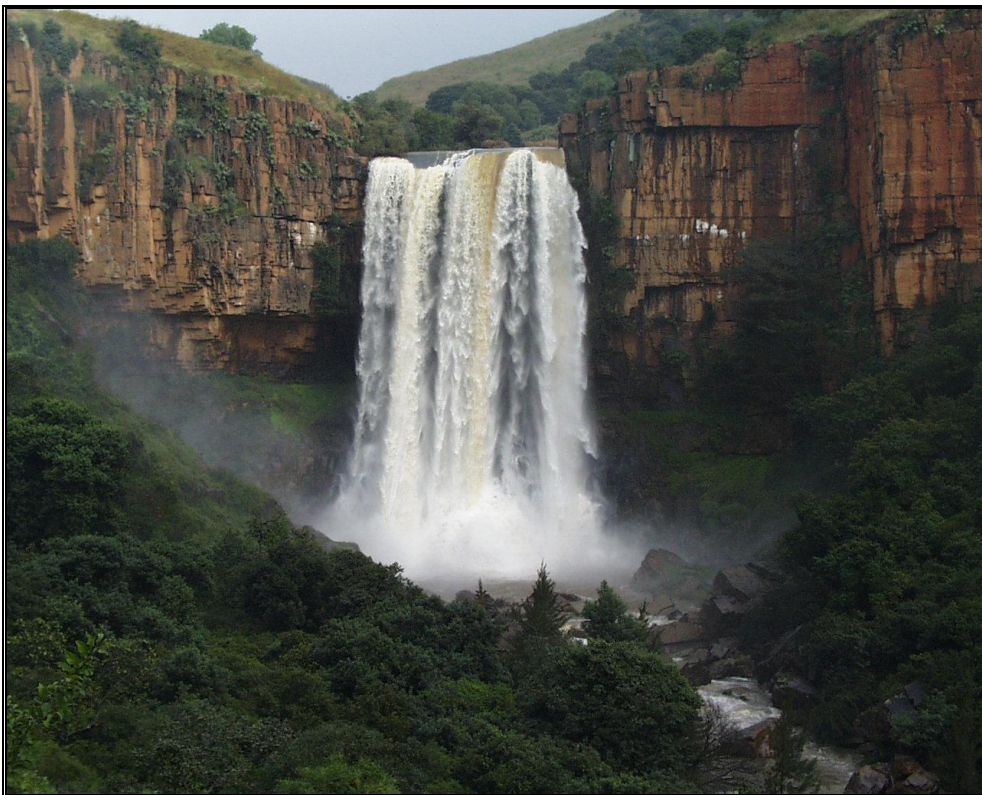


**AN EXPLANATION
OF THE 1: 500 000
GENERAL HYDROGEOLOGICAL MAP**

Nelspruit 2530



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Foreword

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

A major obstacle to the realisation of this prosperity is that insufficient information about groundwater is reaching the planners, decision makers, users and other affected parties. In an attempt to rectify this situation, groundwater information locked away in expert's minds and computer databases is being made available on maps. The first step in this program at the regional level is the preparation of the "General Hydrogeological Maps" at the scale of 1: 500 000.

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

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

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Preface

With the exception of air, water can, with little doubt, be defined as Man's most precious resource. It is said that to deny Man food, his body can sustain life for weeks, but refuse him water and death is likely to come within a few days. The availability of water to even the remotest area is thus vital to maintain this indispensable condition for human existence.

An estimated 3% of fresh water available on Earth occurs on the surface and 97% occurs underground (Johnson Division, 1975). Owing to the lack of perennial streams in the desert to semi-desert parts of South Africa, two-thirds of the 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 Nelspruit Hydrogeological Map and the accompanying explanatory brochure introduces the reader to the current state of groundwater knowledge and basic hydrogeological characteristics of the map area. It needs to be explained that within the map's confines, dissimilar and divergent conditions occur, which, to various degrees, may impact on groundwater. Under these circumstances, groundwater occurrence can vary. Groundwater occurrence is thus referred to in this brochure.

The primary aim of the General Hydrogeological Map is to produce a synoptic overview of the hydrogeological 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 positioning (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 with the ongoing development of groundwater sources and it can play a constructive role in general groundwater education and groundwater awareness building.

In the South African context groundwater has always been an important source of water supply. There is an ever increasing pressure on all natural resources and groundwater will not escape the effects thereof. Groundwater in the area can be regarded as a renewable resource provided it is managed and protected against pollution and over exploitation. In the map area the quality is more under threat than the quantity due to mining, farming and various other industries. It is hoped that this map and brochure will contribute to groundwater awareness and knowledge as it is an important resource.

