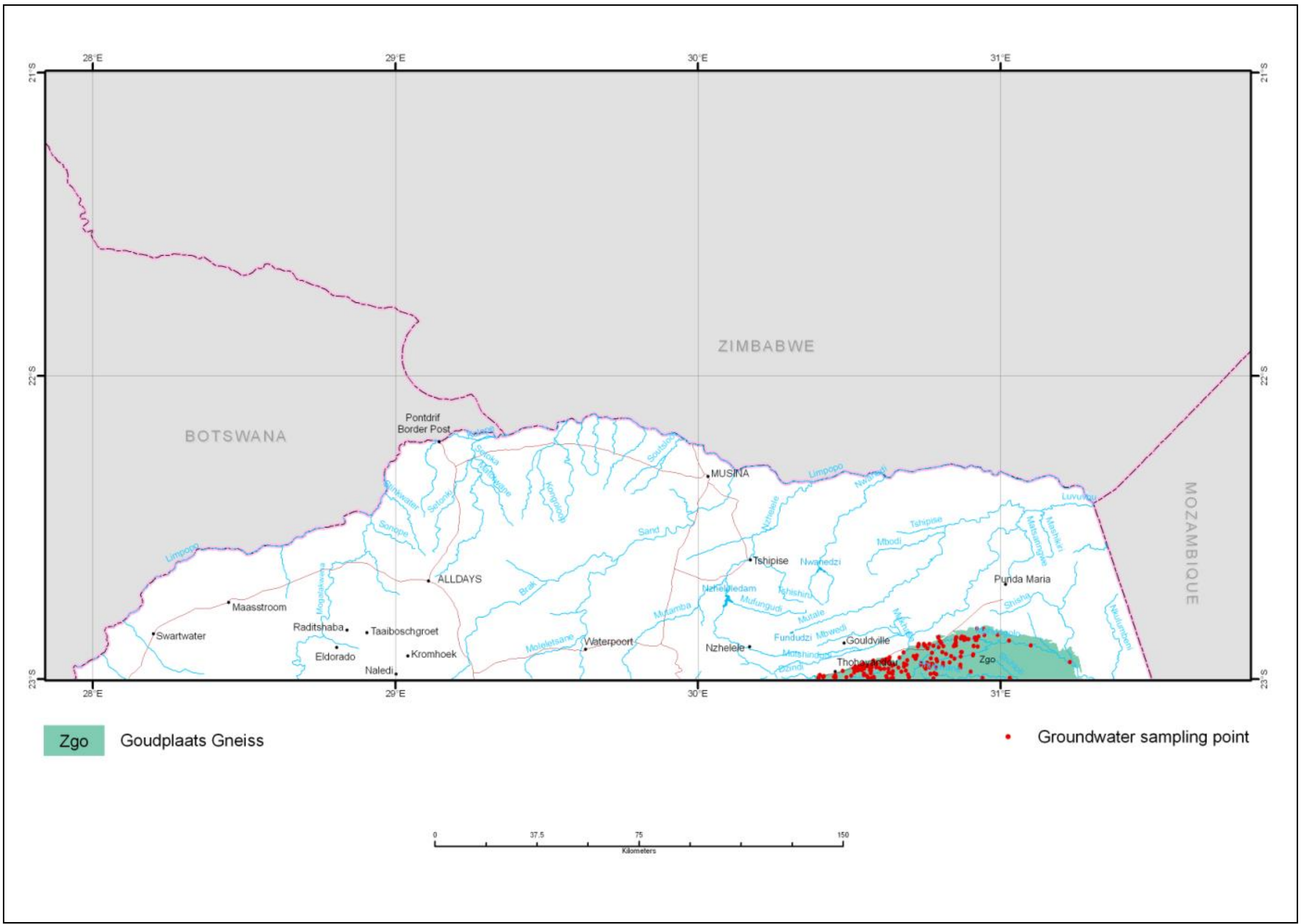

Figure 68: Geographical distribution of the Goudplaats Gneiss (Zgo) and associated groundwater sampling points

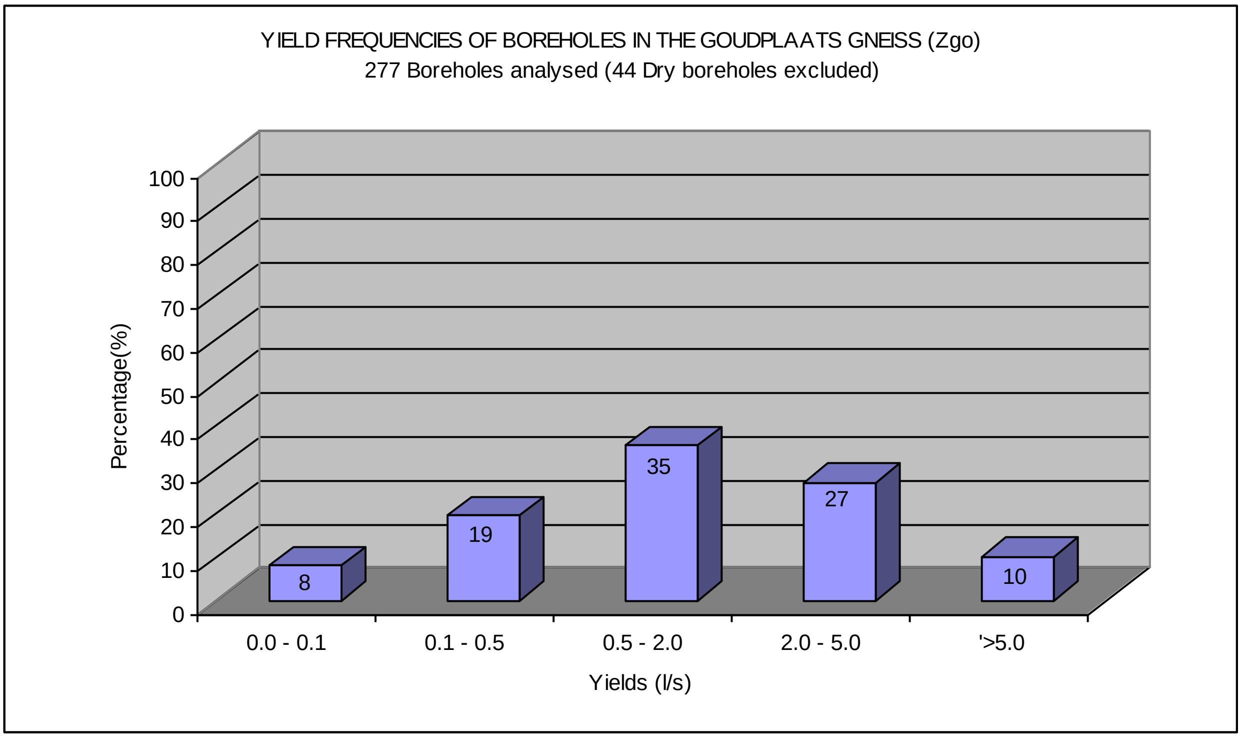

Figure 69: Yield frequency for the intergranular and fractured aquifers of the Goudplaats Gneiss (Zgo)

The quality of the water is generally good with a harmonic mean of 70.8mS/m for the EC of the unit. The EC values varies from 12 to 300mS/m, with 89.9% of the samples with values varying between ideal water quality and the acceptable limit for domestic use (EC < 150mS/m). Fluoride concentrations are not a concern as it varies between 0.03 and 3mg/l with only 0.6% of the boreholes exceeding the maximum allowed limit (F > 1.5mg/l). Nitrate and nitrite (reported as N) concentrations vary from 0.02 to 71mg/l with 18% exceeding the maximum allowed limit (N > 20mg/l). These higher concentrations are attributed to sanitation problems as the sources plots within or near villages. The local laboratory confirmed an increase in quality problems in the area for nitrate (Andrin, personal communications, 2010). Figure 70 shows the dominant anions and cations present. The groundwater displays a magnesium-calcium-sodium-bicarbonate character with slight elevated chloride concentrations.

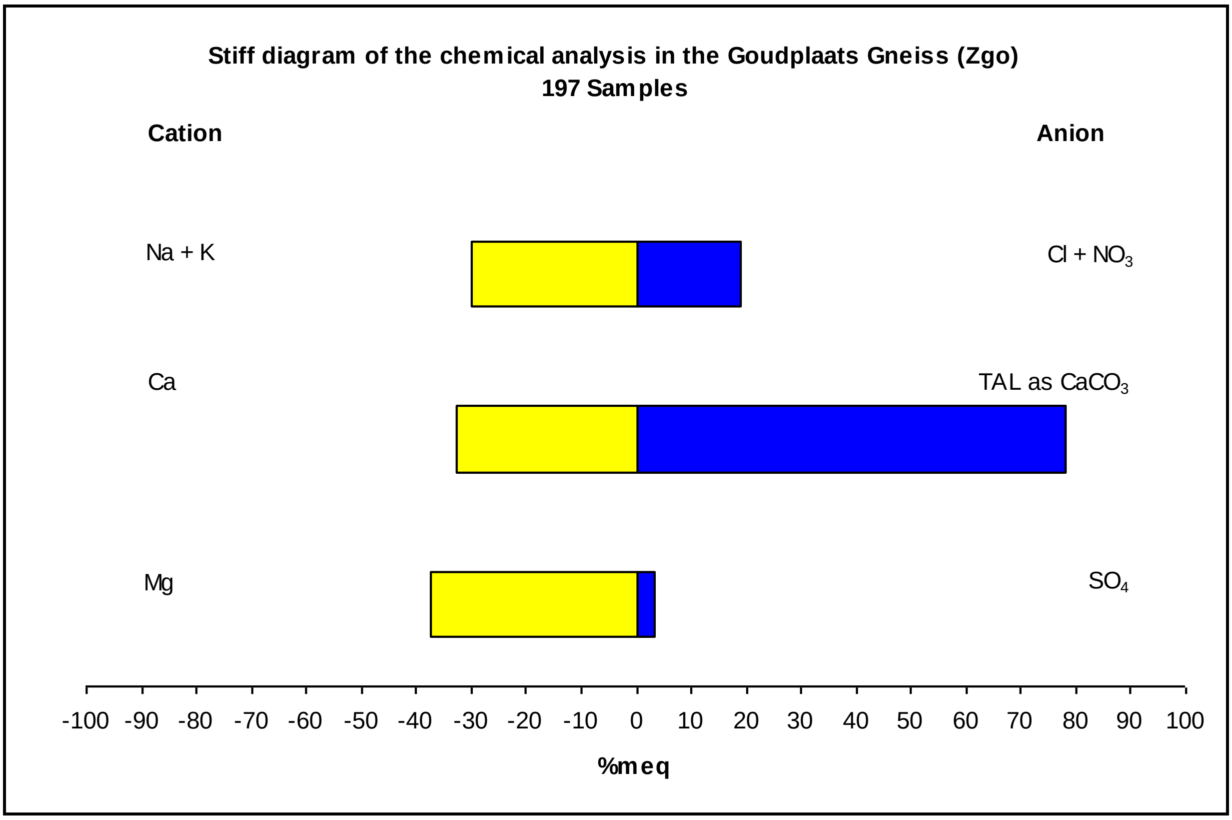

Figure 70: Stiff diagram representing chemical analysis of the Goudplaats Gneiss (Zgo)

7.2.3.13 THE BEIT BRIDGE COMPLEX (Z).

The Beit Bridge Complex forms part of the central zone of the Limpopo Metamorphic Belt and is broadly subdivided into the ***Mount Dowe***, ***Malala Drift*** and ***Gumbu Groups*** *(Brandl, 1981)*. It underlies 38.53% of the map area. The data available is believed to underestimate the total of dry and low yielding boreholes drilled in the area.