Photo 1: Cover photo: Spectacular 90m Elands River Waterfall (in flood) just outside Waterval Boven. The waterfall results from the Elands River plunging over an almost horizontal, resistant ledge of the Daspoort Formation quartzite of the Pretoria Group (Photo W.H. Du Toit, 2006).

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DATA AND REPORTS

DWA (Pretoria)	National groundwater and water quality databases
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DWA (Limpopo)	Limpopo GRIP Data
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Municipalities within the map area	

TABLE OF CONTENTS

1. INTRODUCTION.....	12
1.1 Aims and Objectives	12
1.2 Aquifer legend.....	12
1.3 Mapping Methodology	15
1.3.1 Data sources, quality and quantity:	15
1.3.2 Main map:.....	15
1.3.3 Inset maps:.....	16
1.3.4 Brochure:	16
2. PHYSICAL ENVIRONMENT.....	16
2.1 Climate	16
2.2 Topography.....	17
2.3 Surface Water.....	20
2.4 Geology.....	24
2.4.1 Regional geology.....	24
2.4.1.1 The Barberton Mountain Land	24
2.4.1.2 Gneisses, migmatites and granitoid rocks of the Swazian Basement.....	24
2.4.1.3 Diapiric domes and plutons of Swazian and Radian age	25
2.4.1.4 Pongola Sequence and the associated Usushwana Complex	25
2.4.1.5 Transvaal Super Group	25
2.4.1.6 Diabase dykes and sills.....	25
2.4.1.7 Bushveld Complex	26
2.4.1.8 Timbavati Gabbro.....	26
2.4.1.9 Karoo Super Group.....	26
2.4.1.10 Dolerite dykes and sills.....	27
2.4.1.11 Cretaceous to Quaternary.....	27
2.4.2 Structural geology	29
2.4.2.1 Dykes and sills.....	29
2.4.2.2 Faults and shear zones	29
2.5 General Hydrochemistry	30
2.6 Aquifer Hydrochemistry	32
3. HYDROGEOLOGY OF THE DIFFERENT GEOLOGICAL UNITS	42
3.1 Characteristics and description of the hydrogeological units	42
3.2 Aquifers	42
3.3 Aquifer classes and Yields	42
3.3.1 Intergranular Aquifers	44
3.3.1.1 Alluvial deposits (Q).....	44
3.3.1.2 Maputaland Group (T-Qm).....	47
3.3.2 Fractured Aquifers.....	50
3.3.2.1 Black Reef Formation (Vbl).....	51
3.3.2.2 Pretoria Group (Vp), fractured aquifers	51

3.3.2.3	Dwyka Group (C-Pd).....	53
3.3.2.4	Ecca Group (Pe), fractured aquifers	55
3.3.2.5	Lebombo Group (Jl) (Rhyolite).....	57
3.3.2.6	Tshokwane Granophyre (Jts).....	60
3.3.3	Karst Aquifers.....	61
3.3.3.1	Undifferentiated Black Reef Formation and Chuniespoort Group (Vh-Vbl).....	62
3.3.4	Intergranular and fractured aquifers.....	65
3.3.4.1	Undifferentiated Barberton Super Group (Zr).....	67
3.3.4.2	Undifferentiated Tjakastad Subgroup (Zot-Zoo).....	68
3.3.4.3	Undifferentiated Onverwacht Group, Fig Tree Group, Moodies Group (Zo-Zd).....	71
3.3.4.4	Unnamed Swazian Rocks (Zz).....	73
3.3.4.5	Nelspruit Suite (Ze).....	75
3.3.4.6	Nsuze Group (Zn).....	78
3.3.4.7	Kaap Valley Granite (Zka).....	80
3.3.4.8	Various intrusive rocks of the Mozaan Group and Nsuze Group (Z-Rg).....	83
3.3.4.9	Dalmein Granite (Zda).....	85
3.3.4.10	Hebron Granodiorite (Zhe).....	87
3.3.4.11	Undifferentiated rocks of the Thole and Piet Retief Suite (Rth-Rup).....	87
3.3.4.12	Undifferentiated rocks of the Mozaan Group, Amsterdam Formation, and Usushwana Complex (Rm-Ru).....	88
3.3.4.13	Unnamed Randian Rocks (Rz).....	90
3.3.4.14	Boesmanskop Syenite (Rbs).....	92
3.3.4.15	Salisbury Kop Granodiorite (Rsk).....	94
3.3.4.16	Mpangeni Granite (Rmp).....	95
3.3.4.17	Mozaan Group (Rm).....	97
3.3.4.18	Wolkberg Group (Vw).....	98
3.3.4.19	Pretoria Group (Vp), intergranular and fractured	100
3.3.4.20	Diabase Intrusions (N-Zd).....	102
3.3.4.21	Rustenburg Suite (Vr).....	104
3.3.4.22	Lebowa Suite (Mle).....	106
3.3.4.23	Timbavati Gabbro (Nti).....	106
3.3.4.24	Ecca Group (Pe), intergranular and fractured	109
3.3.4.25	Clarence Formation (Trc).....	111
3.3.4.26	Lebombo Group (Jl), intergranular and fractured.....	113
3.3.4.27	Dolerite (Jd).....	115
3.3.4.28	Zululand Group (K-Tu).....	117
4.	SPRINGS.....	120
4.1	Non-thermal Springs.....	120
4.2	Thermal Springs.....	121
5.	GROUNDWATER RELATED MATTERS.....	122
5.1	The National Water Act (Act 108 1998).....	122
5.1.1	Water user registration and licences.....	122
5.1.2	The Reserve.....	123
5.1.3	Resource Directed Measures.....	124
5.1.4	Monitoring.....	124
5.1.5	Groundwater storage.....	124
5.1.6	Borehole positioning.....	125

5.1.6.1	Additional information on the use of geophysical methods as obtained from existing reports:	128
5.1.7	Subterranean water control areas	129
5.1.8	Groundwater management	129
5.1.9	Groundwater contamination and pollution.....	130
5.1.10	Groundwater utilization.....	130
5.2	Groundwater Availability - Harvest Potential	131
5.2.1	Future groundwater exploration	132
6.	REFERENCES.....	133

LIST OF FIGURES

Figure 1:	Mean annual precipitation (MAP).....	17
Figure 2:	Elevation above sea level.	18
Figure 3:	Terrain Morphology (Kruger, 1983).....	19
Figure 4:	Primary Catchments, rivers and major dams.....	22
Figure 5:	Simplified regional geology of the map area (after DWA, 2011).	28
Figure 6:	Faults inferred and observed (after DWA, 2012).	30
Figure 7:	Electrical conductivity, (EC) with points representing boreholes with nitrate and fluoride values exceeding the acceptable levels for human consumption (DWA, 1996).	41
Figure 8:	Geographical distribution of the Intergranular aquifers.	44
Figure 9:	Geographical distribution of the Alluvium deposits (Q) and associated sampling points.	45
Figure 10:	Yield frequency of boreholes in the alluvium deposits (Q).	46
Figure 11:	Stiff diagram representing chemistry for aquifers of the alluvium deposits (Q).....	46
Figure 12:	Geographical distribution of the Maputaland Group (T-Qm) and associated sampling points.....	48
Figure 13:	Yield frequency of boreholes in the Maputaland Group (T-Qm) after King, 2003.	48
Figure 14:	Stiff diagram representing chemistry for aquifers of the Maputaland Group (T-Qm).	49
Figure 15:	Geographical distribution of the fractured aquifers.	50
Figure 16:	Geographical distribution of the fractured aquifers of the Black Reef Formation (Vbl). ..	51
Figure 17:	Geographical distribution of the fractured aquifers of the Pretoria Group (Vp) and associated sampling points.	52
Figure 18:	Yield frequency of boreholes in the fractured aquifers of the Pretoria Group (Vp).	52
Figure 19:	Geographical distribution of the Dwyka Group (C-Pd) and associated sampling points.	53
Figure 20:	Yield frequency of boreholes in the Dwyka Group (C-Pd).....	54
Figure 21:	Stiff diagram representing chemistry for aquifers of the Dwyka Group (C-Pd).	54
Figure 22:	Geographical distribution of the fractured aquifers of the Eccca Group (Pe) and associated groundwater sampling points.	55
Figure 23:	Yield frequency of boreholes in the fractured aquifers of the Eccca Group (Pe).	56
Figure 24:	Stiff diagram representing chemistry for the fractured aquifers of the Eccca Group (Pe).	56
Figure 25:	Geographical distribution of the fractured aquifers of the Lebombo Group (Jl) and associated groundwater sampling points.	58
Figure 26:	Yield frequency of boreholes in the fractured aquifers of the Lebombo Group (Jl).	59
Figure 27:	Stiff diagram representing chemistry for the fractured aquifers of the Lebombo Group (Jl).	59
Figure 28:	Geographical distribution of the Tshokwane Granophyre (Jts) and associated groundwater sampling points.	60
Figure 29:	Yield frequency of boreholes in the Tshokwane Granophyre (Jts).	61
Figure 30:	Geographical distribution of the undifferentiated Black Reef Formation and Chuniespoort Group (Vh-Vbl) and associated groundwater sampling points.	62