The complex geology of the Beit Bridge Complex around Musina is best seen south of the town in the Musina Nature Reserve which is an area well known for its many spectacular ancient baobab trees. Here the high-grade metamorphic gneisses of the complex show incredible patterns of ductile deformation and are best seen in the bed of the usually dry Sand River. This world-famous and accessible geosite is located close to the road bridge along the R508 to Tshipise approximately some 8km southeast of Musina.

In the south-western sector of the map sheet and more specifically in the Swartwater and Beauty areas various geological lineaments namely granophyre dykes, amphibolite dykes, diabase dykes, dolerite dykes and fault and/or shear zones were observed. This area is located within the central part of the Limpopo Mobile Belt. Dominant strike directions in the Swartwater area are northeast/southwest and east/west in the Beauty area (Bush, 1989).

From a study done in the Swartwater area linear features such as dolerite and diabase dykes do not possess favourable geohydrological properties and should not be considered target zones for drilling. It was found that dyke/host rock contacts are usually devoid of fracturing and that those fractures which occur at the contact or within the dyke itself are in filled with calcareous or other deposits. In some cases the infilling of fractures is associated with poor yielding boreholes in favourable hydrogeological areas. It was concluded that zones of fracturing, shearing or faulting form favourable target zones for groundwater exploration in regions where rest water levels do not exceed 35m. At depths greater than this the probability of intersecting open cracks and fissures is reduced despite the fact that jointing/fracturing usually extends to these levels. From a hydro census done in the area followed by a geophysical survey undertaken across 147 boreholes indications are that the deepest weathering in the area extends to 43m, although the semi-weathered or transitional zone may extend to 54m. On average the depth of weathering ranges from 18m - 30m. There is no evidence of any favourable fracturing, jointing or weathering occurring at the contacts between any of the lithological rock types in the Swartwater area. There is also no evidence of such features occurring within gneissic banding. All contacts were found to be welded or transitional in nature, a consequence of metamorphism (Bush, 1989).

7.2.3.13.1 GUMBU GROUP (Zbg).

The **Gumbu Group** consists of marble and calc-silicate rocks with minor metaquartzite, quartzo-feldspathic gneiss, metapelite and amphibolite. The Marble and calc-silicate rocks are intimately associated, and are often seen to give rise to a number of prominent horizons. They form positive features due to the relatively dry climate of the area. Whereas the calc-silicate rocks generally give rise to narrow steep features, the marbles form rather wide, low ridges which are often covered by calcrete. The Group occupies the smallest area within the Beit Bridge Complex, but is still underlying 4.22% of the map area.

The *marble* is a medium- to coarse-grained, often massive re-crystallized rock which weathers to a blackish grey or dark brown skin on which the more resistant accessory minerals stand out as small protuberances. The colour of fresh specimens can range from milky white through light grey to bluish grey and locally an attractive pink colour is developed. Colour generally depends on the amount of the accessory minerals present and where these accessories are more abundant the marble attains a rather banded appearance showing gradations into a calc-silicate rock. Maximum thickness of individual marble horizons is at least 20m. The marble consists mainly of interlocking grains of calcite/dolomite which average 0.5-3mm in size but can range up to 20mm. The accessory minerals can reach up to about one third of the rock and consist mainly of olivine, pyroxene, biotite, spinel and amphibole. Pure white marble is rare the most common marble type being an olivine marble in which the olivine (forsterite) is variously altered to antigorite. Grain size of the olivine is generally much smaller than that of calcite/dolomite, but occasionally grains can be up to 6.0 mm. Geochemical analyses indicate that the precursors of the marbles were pure to slightly impure carbonates. Some carbonate horizons are almost entirely calcite whereas others can be entirely dolomite.

Calc-silicate rocks are in general intimately associated with the marbles where they occur as narrow discontinuous horizons. They probably rarely exceed a width of 10m. Often the rocks are seen to exhibit a strong lineation. Unusual gradation along strike into amphibolite can be seen locally. The calc-silicate rock, when fresh is dark to pale grey or greenish but weathers into a light brown, pitted or grooved surface which is caused by the differentiated weathering of the silicate- and carbonate-rich bands. Like elsewhere, the calc-silicate rocks of the map area consist of a great variety of mineral phases. They generally include clinopyroxene, quartz, microcline, scapolite, calcite/dolomite, plagioclase and minor opaques. Grains can be up to 6mm in length. The origin of the carbonates is not clear, but might be due to organically induced carbonate precipitation probably in the form of aragonite. The relatively high MgO content of some marbles was probably caused by later selective dolomitisation. Protolith of the calc-silicate rocks was calcareous shale with variable carbonate content.

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. The yield frequency diagram (Figure 72) shows that 75% of the successful boreholes yield less than 2ℓ/s.

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. These factors, together with abstraction contributed significantly to the generally deep water levels (30-60m) occurring in the area (Bush, 1989).

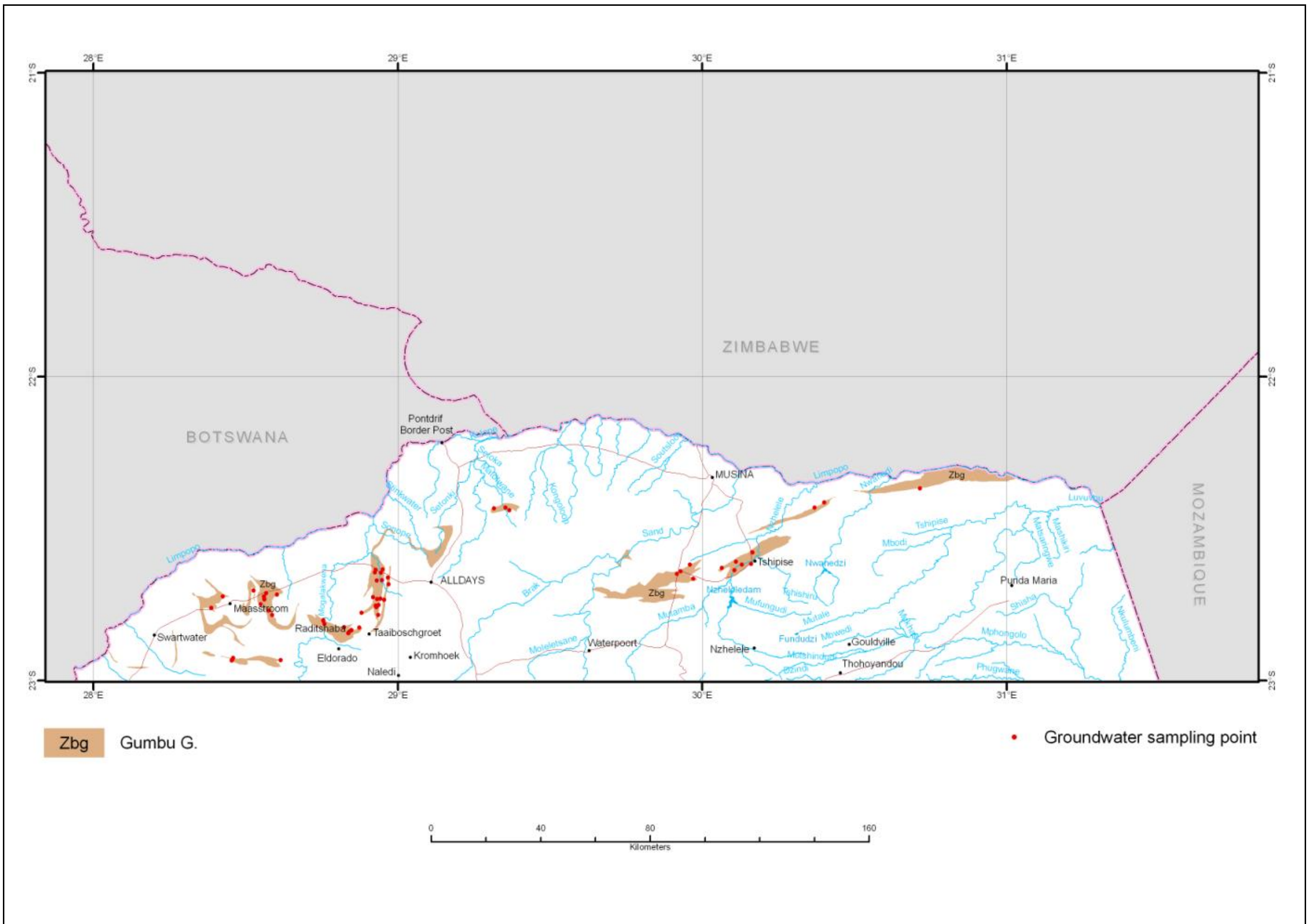

Figure 71: Geographical distribution of the Gumbu Group (Zbg) and associated groundwater sampling points

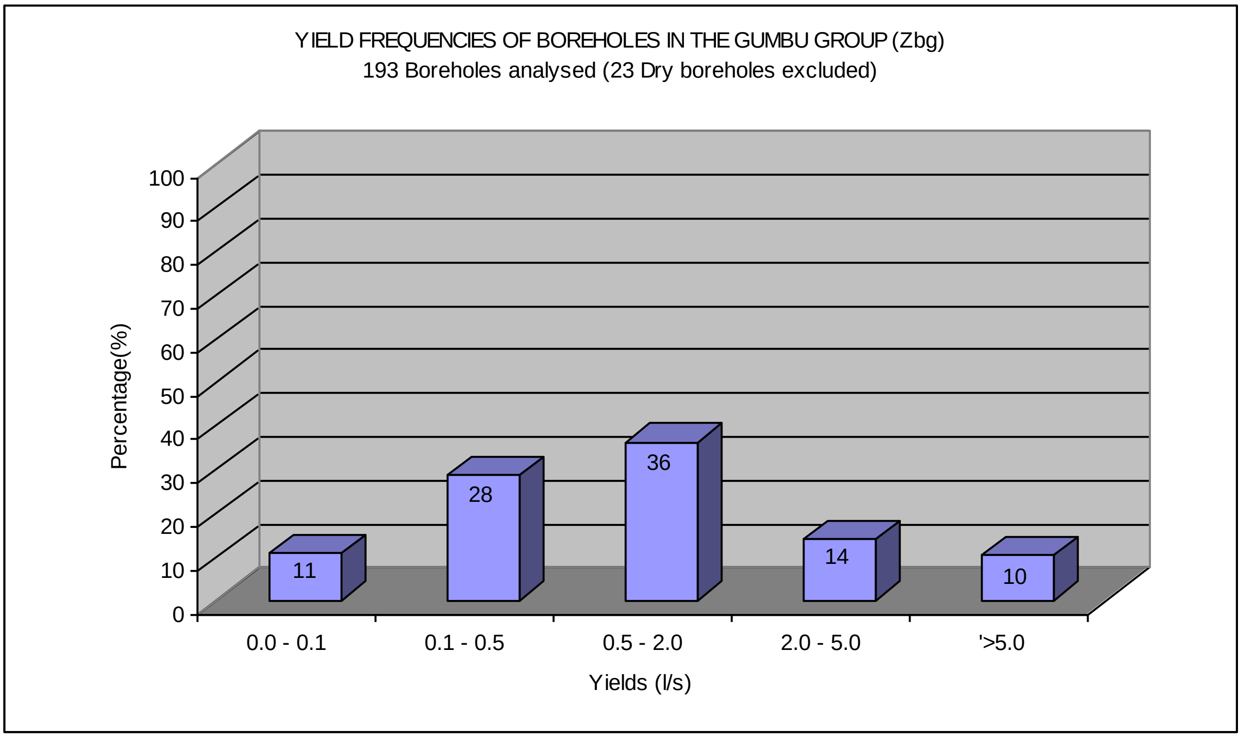

Figure 72: Yield frequency for the intergranular and fractured aquifers of the Gumbu Group (Zbg)