Figure 31: Yield frequency of boreholes in the undifferentiated Black Reef Formation and Chuniespoort Group (Vh-Vbl).....	63
Figure 32: Stiff diagram representing chemistry for the undifferentiated Black Reef Formation and Chuniespoort Group (Vh-Vbl).....	63
Figure 33: Geographical distribution of the intergranular and fractured aquifers.....	66
Figure 34: Geographical distribution of the undifferentiated Barberton Super Group (Zr) and associated groundwater sampling points.	67
Figure 35: Yield frequency of boreholes in the undifferentiated Barberton Super Group (Zr).....	68
Figure 36: Geographical distribution of the undifferentiated Tjakastad Subgroup (Zot Zoo) and associated groundwater sampling points.	69
Figure 37: Yield frequency of boreholes in the undifferentiated Tjakastad Subgroup (Zot-Zoo).....	70
Figure 38: Stiff diagram representing chemistry for the undifferentiated Tjakastad Subgroup (Zot-Zoo).....	70
Figure 39: Geographical distribution of the undifferentiated Onverwacht, Fig Tree and Moodies Groups (Zo Zd) and associated groundwater sampling points.	71
Figure 40: Yield frequency of boreholes in the undifferentiated Onverwacht, Fig Tree and Moodies Groups (Zo Zd).	72
Figure 41: Stiff diagram representing chemistry for the undifferentiated Onverwacht, Fig Tree and Moodies Groups (Zo-Zd).....	73
Figure 42: Geographical distribution of the unnamed Swazian rocks (Zz) and associated groundwater sampling points.	74
Figure 43: Yield frequency of boreholes in the unnamed Swazian rocks (Zz).....	74
Figure 44: Stiff diagram representing chemistry for the unnamed Swazian rocks (Zz).	75
Figure 45: Geographical distribution of the Nelspruit Suite (Ze) and associated groundwater sampling points.....	76
Figure 46: Yield frequency of boreholes in the Nelspruit Suite (Ze).....	76
Figure 47: Stiff diagram representing chemistry for the Nelspruit Suite (Ze).....	78
Figure 48: Geographical distribution of the Nsuze Group (Zn) and associated groundwater sampling points.....	79
Figure 49: Yield frequency of boreholes in the Nsuze Group (Zn).	79
Figure 50: Stiff diagram representing chemistry for the Nsuze Group (Zn).....	80
Figure 51: Geographical distribution of the Kaap Valley Granite (Zka) and associated groundwater sampling points.....	81
Figure 52: Yield frequency of boreholes in the Kaap Valley Granite (Zka).....	81
Figure 53: Stiff diagram representing chemistry for the Kaap Valley Granite (Zka).....	82
Figure 54: Geographical distribution of the various intrusive rocks of the Mozaan and Nsuze Groups (Z-Rg) and associated groundwater sampling points.	83
Figure 55: Yield frequency of boreholes in the various intrusive rocks of the Mozaan and Nsuze Groups (Z-Rg).....	84
Figure 56: Stiff diagram representing chemistry for the various intrusive rocks of the Mozaan and Nsuze Groups (Z-Rg).....	84
Figure 57: Geographical distribution of the Dalmein Granite (Zda) and associated groundwater sampling points.....	85
Figure 58: Yield frequency of boreholes in the Dalmein Granite (Zda).	86
Figure 59: Stiff diagram representing chemistry for the Dalmein Granite (Zda).	86
Figure 60: Geographical distribution of the Hebron Granodiorite (Zhe) and associated groundwater sampling points.	87
Figure 61: Geographical distribution of the undifferentiated rocks of the Thole and Piet Retief Suite (Rth-Rup) and associated groundwater sampling points.	88
Figure 62: Geographical distribution of the undifferentiated rocks of the Mozaan Group, Amsterdam Formation and Usushwana Complex (Rm-Ru) and associated groundwater sampling points.	89
Figure 63: Yield frequency of boreholes in the Undifferentiated Mozaan Group, Amsterdam Formation and Usushwana Complex (Rm-Ru).....	89