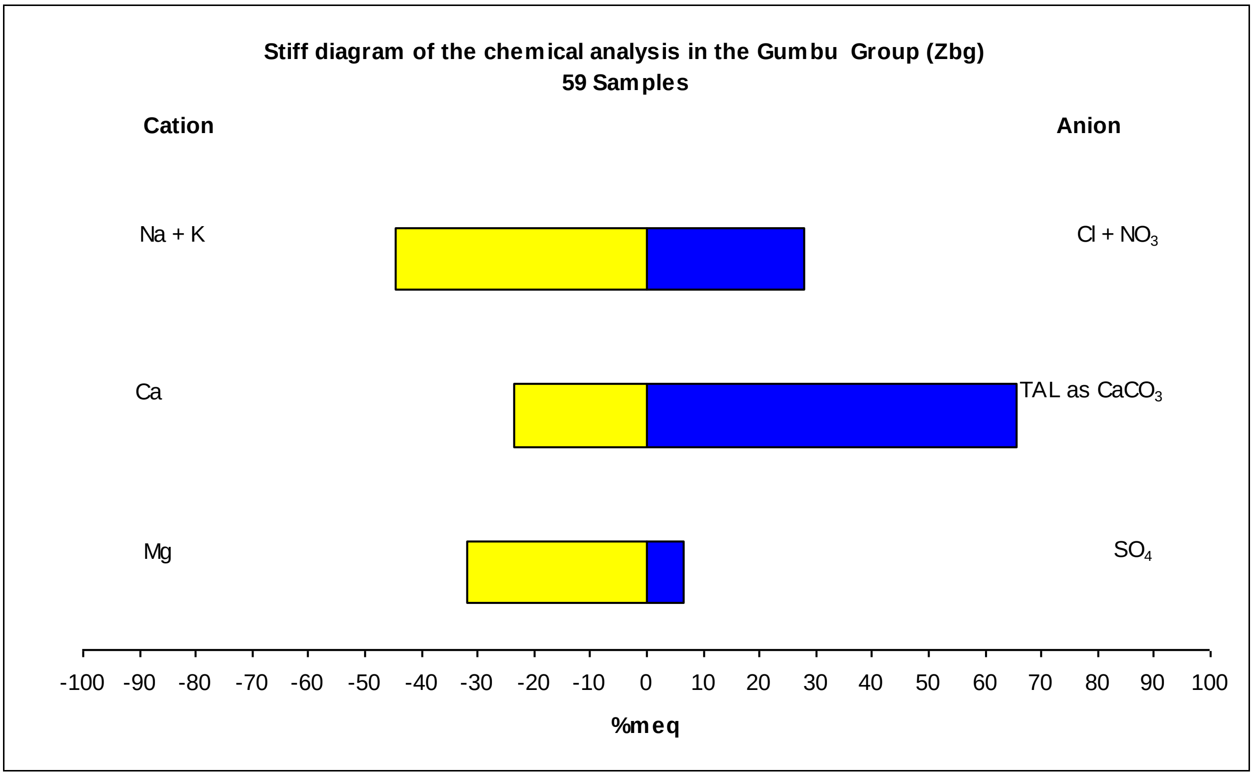

Figure 73: Stiff diagram representing chemical analyses of the Gumbu Group (Zbg)

Chemical data for the unit is represented in a stiff diagram (Figure 73). The water exhibits a sodium-magnesium-bicarbonate water type with elevated calcium and chloride concentrations. Magnesium concentrations vary between 22 to 1016mg/l, with 39% exceeding the maximum allowed limit (Mg > 100mg/l). EC values vary between 80 and 1560mS/m with a harmonic mean of 155.9mS/m. 18.6% of the analysis have EC values exceeding the maximum allowed limit (EC > 370mS/m) for domestic use. Fluoride concentrations vary between 0.05 to 4mg/l with 25.4% of the boreholes exceeding the maximum allowed limit (F > 1.5mg/l). Nitrate and nitrite (reported as N) concentrations vary between 0.04 to 105mg/l with 29.3% exceeding the maximum allowed limit (N > 20mg/l). 18.6% of sodium (Na > 400mg/l) concentrations and 22% of the chloride (Cl > 600mg/l) concentration exceed maximum allowable limits for domestic use. Water quality in this unit is poor to moderate. The water is mainly used for livestock watering and domestic purposes with limited irrigation.

7.2.3.13.2 MALALA DRIFT (Zba)

The ***Malala Drift Group*** underlies extensive parts of the Central to western zone of the map (Figure 74) and consists predominantly of leucocratic quartz-feldspathic gneisses, (leucogneiss), Metaquartzite, pink granitoid hornblende gneiss, felsic granulite, metapelite, amphibolite or mafic granulite and marble or calc-silicate rocks occur as subordinate intercalations. The most extensive of the Beit Bridge Complex and all the units in the map sheet underlies 21.75% of the map area.

The *quartz-feldspathic gneiss* is volumetrically the most common rock-type of the Central Zone, estimated to make up about 50% of the gneisses present. However, exposures are in general poor and the ground is often covered by a thin immature soil containing abundant quartz and feldspar. The gneiss is a medium-to coarse-grained, in places pegmatitic, rock of whitish, whitish-grey, or locally pinkish. Where no ferromagnesian minerals are developed in the rock it is massive and may locally form a few prominent outcrops. Otherwise the rock is well foliated with the fabric defined by the parallel orientation of the platy minerals or by the dimensional orientation of quartz ribbons. The gneiss is dominated by quartz and feldspar (80-90% combined) occurring in roughly equal amounts. The feldspars include orthoclase, microcline and plagioclase with the proportions of K-feldspar and plagioclase varying widely. As minor additional phases, garnet, biotite, hornblende and sillimanite can be present. Most of the quartz-feldspathic gneisses are presently interpreted to represent intrusive granitoid rocks.

Layers of *amphibolite* are only rarely developed and are generally not wider than 100 m. In hand specimens, the amphibolite is bluish black or brownish depending on the amount of pyroxene present. Sometimes the rocks have a typically speckled appearance. Texturally, two main varieties can be distinguished: a fine- to medium-grained type and a coarse-grained one. The latter forms massive outcrops generally with no intercalations of other supracrustal gneisses. The major constituents of the amphibolite are plagioclase, hornblende, clinopyroxene, hypersthene, quartz and biotite. Garnet is a major constituent in only a few units and is often associated with thin felsic bands. Major units of garnetiferous amphibolite are rarely developed. Hornblende can be up to 6 mm in length, is greenish or olive brown, and occasionally is seen to be overgrown by hypersthene or partially replacing pyroxene. Plagioclase is mainly andesine and generally shows zoning and partial alteration to sericite and epidote. Biotite occurs either as relatively large subidioblastic grains or as an alteration product along fractures in hornblende. Garnet which can measure up to 20 mm across, is poikiloblastic displaying numerous inclusions of generally quartz and plagioclase. The supracrustal amphibolites that have a relatively small grain size can be of igneous extrusive (basaltic lava) or sedimentary (marly sediment) origin. Of sedimentary origin are probably those amphibolites which form thin bands and which are intimately interlayered with clastic and calcareous rocks. Amphibolites forming layers of considerable thickness and having a uniform appearance are interpreted to represent mainly basaltic lavas. The coarse-grained amphibolites are thought to have derived from gabbroic sills or stocks.

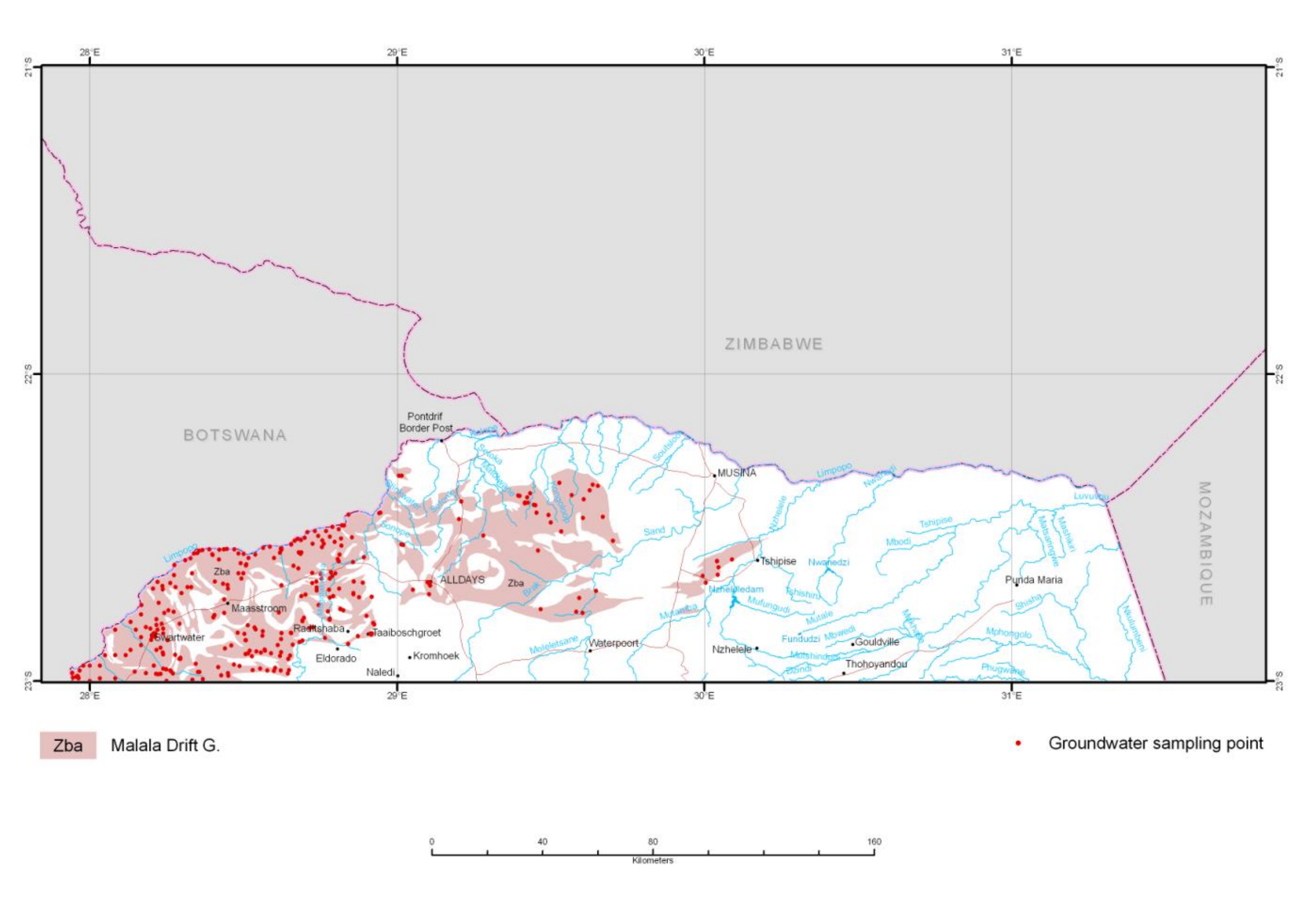

Figure 74: Geographical distribution of the Malala Drift Group (Zba) and associated groundwater sampling points

In the Swartwater area a study found that groundwater levels fall within the range 6m to 24m. The deepest groundwater levels are located on the major surface water divides and also in other high lying areas. The depth to weathering varies within the area, but dominantly boreholes have depths to bedrock of less than 30m. In some areas, however, weathering extends to a depth of 43m although semi-weathered or transitional zone material may extent to 54m. Where groundwater levels extend to below the base of the weathered zone, groundwater is obtained from deeper fractured horizons (Bush, 1998).

For the Swartwater area another study found that it is unlikely that any significant lateral groundwater flow takes place (Vegter, 1988). The regional groundwater levels largely mimic that of the surface water flow pattern.

The groundwater potential of these gneisses and amphibolites is generally low as approximately 77% of the successful boreholes yield less than 2ℓ/s (Figure 75). Only 4% of the recorded boreholes were dry. It is believed that the low yielding and dry boreholes are poorly recorded on the data base. From the available data the average static water level for the unit is shallow with an approximate level of 9mbgl. Groundwater is mainly used for livestock watering and domestic purposes although some irrigation from boreholes takes place. Surface water is used for irrigation along the Limpopo and Mogalakwena Rivers.

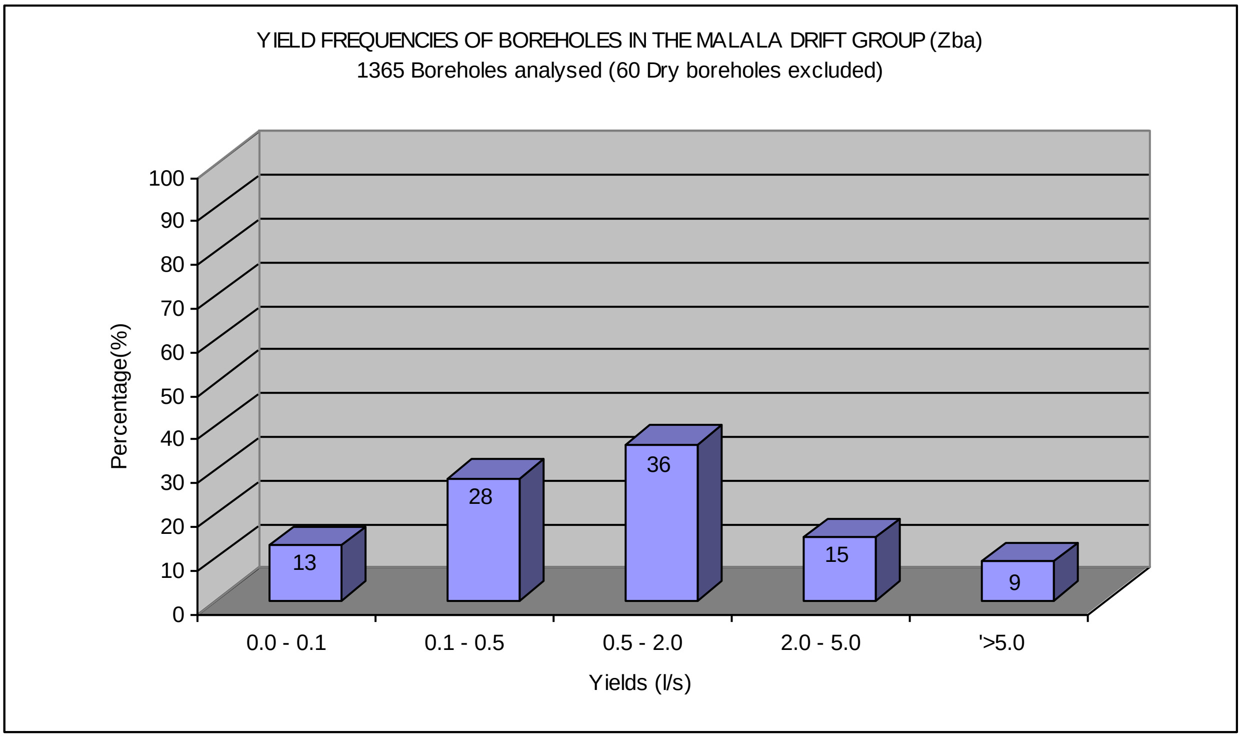

Figure 75: Yield frequency for the intergranular and fractured aquifers of the Malala Drift Group (Zba)

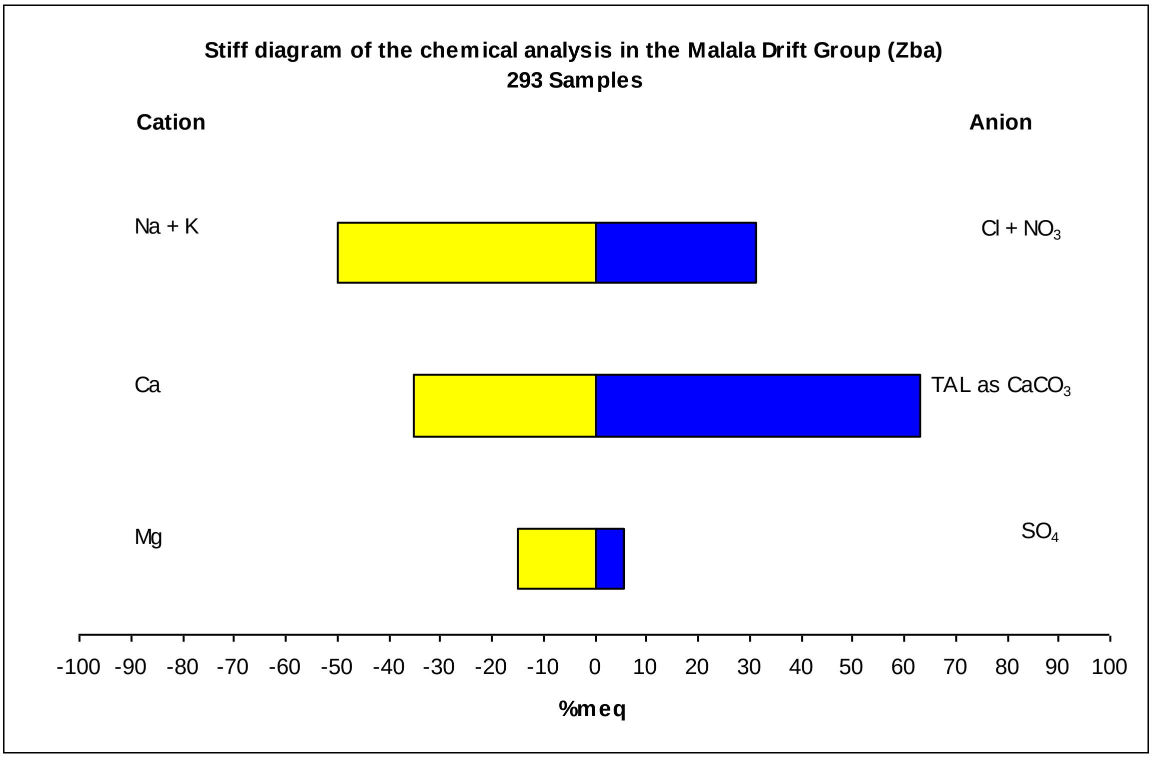

Figure 76: Stiff diagram representing chemical analysis of the Malala Drift Group (Zba)

The stiff diagram (Figure 76) shows the broad classification according to anions and cations. The water exhibits a sodium-calcium-bicarbonate water type with high chloride concentrations. The analysis of cations indicates no dominance of any particular cation although the extension of the field towards the Na and K suggest that a certain amount of natural base exchange may be taking place. The plot of anions indicates a variation in dominance from CO3 + HCO3 to Cl + SO4 anions. The above trends are best explained by a natural variability in the hydrochemistry of the water due to differing residence times in the case of cations and sulphate reduction in the case of anions.

Nitrate and nitrite concentrations (reported as N) are exceeding the maximum allowed limit in 29.7% of the samples (N > 20mg/l). Fluoride concentrations exceed the maximum allowed limit in 23% (F > 1.5mg/l) and magnesium in 11.3% (Mg > 100mg/l) of the samples. The water quality is moderate with EC values ranging from 2.3 to 760mS/m and the harmonic mean calculated as 88.5mS/m. This is well within the acceptable limit (EC < 150mS/m) for domestic use.

7.2.3.13.3 MOUNT DOWE GROUP (Zbo)

The ***Mount Dowe Group*** is characterised by the presence of thick layers of metaquartzite containing minor interlayered horizons of magnetite quartzite, leucocratic quartz-feldspathic gneiss, metapelite, amphibolite or mafic granulite, and marble or calc-silicate rocks. It underlies 12.15% of the map area.