Figure 64: Stiff diagram representing chemistry for the Undifferentiated Mozaan Group, Amsterdam Formation and Usushwana Complex (Rm-Ru).....	90
Figure 65: Geographical distribution of the Unnamed Radian rocks (Rz) and associated groundwater sampling points.	91
Figure 66: Yield frequency of boreholes in the Unnamed Radian rocks (Rz).....	91
Figure 67: Stiff diagram representing chemistry for the Unnamed Radian rocks (Rz).....	92
Figure 68: Geographical distribution of the Boesmanskop Syenite (Rbs) and associated groundwater sampling points.	93
Figure 69: Yield frequency of boreholes in the Boesmanskop Syenite (Rbs).....	93
Figure 70: Geographical distribution of the Salisbury Kop Granodiorite (Rsk) and associated groundwater sampling points.	94
Figure 71: Yield frequency of boreholes in the Salisbury Kop Granodiorite (Rsk).....	95
Figure 72: Geographical distribution of the Mpangeni Granite (Rmp) and associated groundwater sampling points.	96
Figure 73: Yield frequency of boreholes in the Mpangeni Granite (Rmp).	96
Figure 74: Geographical distribution of the Mozaan Group (Rm) and associated groundwater sampling points.	97
Figure 75: Yield frequency of boreholes in the Mozaan Group (Rm).	98
Figure 76: Geographical distribution of the Wolkberg Group (Vw) and associated groundwater sampling points.	99
Figure 77: Yield frequency of boreholes in the Wolkberg Group (Vw).	99
Figure 78: Geographical distribution of the fractured and intergranular aquifers of the Pretoria Group (Vp) and associated groundwater sampling points.	100
Figure 79: Yield frequency of boreholes in the fractured and intergranular aquifers of the Pretoria Group (Vp).....	101
Figure 80: Stiff diagram representing chemistry for the fractured and intergranular aquifers of the Pretoria Group (Vp).....	102
Figure 81: Geographical distribution of the Diabase intrusions (N-Zd) and associated groundwater sampling points.	103
Figure 82: Yield frequency of boreholes in the Diabase intrusions (N-Zd).	103
Figure 83: Geographical distribution of the Rustenburg Suite (Vr) and associated groundwater sampling points.	104
Figure 84: Yield frequency of boreholes in the Rustenburg Suite (Vr).	105
Figure 85: Stiff diagram representing chemistry for the Rustenburg Suite (Vr).	105
Figure 86: Geographical distribution of the Lebowa Suite (Mle) and associated groundwater sampling points.	106
Figure 87: Geographical distribution of the Timbavati Gabbro (Nti) and associated groundwater sampling points.	107
Figure 88: Yield frequency of boreholes in the Timbavati Gabbro (Nti).....	108
Figure 89: Stiff diagram representing chemistry for the Timbavati Gabbro (Nti).	108
Figure 90: Geographical distribution of the intergranular and fractured aquifers of the Eccca Group (Pe) and associated groundwater sampling points.	109
Figure 91: Yield frequency of boreholes in the intergranular and fractured aquifers of the Eccca Group (Pe).....	110
Figure 92: Stiff diagram representing chemistry for the intergranular and fractured aquifers of the Eccca Group (Pe).	110
Figure 93: Geographical distribution of the Clarence Formation (Trc) and associated groundwater sampling points.	111
Figure 94: Yield frequency of boreholes in the Clarence Formation (Trc).....	112
Figure 95: Stiff diagram representing chemistry for the Clarence Formation (Trc).....	112
Figure 96: Geographical distribution of the intergranular and fractured aquifers of the Lebombo Group (Jl) and associated groundwater sampling points.	113
Figure 97: Yield frequency of boreholes in the intergranular and fractured aquifers of the Lebombo Group (Jl).....	114

Figure 98: Stiff diagram representing chemistry for the intergranular and fractured aquifers of the Lebombo Group (Jl).....	114
Figure 99: Geographical distribution of the Karoo Dolerite (Jd) and associated groundwater sampling points.....	115
Figure 100: Yield frequency of boreholes in the Karoo Dolerite (Jd).....	116
Figure 101: Stiff diagram representing chemistry for the Karoo Dolerite (Jd).....	117
Figure 102: Geographical distribution of the Zululand Group (K-Tu) and associated groundwater sampling points.....	118
Figure 103: Yield frequency of boreholes in the Zululand Group (K-Tu), after King 2003.....	118
Figure 104: Stiff diagram representing chemistry for the Zululand Group (K-Tu).....	119
Figure 105: Non-thermal and thermal springs as well as listed springs without any data.....	120
Figure 106: Harvest Potential (after Seward, Baron & Seymour, 1996).....	131