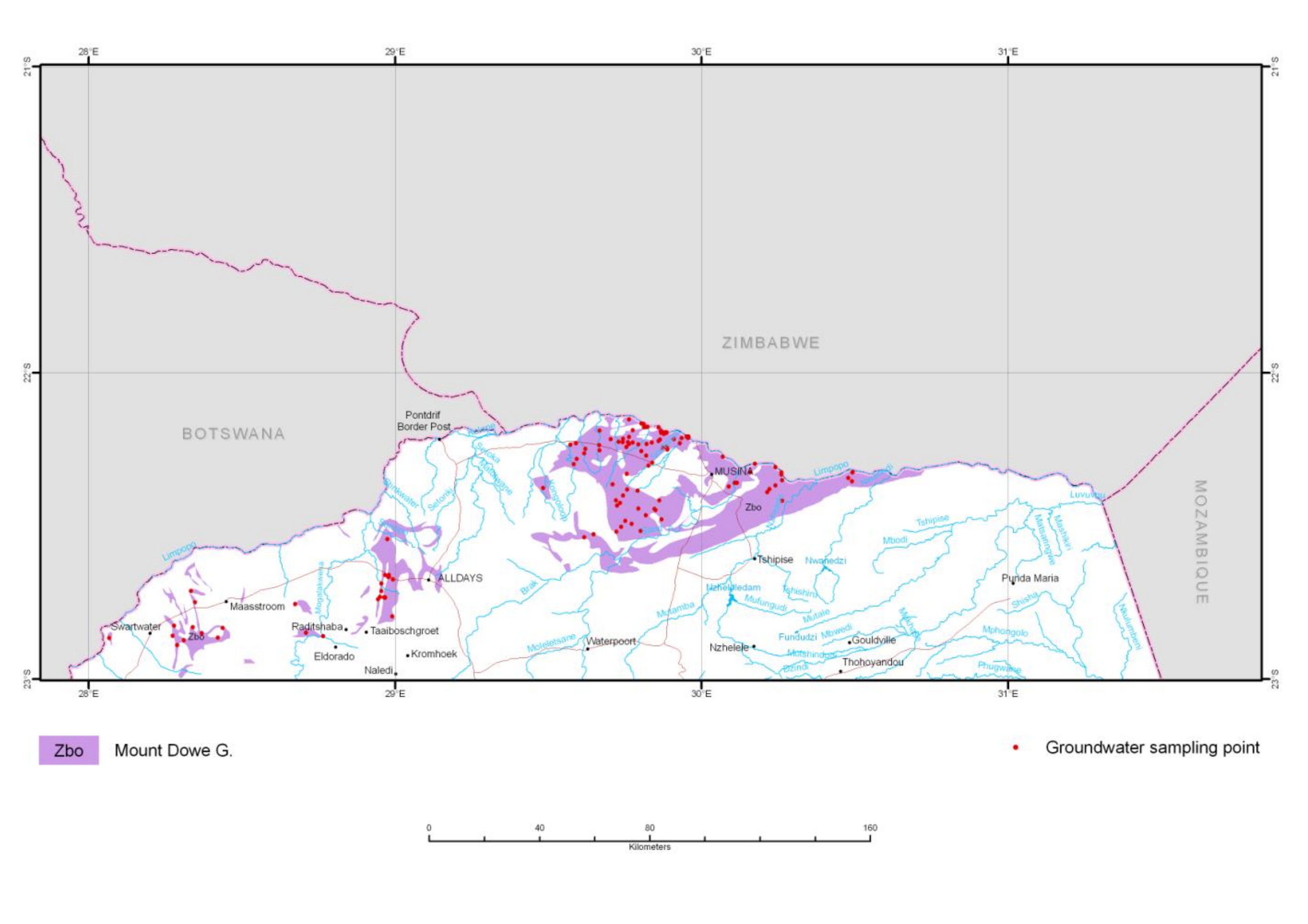

Figure 77: Geographical distribution of the Mount Dowe Group (Zbo) and associated groundwater sampling points

Owing to its highly resistant nature, *metaquartzite* forms the main topographic features in the map area underlain by rocks of the Beit Bridge Complex. These features can be followed for many kilometres across the area and the steep slopes are often littered by large blocks and scree. The width of individual horizons probably nowhere exceeds 50 m. The rock is generally massive, medium- to coarse-grained, and where fresh has mostly a milky to greyish white colour but pinkish, greenish or brownish varieties do occasionally occur. As the metaquartzite is in general largely recrystallized it frequently assumes the appearance of vein quartz. A well developed joint system can often be seen in the competent rock. The metaquartzite is entirely recrystallized and consists of an interlocking mosaic of mainly quartz grains which show undulose extinction or extinction bands. Grain boundaries are often strongly sutured. Individual grains can be up to 5 mm in length but are generally around 3 mm. Minor constituents of the massive variety include plagioclase, K-feldspar, pyroxene, grunerite and garnet. Besides the common massive metaquartzite, foliated varieties can locally be developed in which the fabric is accentuated by biotite, muscovite, fuchsite or sillimanite. The foliation planes which can be spaced from a few millimetres to several centimetres may represent original bedding planes. Biotite-bearing metaquartzite is the most common foliated variety and usually occurs where metaquartzite grades into metapelitic rocks. Most of the metaquartzite, at least the fairly thick layers, are interpreted to be of sedimentary (quartz arenite) rather than of chemical (chert) origin. The complete lack of coarse material and the often observed association with marble may indicate that the metaquartzite represents mainly a marine shelf deposit with the adjacent hinterland having been a low lying stable land surface.

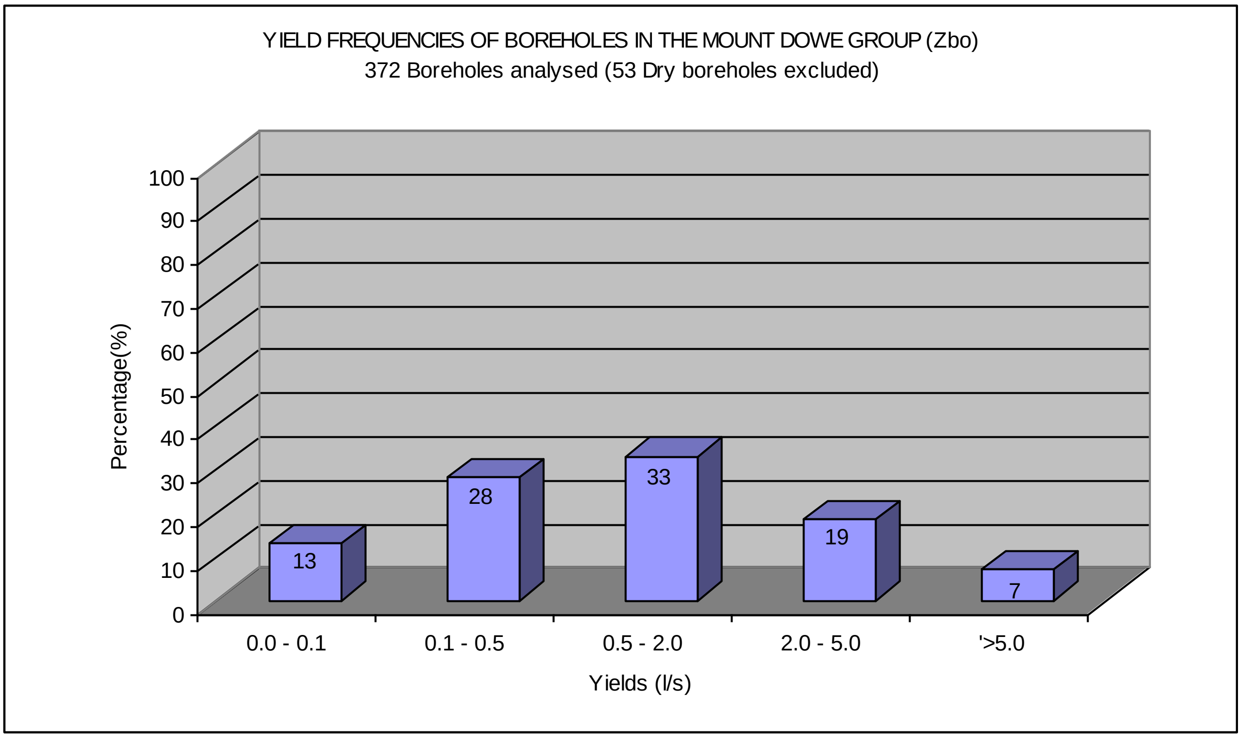

Figure 78: Yield frequency for the intergranular and fractured aquifers of the Mount Dowe Group (Zbo)

Analysis of the yield frequency diagram (Figure 78) show 74% of the sources to yield less than 2l/s with 12% drilled dry. 7% yields more than 5l/s.

The water quality is moderate to poor with EC values ranging from 38 to 1140mS/m and the harmonic mean calculated as 130.6mS/m. Nitrate and nitrite (reported as N) concentrations ranges from 0.02 to 71mg/l. In 26.7% of the samples nitrate exceeds the maximum allowable limit (N > 20mg/l). Fluoride concentrations range from 0.22 to 4.2mg/l. In 32.5% of the samples fluoride (F > 1.5mg/l) exceeding the maximum allowed limit. In 22.5% of the samples magnesium (Mg > 100mg/l) and in 10% sodium (Na > 400mg/l) exceeds the maximum allowable limits. The groundwater exhibits a sodium-magnesium-bicarbonate-chloride character. Groundwater from this Group is mainly abstracted for livestock watering, game farming and domestic purposes and, to a limited extent, for irrigation.

Groundwater occurs in faults and associated shear zones, fractures related to quartz veins, deep weathered zones and pegmatites. Secondary fractures related to intrusive dykes are targeted with varying success.

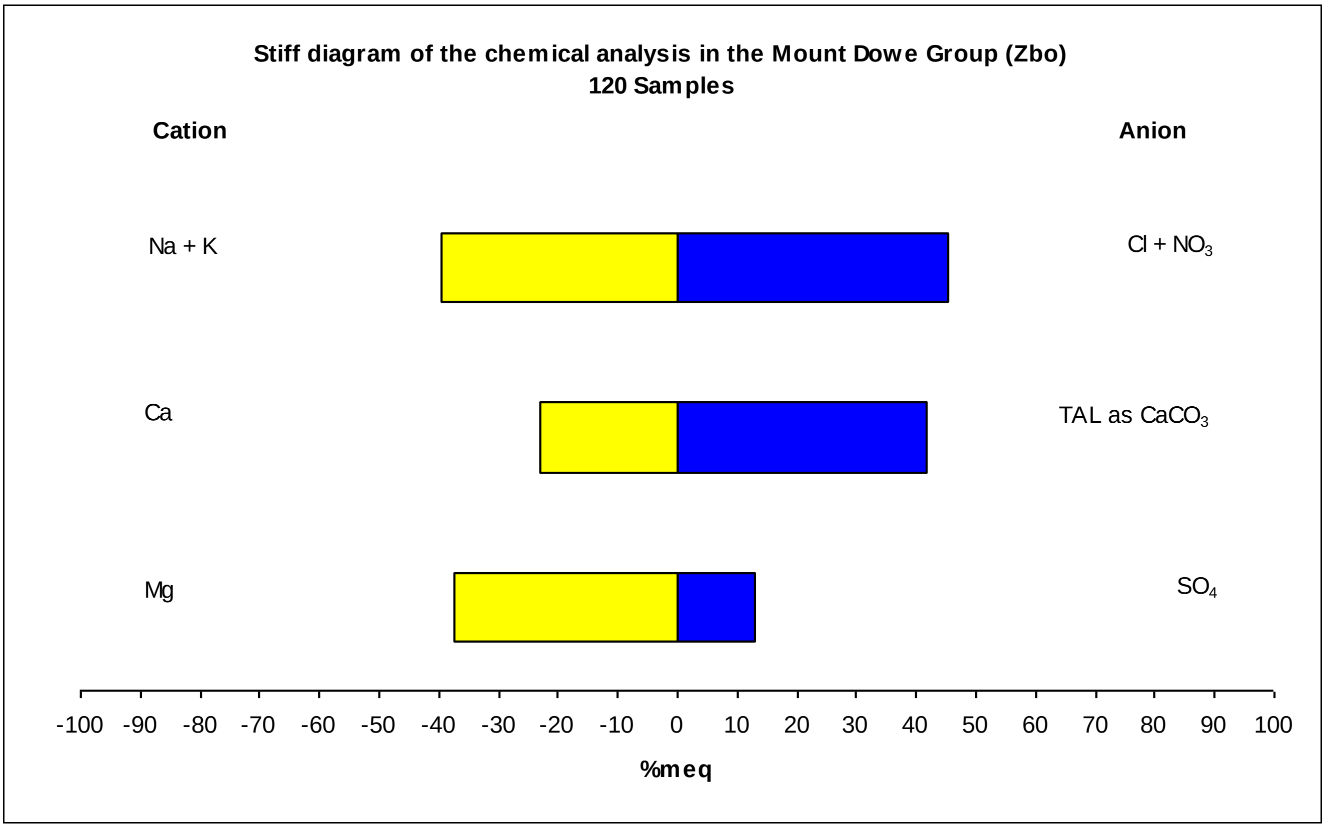

Figure 79:*Stiff diagram representing chemical analysis of the Mount Dowe Group (Zbo)*

8 SPRINGS AND ARTESIAN BOREHOLES

8.1 Hot Springs

At least 33 thermal springs and boreholes are located in the Limpopo Province. They occur in two main regions or ‘belts’, namely the Waterberg area in the southwest and the Soutpansberg area in the northeast of the Province. The Soutpansberg area falls within the Messina map sheet with 8 thermal springs (depicted in Figure 80) listed as follows:

- Tugela
- Evangelina
- Vetfontein
- Tshipise
- Moreson
- Siloam
- Mphephu
- Sagole

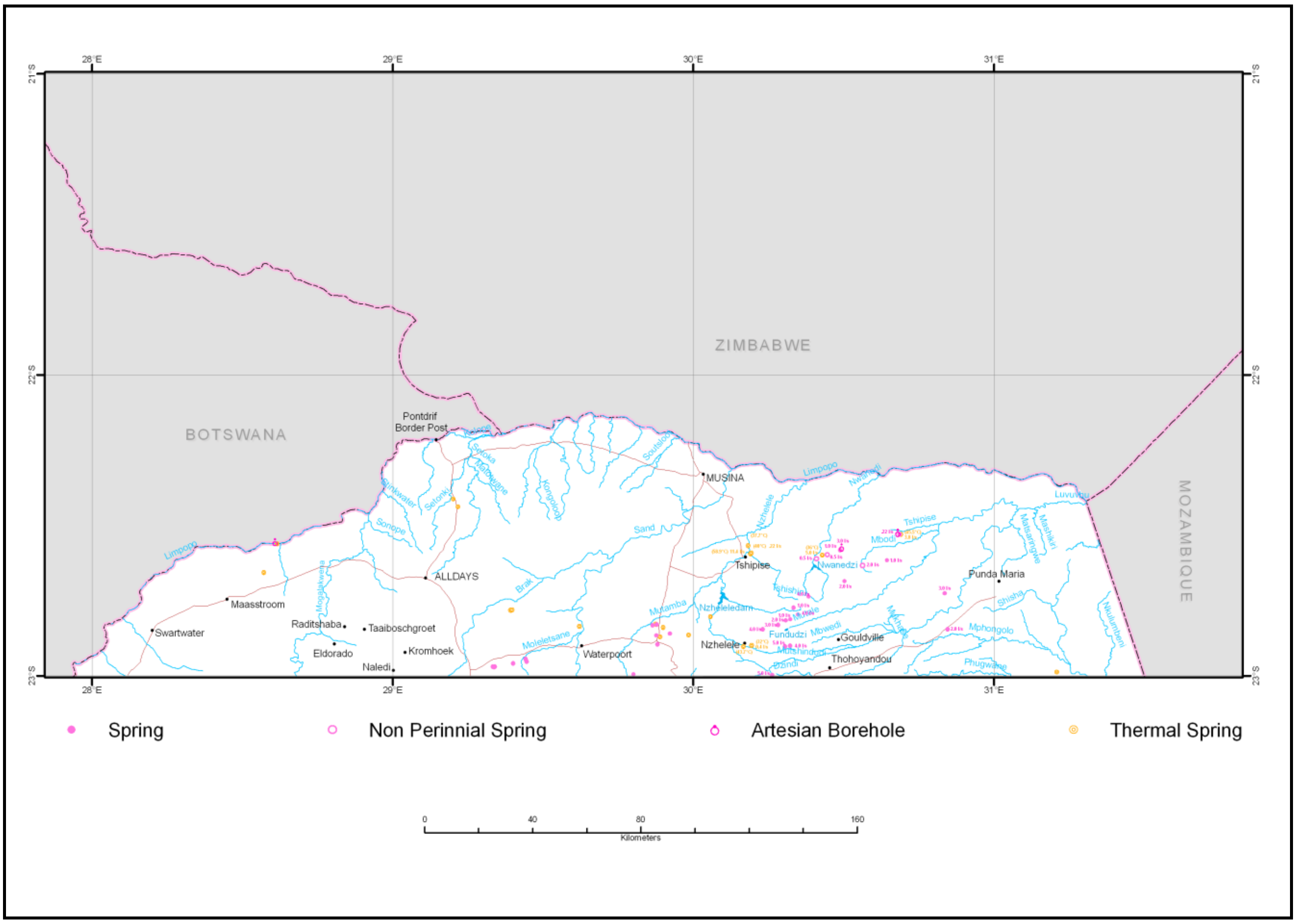

Figure 80: Springs and artesian boreholes in the Messina map area.

Since active volcanic regions are non-existent in South Africa, magmatic water cannot play a role with regard to the origin (source) of the hot water or 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 very long process.

The research indicates that most thermal springs (exceeding temperatures of 25^{0}C) in Limpopo are associated with major faults in the Waterberg and Soutpansberg regions of the country. Geological studies have also shown conclusively that the origin of each individual thermal spring can be attributed to the local presence of deep geological structures such as folds, fractures, faults and dykes that provide a means for the circulation to depth and the return of the heated waters to the surface. The rocks generally possess no primary permeability, the aquifers are secondary, the effective porosity and permeability being due to fracturing by faulting, shearing or jointing.

The main geological features underlying the northern thermal springs, are volcanic and sedimentary rocks of the Soutpansberg Group (e.g. Siloam), as well as volcanic and sedimentary rocks of the Karoo Supergroup (e.g. Sagole and Tshipise). Table 11 is a summary of the geological structures associated with the thermal springs on the Messina Map Sheet.

Table 11: Geological structures associated with the thermal springs on the Messina map sheet (Adapted from Bond, 1947; Kent 1946, 1949, 1952, 1969; Kent and Russell, 1950; Hoffman, 1979; Ashton and Schoeman, 1986).

Name	Geological Structure
Evangelina	Diabase dyke in Archaean gneiss
Moreson	Fault in Archaean gneiss
Mphephu	Pre-Karoo fault
Sagole	Klein Tshipise fault (1:250 000 Messina sheet) in mudstone, shale
Siloam	Siloam fault (1:250 000 Messina sheet) in basalt
Tshipise	Intersection of two post-Permian faults in Upper Karoo
Tugela	Fault in Archaean gneiss
Vetfontein	Post Karoo fault

Boreholes have been drilled at some of the thermal springs to augment water supply for the development of resorts. At Tugela 171MR for example, a 20m deep borehole flows at $70m^3$/d. The water has a temperature of 48.9^0C compared with 42.8^0C for the natural spring. The temperature recorded in the 2228 geological map sheet explanatory booklet gives the temperature of the spring as 60^0C. The springs at Icon 95MS and nearby Evangelina 71MS is given as 45^0C. Vetfontein 360MS and Sulphur Springs 653 MS is 35^0C with a high H_2S concentration. Other springs mentioned includes Windhoek 649MS, Mphephu 202MT, Crimea 747MS and Kalkvlakte 670MS. All the springs are associated with post-Karoo brittle shear zones (Brandl, 2002).

All thermal springs in the study area are of meteoric origin and have temperatures ranging from 25^oC to 67.5^oC. The mineral composition of the thermal waters reflects the geological formations found at the depth of origin of the thermal spring water rather than the surface formations. This indicates that the spatial distribution of the thermal springs does not dictate the physical and chemical characteristics of the springs and that two or more springs located in close proximity to each other may differ markedly from one another with respect to their temperatures, flow rates and chemical composition and may not share the same development potential. Thermal springs very close to each other where the temperature differs significantly are at Tshipise (58^oC) and Moreson (40^oC). A difference of 28^oC also occurs between Mphephu (43^oC) and Siloam (67^oC), less than 2km apart. Measurements done at a private artesian borehole also in Siloam averages around 70^oC. An artesian borehole at Siloam Hospital averaged around 40^oC whilst a borehole at the Mphephu Resort is fairly constant at 42^oC.

The Tshipise spring (Plate 1) is the second hottest spring in South Africa. It occurs where the Tshipise fault joins up with another minor fault. The water of Tshipise has an appreciable HCO_3 content although it is essentially moderate saline water. It is of mixed origin as various rock types including leucocratic quartz-feldspathic gneiss, marble and calc-silicate rocks of the Gumbu Group is brought together by the Tshipise fault with sediments of the upper Karoo Supergroup including the basalt of the Letaba Formation and the sandstone of the Clarens Formation in close proximity of a dolerite sill.

The fluoride and bromine concentrations of waters from the majority of springs in the study area do not conform to domestic water quality guidelines and make the water unfit for human consumption.

Unacceptably high values of trace elements such as antimony, mercury, selenium and arsenic were found at some springs.

8.2 Cold Springs

Nine cold springs (temperature < 25º), all occurring within the Soutpansberg Supergroup are listed in the map area. The highest recorded yield is 3l/s at H20F0534. The data plot shows that 50% occur near diabase sills and 40% might be associated with fault zones. The springs are also underlain by the Wyllies Poort, Nzhelele and Fundudzi Formations. Two of the springs are recorded to be formed in a narrow valley where a mudslide filled part of the valley. The streams flowing in these valleys disappear to re-surface as a spring lower down the valley. The springs occur within the southern part of the Soutpansberg Mountain range. The high rainfall combined with the sedimentary regional geology as well as the numerous fault zones, intrusive diabase sills and mountainous topography gives possible reasons for the incidence of springs. Interflow especially along the southern escarps of this mountain range is related to rainfall events. Small plants growing on seemingly solid outcrop act as sponges resulting in minor water flow long after a rainfall event. In the area underlain by the Beit Bridge Complex no functional springs are recorded although some farm names have fountain as part of the name. This might be associated with the historic drop in static water levels investigated by Fayazi and Bush.