LIST OF TABLES

Table 1: Adapted hydrogeological classification of the principle occurrences of groundwater within the boundaries of the Nelspruit Hydrogeological map sheet, according to origin and nature of the saturated interstices with subdivisions based on borehole yields (After Orpen, 1994).	14
Table 2: Number of borehole records extracted and evaluated for the brochure from the NGDB, NGA, WMS and other sources.....	15
Table 3: Explanation for Figure 3, Terrain Morphology.....	20
Table 4: Drainage and dams.....	23
Table 5: Guideline sheet using electrical conductivity as indicator for the suitability of groundwater for domestic, livestock and irrigation usage (DWA 1996).	32
Table 6: Summary table, calculated harmonic mean values for various chemical parameters for each unit.....	34
Table 7: Percentage samples in each unit, classed for domestic use for chloride, nitrate and sulphate concentrations.....	35
Table 8: Percentage samples in each unit, classed for domestic use for calcium, potassium, magnesium and sodium concentrations.....	37
Table 9: Percentage samples in each unit, classed for domestic use for Electrical Conductivity (EC), pH and fluoride concentration.....	39
Table 10: Summary yield frequency analysis for each unit.....	43
Table 11: Usefulness of near surface geophysical methods after Geomatrix Earth Science LTD.....	126
Table 12: Recommended geophysical survey techniques to use in the search for groundwater for each hydrogeological unit.....	127
Table 13: Localities where large-scale groundwater abstraction (2-5 m ³ /a) is taking place.....	131

LIST OF PHOTOS

Photo 1: Cover photo: Spectacular 90m Elands River Waterfall (in flood) just outside Waterval Boven. The waterfall results from the Elands River plunging over an almost horizontal, resistant ledge of the Daspoort Formation quartzite of the Pretoria Group (Photo W.H. Du Toit, 2006).	2
Photo 2: The eastern escarpment is characterised by numerous waterfalls. The most spectacular one is the Mac-Mac Falls in the Mac-Mac River where resistant Black Reef Quartzite forms a thick ledge over which this 65m-high waterfall tumbles, cutting back a deep gorge into the escarpment (photo W.H. Du Toit, 2006).....	17
Photo 3: The area around Chrissiesmeer and Lothair, which is underlain by sediments of the Vryheid Formation, are characterized by the occurrence of numerous fresh water lakes where the interaction between surface and groundwater is an important parameter in the existence of	

these lakes. Chrissiesmeer is one of the biggest fresh water lakes in the country (photo W. H. Du Toit, 2006).....	21
Photo 4: Dykes of various compositions and orientations are a common occurrence within the basement rocks of the area. North-east appears to be the more dominant orientation. This dolerite dyke occurs in a road cutting in the Kruger National Park on the northern bank of the Sabie River. Fractured dolerite and/or its contact with the host rock are important targets for successful groundwater supplies (photo W.H. Du Toit, 2006).	27
Photo 5: The entrance to the Sudwala Caves located about 30km west of Nelspruit. The caves, which extend for several kilometres into the mountain, are located high up on the slopes of a mountain consisting of dolomite of the Malmani Subgroup. It is not far below the contact with the overlying shales and quartzites of the Pretoria Group. The caves developed as the result of the dissolution of the dolomite ($MgCO_3$) by a weak carbonic acid derived from carbon dioxide (CO_2), (photo W.H. Du Toit, 2006)	62
Photo 6: Stromatolites in the dolomites of the Malmani Subgroup at the Sudwala Caves. Stromatolites are finely layered, concentric, mound-like structures found in dolomite and formed by microscopic algal organisms (W.H. du Toit, 2006).....	64
Photo 7: The Consort Gold mine northeast of Barberton. Mineralization occurred along the folded and silica-rich contact between amphibole schist and interlayered leptite of the Onverwacht Group and hornfels and trachyte of the Fig Tree Group (photo W.H. Du Toit, 2006).	68
Photo 8: Contact between biotite-trondhjemite gneiss of the Stenton Pluton and green stones (mafic and ultramafic schist) of the Onverwacht Group (photo W.H. Du Toit, 2006).	68
Photo 9: Fractured schist of the Theespruit Formation in a road cutting between Kaapmuiden and Barberton (photo W.H. Du Toit, 2006).	69
Photo 10: In the Kruger National Park, granite-gneiss of the Nelspruit Suite is well exposed in numerous bare exfoliation domes, formed by the splitting-off of rock slabs by a process of mechanical weathering. This often results in spectacular patterns of stacked boulders appearing almost as if there was human interference (photo W.H. Du Toit, 2006).	77
Photo 11: Fractures in the gneiss of the Nelspruit Suite was initially formed by a process of mechanical weathering. Over an extended period of time chemical weathering caused by penetrating rainwater enlarged the fractures (photo W.H. Du Toit, 2006).	77
Photo 12: Proterozoic dyke in the Kaap Valley Granite between Badplaas and Barberton. Dykes are important targets for successful groundwater development in the map area (photo W.H. Du Toit, 2006).	80
Photo 13: Fractured Kaap Valley granite in a road cutting between Badplaas and Barberton (photo W.H. Du Toit, 2006).	82
Photo 14: The remains of a volcanic breccia pipe just west of Lydenburg. The pipe, which is about 30m in diameter, is known as the Motlolo Volcano and occurs in shale of the Silverton Formation. The breccia includes fragments of rocks from many of the formations in the lower part of the Pretoria Group (photo W.H. Du Toit, 2006).	101
Photo 15: The presence of groundwater and subsequent subsidence in the Malmani dolomites seriously hampered mining activities in Glynn's Lydenburg Gold Mine just outside of Sabie. To continue mining, the mine had to pump water from the waterlogged South Shaft area at a rate of 82 000m ³ per day. To solve the problem a drainage tunnel 5 kilometres long was driven underneath the mine. Springs in the mining area stopped flowing almost overnight after the tunnel was connected with the South Shaft area in 1940. Flow was measured at a rate of 477l/s. As a result of this tunnel, the flooded workings dried sufficiently to make renewed mining possible. Although mining stopped a long time ago groundwater is still flowing from the tunnel at an estimated rate of 500 l/s. The Sabie municipality obtains water from this source (photo and explanation W. H. Du Toit, 2006).	120