8.3 Artesian boreholes

Thirteen boreholes, all occurring within the Soutpansberg Supergroup are listed in the map area with artesian static water level conditions of which 9 (69%) are associated with the Klein Tshipise fault. Two are associated with the Tshipise hot water spring, one to an east-west fault zone within the Sibasa Formation also reported as warm water and the last with a southeast-northwest trending fault within the Wyllies Poort Formation. No information is given on the temperature of this borehole. The highest overflow yield was measured as 3.6l/s at H19-0352 after drilling 19/03/2009. The flow was recorded as 2.29l/s on the 25/03/2009 after pump testing of the borehole. The average over flow rate differs during wet and dry seasons. Some of the holes are used for communal water supply with the static level dropping during pumping. Within varying times after pumping artesian conditions return. In certain villages this water is used to irrigate small areas. In other areas the community does not allow drilling of additional boreholes as they fear that their current production boreholes will dry up (Sagole). Some of the artesian boreholes not in use were sealed by DWA during 2009-2010. The water quality of the boreholes drilled in the Tshipise fault have acceptable domestic water qualities except in one borehole, H20-1519, which has a high fluoride concentration (F = 2.6mg/l). No chemical analysis is available for the two boreholes at the Tshipise hot spring. The remaining borehole reported as hot, H27-0138, has a fluoride concentration of 4.6mg/l.

Plate 8: Drilling on the Klein Tshipise fault zone at Folovhodwe showing artersian Conditions (Photo, P.J. Lubbe, 2008).

9 GROUNDWATER RELATED MATTERS

9.1 The National Water Act (Act 108 1998)

The **National Water Act** (Act 108 of 1998) replaces the old Water Act (Act 56 of 1956). 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) which 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. All users, except the users 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 Eskom, 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 receives water from a local government or any other bulk supplier there is no need to register. The local government or any other bulk supplier must register. All 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 area 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 25lt/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 assessing 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 25lt/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. In a hydrogeological study done between Mopani and Tshipise, the analysis of available borehole data showed a general drop in water levels throughout the area over the years. This drop seems to be greatest in the granite-gneiss, where a drop of up to 25m has been recorded in the time frame ranging from 1928 to 1980. In the Ecca Formation a drop of 10m was recorded during the same period. The cause is not certain, but it is unlikely to be caused just by the fairly limited and moderate abstraction rates as used for livestock watering. Severe continuous drought in this area and possible overgrazing caused changes in vegetation cover thereby increasing run-off resulting in the decrease in water available for infiltration to the water table. This began the cycle of water level lowering. The effect of building dams to aid replenishment at sites and to control run-off near boreholes to improve the infiltration has already been shown to be very effective (Fayazi e*t al*, 1981). The position of monitoring points is indicated in Figure 81. The Messina 2127 map sheet was produced in 1995. At that time no monitoring network existed within the map area.

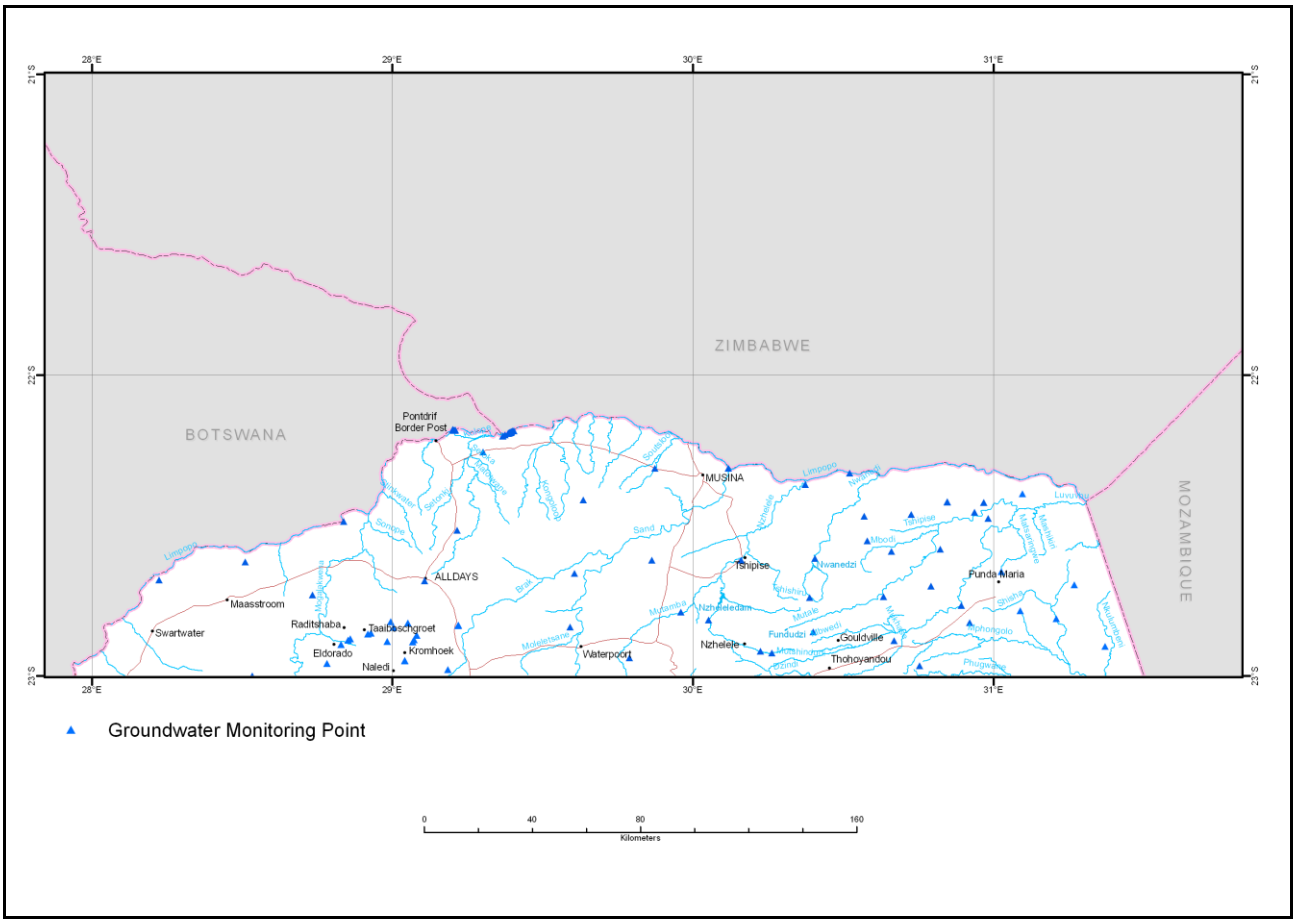

Figure 81: DWA monitoring boreholes in the map area

9.1.5 Groundwater storage

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 Messina 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.

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.

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 this 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.

9.1.6 Borehole positioning

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

GROUP/FORMATION	HYDRO-GEOLOGICAL UNIT	MODE OF OCCURRENCE	RATING						
			1a	1b	2a	2b	3	4	5
Tertiary - Quaternary alluvial deposits	Q	A	***	***	**			**	**
Malvernia Formation	Kma	B	**	**	**	**	***	**	*
Lebombo group-Jozini and Letaba Formation	Jl	B,D	**	***	***	*	***	*	*
Bosbokpoort-, Solitude Formations, Undifferentiated Ecca Group and Clarens formation, Ecca Group	Trb, P-Trs, Pe-Trc, Pe	B	**	**	**	**	***	*	*
Dolerite and Diabase intrusions,	Jd, N-Zd	D	**	**	***	***	***	*	*
Soutpansberg Supergroup, Nzhelele -, Wyllies Poort-, and Fundudzi Formation	Msn, Msw, Msf	B	**	***	***	**	***	*	*
Soutpansberg Supergroup, Sibasa-, Stayt Formation.	Mss, Msa	D	**	**	***	**	***	*	*
Bulai-,Alldays-,Hout River-, Sand River-,Goudplaats Gneiss,	Rbu, Zal, Rho, Zsa, Zgo	D	***	***	***	***	***	*	*
Messina Suite, Madiapala Syenite, Beit Bridge Complex (Gumbu-, Malala Drift-,Mount Dowe Group)	Zbm, Zma, Zbg, Zba, Zbo	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 hydrogeologist will also take vegetation, topographical setting, soil changes, possible recharge zones and other visible signs into consideration during the survey. The position and direction of geophysical traverses is very important and the data interpretation should be checked in the field to validate the expected target with the anomaly as the choice of drilling position depends greatly on the type of lineament. As an example, the drilling position on a geophysical anomaly will most likely be different for a dyke than a fault zone.

Additional comments from reports where geophysical methods were used:

Electrical Resistivity Soundings: Schlumberger and Wenner vertical electrical soundings (VES) were excessively and successfully used in the past in granitoid, gneissic and sedimentary environments. Cost and time implications limit the current use in groundwater development. The Wenner configuration was used with moderate success in areas where shallow weathering occurs i.e. <36 metres. Although the empirical method of interpretation is a quick method the estimated depth to bedrock can be grossly in error because of the higher than normal susceptibility to lateral effects. Despite being costly the accuracy and high resolution of data obtained with the Schlumberger configuration makes this a highly recommended method. The interpretation of the data has to be done by qualified and experienced personnel.

Electrical Resistivity Profiling: These older instruments limit the user to a single theoretical depth of investigation making the method time consuming and expensive. The geological environments investigated are the same as with the resistivity soundings. This method was usually used as a relatively fast way to cover vast distances before doing soundings. The development of electromagnetic methods replaced the single spacing profiling method in groundwater surveys. The development of resistivity profiling instruments that can measure apparent resistivity at multiple theoretical depths (such as the Lund) reinstated the resistivity method as a highly recommended tool. The method should be used in a combination with other instruments and, as with all methods, the surveyor should have an understanding of hydrogeological conditions.

Electromagnetic EM-34: Can be successfully used in most of the units to locate geological lineaments related to dykes and faults as well as deep weathered and fracture zones. Shallow highly conductive layers must be taken in consideration during interpretation. In various studies it was successfully used to locate fault zones where the magnetic response was limited such as the Tshipise and Xmas fault zones. The theoretical depth of applicability is approximately 60m, reducing use in deep water table environments. The interpreted dip and width of structures is usually extrapolated in such cases.

Electromagnetic Genie: An electromagnetic system developed to obtain data at depths up to 150m. The Stratagem is similar but much more advanced. The Genie has distinguished itself as a reliable and useful instrument in detecting water bearing zones located in a conductive environment. Its effectiveness, from a groundwater exploration point of view diminishes tremendously in higher resistive environments (Du Toit, 1998). As with the Stratagem, interpretation of data should be done by an experienced geophysicist. Due to time and cost implications the use of the Genie is limited. Surveys with the Stratagem are expensive and are mostly used for mine exploration.