ABBREVIATIONS

DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EC	Electrical conductivity
HARMEAN	Harmonic mean
GRIP	Groundwater Resource Implementation Programme
KNP	Kruger National Park
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
WMS	Water Management System
WRPS	Water Resource Planning Systems

SYMBOLS AND UNITS

km ²	square kilometre
ℓ/s	litres per second
m	Metre
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
SA m ³ /km ²	Save abstraction cubic metre per square kilometre
%	Percentage

CHEMICAL SYMBOLS

Al	Aluminium	Mn	Manganese
As	Arsenic	NO ₃	Nitrate
Cd	Cadmium	NO ₂	Nitrite
Ca	Calcium	N	Nitrate (NO ₃) + Nitrite (NO ₂)
Cl	Chloride	K	Potassium
Cu	Copper	Na	Sodium
F	Fluoride	SO ₄	Sulphate
Fe	Iron	Si	Silica
TH	Total hardness	Zn	Zinc
Mg	Magnesium		

1. INTRODUCTION

The Nelspruit 2530 Hydrogeological Map at a scale of 1:500 000 forms part of the General Hydrogeological Map Series of South Africa, which comprises of 23 map sheets. The Nelspruit map sheet represents the first general synthesis of the groundwater resources of the area bordered by latitudes 25° and 27° south and longitudes 30° and 34° east. It falls mainly in the Mapumalanga Province (94.5%) followed by KwaZulu-Natal (5.2%) and with a small part within the Limpopo Province (0.2%). The map sheet covers a land surface area of 3 282 361ha or 32823.611km² excluding areas outside the border of South Africa. Two international borders frame the area, Swaziland along the south-eastern border and Mozambique along the north-eastern border.

1.1 Aims and Objectives

The main aim of this map and accompanying explanation brochure is to serve as a general reference for the planning, development, and management of groundwater resources as well as for educational purposes.

This map illustrates general hydrogeological conditions on a relatively large scale and specific local conditions can differ from the regional trend. Site-specific detailed investigations will still be required to determine local hydrogeological conditions such as when developing a new groundwater source. The map and accompanying explanation brochure will, however, provide general guidelines as to which detailed investigations are required and what expected hydrogeological conditions are likely to occur.

The main features shown on the map are borehole yield, aquifer type, groundwater quality, groundwater use, and lithology. This brochure provides supplementary information on these topics and also discusses topics such as source development, the management of groundwater, the water law and the protection of groundwater from over-abstraction and contamination. The map sheet was compiled in 1995 and the brochure in 2012 using the latest available data.

1.2 Aquifer legend

The international UNESCO classification for hydrogeological maps (UNESCO 1983) was adapted to suit South African hydrogeological conditions and groundwater occurrences. **Table 1**, (p14) depicts the adapted hydrogeological classification used for the Nelspruit map sheet according to the origin and nature of the saturated interstices combined with subdivisions based on existing known blow yields (after Orpen, 1994).