Magnetic: Still the most widely used method due to cost and time effectiveness. It is a highly recommended method to use in combination with all the other available methods in all the units on the map sheet. In the Tertiary - Quaternary alluvial deposits the use will be to locate secondary targets associated with lineaments overlain by the deposits while in the other units it will be used to locate lineaments such as dykes when using it as a single geophysical method or to confirm and to identify the type of lineament when using the method in conjunction with other methods. Certain fault zones did not have a noticeable magnetic response but when using it with other methods the smaller anomalies can be interpreted. When interpreting data one should be aware of responses related to amphibolite, or the presence of magnetite in the gneisses and magnetite quartzite when working in areas underlain by rocks of the Beit Bridge Complex. In the Goudplaats and Hout River gneiss the presence of greenstone xenoliths must be taken in account. The magnetic response over lavas especially the Letaba basalt is very erratic making the identification of anomalies associated with intrusive dykes difficult.

Gravity: Due to its cost and use in mainly dolomitic rocks the method is not widely used in the map area. It is known from verbal conversations with various surveyors that the method can be successfully applied to locate drilling targets in schist, gneiss and granitoid. In dolomitic environments the use of this method together with the magnetic method is highly effective. Reports where the gravity method was used on other geological environments was not available for the map area. The viability of this method should be investigated within the units where the success rate is low in developing high yielding boreholes.

Seismic: Due to cost, time and logistical implication this method is not widely used in the map area. In the Swartwater area the method was applied with limited success.

9.1.7 Subterranean water control areas

No subterranean water control area occurs within the area.

9.1.8 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 a local level, Catchment Managing Agencies (CMAs) and Water User Associations (WUAs) must be established that 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.

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. Mining of coal within the map sheet is increasingly occurring, often without the proper licences. Through the media these mines are brought into public awareness. One of the mines is near the Mapungubwe Conservation area. The balance between conservation and economic growth will always be an issue. An issue that should be debated with all these mines is that the short term economic gain will not become the pollution problem of future generations with an economic burden that is bigger than the current gain. The environmental and groundwater laws should be applied and managed very strictly to ensure this. This was one of the reasons for the Department of Water Affairs integrating with the

Department of Environmental Affairs to ensure a combined effort to close loopholes in inter-government legislation.

Part of water usage licence requirements can be that water users must monitor abstraction and quality at all levels from local authorities such as the Musina municipality, mines and 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 81). 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. The data is available on request from the Department's National Groundwater Archive (NGA) in Pretoria.

9.1.9 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,
    - any aquatic or non-aquatic organisms,
    - 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. 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 Venetia Diamond mine, mining along the Limpopo for alluvial diamonds, Tshikondeni coal mining, the new coal mines along the southern boundary of the Tshipise basin, and in the Tuli basin near Mapungubwe Conservation area are all potential sources of pollution if not properly managed.

9.1.10 Groundwater utilization

The Kruger National Park is situated in the eastern part of the map area, therefore groundwater use is restricted to game watering and domestic use for camps. The area directly west of the Park is the rural areas of Venda and northern Malemulele. Groundwater abstraction in these areas is for rural village supply, small scale irrigation and livestock watering. Groundwater data is well documented for these areas. Irrigation in the Tshipise area towards Nzhelele Dam is predominantly from surface water, although boreholes are also used. In the Waterpoort area towards Vivo excessive use is made from groundwater occurring in faults, minor alluvium, and deep boreholes utilizing water from the Letaba and Clarens formations. Along major rivers such as the Limpopo (Weipe area) and Sand River water is abstracted from alluvium. The Glen Alpine Dam in the Mogalakwena River supply water for irrigation. In the rest of the area irrigation is from strong groundwater sources and where there is no strong groundwater sources livestock or game farming is practiced. On the main map sheet major abstraction areas are indicated as solid red circles.

The harvest potential map (Figure 82) gives a quantitative depiction of sustainable volumes of groundwater potentially available for abstraction. The Malvernia Formation is indicated as a high potential area. The Formation has a limited thickness and there is not enough borehole data to confirm the potential. More investigations are recommended. A piezometric contour map compiled for the Kruger National Park revealed the Malvernia Formation as a groundwater recharge area (Du Toit, 1998).

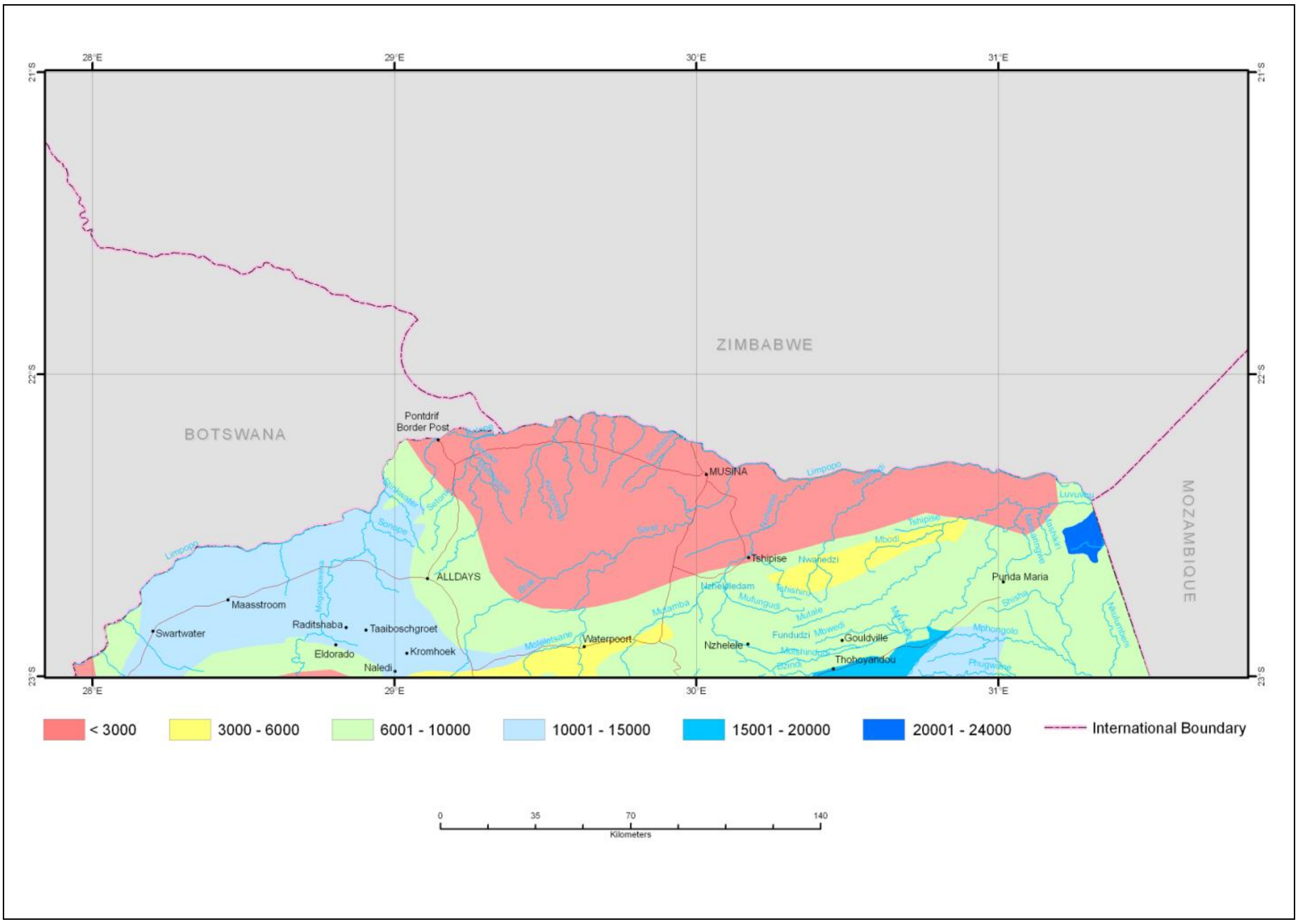

Figure 82: Harvest Potential (Seward, Baron & Seymour, 1996)

Table 13: Localities where large-scale groundwater abstraction (>400 000 M³/a) are taking place.

LOCALITY/AREA	APPROXIMATE ABSTRACTION (10^6 m³/a)	
	DOMESTIC	AGRICULTURAL/MINING
Alldays (Kromhoek aquifer)	1.0	
Musina	3.6	7.2
Regional supply scheme Taaibos Fault		
Small village supplies Vhembe district	8.0	
Venetia mine-sand points in Limpopo River, in dry periods limited during flow maximum		3.6
Tshikondeni		0.38
Weipe		> 55

9.1.11 Future groundwater exploration

Groundwater is and will in future still be used on a large scale for mining, scattered, semi urban and urban village and town supplies as well as a supplement for bulk surface regional water supply, irrigation, livestock watering and game farming. The mining environment is a potentially big polluter rather than a big user of groundwater. This will be one of the biggest challenges for groundwater in the Tuli and Tshipise basins. Within the map area particularly where game and livestock farming is practiced, National Parks and scattered rural settlements, the groundwater is not yet over exploited. The groundwater challenge at this stage is the protection against pollution such as the increasing nitrate concentrations in groundwater within or near villages as well as from pollution from irrigation practices and mining activities.

Future development of geophysical equipment combined with increasing knowledge of the hydrogeological characteristics of the map area will ensure the means to develop groundwater to its full potential. Regional surface supply projects will ensure bulk water to major users such as the Nondoni dam, (just south of the map area) that will supply parts of northern Malemulele and areas around Thohoyandou. Groundwater should be integrated in these bulk systems on the basis that only the high yielding boreholes be used to keep maintenance cost low. This will also ensure that well fields can be developed far from villages as most groundwater development projects concentrates in the immediate area in and around communities. The cost of regional pipelines makes groundwater as supply for small villages the most viable.

From a study on the Taaibos Fault (now also referred as Tshipise fault) the following recommendations were made ((IAEA study, 1999-2003):

- In view of the widespread occurrence of high nitrate concentrations in ground water in Limpopo Province, the investigation into their origins, and their mitigation, should continue to be an important component in this ongoing study.
- As there is now a unique body of hydrogeological and other data, the Tshipise fault area should continue to be the central focus of this study.
- As nitrogen isotopes constitute a potentially powerful tool in examining the nitrogen cycle in ground water they should form an integral part of this ongoing study.
- As indications are at present that the basalt and sandstone aquifers may at least in some areas be hydraulically connected, extreme caution is required in the exploitation of the latter in order to control possible contamination by drawing in water from the former.

The growing population and development in South Africa is 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 additional points should be addressed:

- Recharge from earth dams,

- Hydro census and updating of information in areas with poor coverage,

- The enforcement of the use of public money when municipalities develop groundwater sources to ensure the use of groundwater experts to ensure the updating of information on the National Archive. Currently there are major problems as holes are drilled in the vicinity of production holes or possible pollution sources,

- The enforcement of environmental and groundwater laws to minimize possible pollution from mines, sewerage works, landfill sites, burial sites, petrol stations and large scale farming,

- Prevention of high concentrations of nitrates in rural areas by using more environmental friendly sanitation,

- Geophysical exploration techniques to detect deep aquifers in hard rock formations,

- Application of remote sensing techniques (LANDSAT imagery, earth research satellite imagery such as Terra Aster, aerial photography, 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,

- Prevention of erosion, storm water control in rural villages, protection of water ways and riparian vegetation,

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