The main aquifer legend changes were:

- The removal of the division between local/discontinuous aquifers and extensive aquifers. (This division is superfluous because the majority of South African aquifers fall into the local/discontinuous category.)
- The addition of a “fractured and intergranular” mode of occurrence because of its prevalence.
- The differentiation of low yielding aquifers into an appropriate mode of occurrence. The UNESCO legend does not differentiate between fractured or intergranular when yields are very low, and places everything together as “low-yielding” or “poor” aquifer. Since so many of the South African aquifers are low yielding it was considered important to specify what type of aquifer it was.
- Specifying numerically what is meant by “low yield,” “moderate yield,” etc.

Four classes of groundwater occurrence were used:

Class A = Intergranular

Class B = Fractured

Class C = Karst

Class D = Intergranular and Fractured

On the main map the principal regional aquifers are depicted, disregarding small individual occurrences or combinations thereof. The principal aquifer is regarded as the aquifer with the highest yields and best quality water. If for example the top most aquifer is a saturated silt layer with low yields or irrelevant in recharging the underlying aquifer it would be ignored if the underlying bedrock provided higher borehole yields. In cases such as these, the aquifer is fractured.

In some cases large quantities of water are often stored in the weathered layer, but the transmissivity of this layer is often too low to allow water to be abstracted economically from it. If this top layer significantly contributes to the underlying fracture system, thus ensuring that water from the lower aquifer can be economically abstracted, the unit is intergranular and fractured.

In areas where the upper weathered layer and underlying fracture system contains economically usable water the aquifer is intergranular and fractured.

The definition of the productive yield ranges indicated on the main map is the same for all the maps in the hydrogeological map series. On the main map the four-aquifer classes are represented by colours and the five yield subdivisions by the tone of the respective colour. Subsurface lithology is presented by lithologic ornaments and the chronostratigraphy by alphabetical symbols. The productive yield ranges and possible uses 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 to 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 to 2ℓ/s; can be used for domestic and livestock watering supply to rural settlements, hospitals and health centres or small-scale irrigation at community vegetable gardens.
- Very low borehole yields; generally 0.1 to 0.5ℓ/s; can be used for domestic supply to single homesteads, schools, police stations, clinics, small rural villages (250 persons) or livestock watering. Boreholes in this group are mostly equipped with hand, submersible or wind pumps.
- Un-economical borehole yields; generally 0.0 to 0.1ℓ/s; can be used for non-reticulated water supply for isolated households or for monitoring in certain cases. Suitability depends on factors such as construction, objective of monitoring, location and geological setting.

Table 1: Adapted hydrogeological classification of the principle occurrences of groundwater within the boundaries of the Nelspruit Hydrogeological map sheet, according to origin and nature of the saturated interstices with subdivisions based on borehole yields (After Orpen, 1994).

CLASS A				CLASS B			CLASS C			CLASS D					
INTERGRANULAR				HARD, CONSOLIDATED ROCK MATERIAL											
A water saturated zone, generally unconsolidated but occasionally semi-consolidated. Groundwater storage and flow through intergranular interstices in porous and permeable medium.				Fissured and fractured bedrock resulting from decompression and/or tectonic forces. Groundwater flow predominantly through fractures, faults, joints and fissures (acting as conduits), and micro-fissures in the bedrock, Rock matrix provides storage.											
				Where the principal water strike is in a fracture or in the contact between two different rock types, interporosity groundwater flow can occur within the rock matrix (double-porosity matrix).			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.			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.					
Group	Typical borehole yield		Colour code	Group	Typical borehole yield		Colour code	Group	Typical borehole yield		Colour code	Group	Typical borehole yield		Colour code
	Range	ℓ/s			Range	ℓ/s			Range	ℓ/s			Range	ℓ/s	
a1	Un-economical	0.0-0.1		b1	Un-economical	0.0-0.1		c1	Un-economical	0.0-0.1		d1	Un-economical	0.0-0.1	
a2	Very low	0.1-0.5		b2	Very low	0.1-0.5		c2	Very low	0.1-0.5		d2	Very low	0.1-0.5	
a3	Low	0.5-2		b3	Low	0.5-2		c3	Low	0.5-2		d3	Low	0.5-2	
a4	Moderate	2-5		b4	Moderate	2-5		c4	Moderate	2-5		d4	Moderate	2-5	
a5	High	>5		b5	High	>5		c5	High	>5		d5	High	>5	
Alluvial deposits of limited extent along river terraces such as sand and gravel. Weathered crystalline rock with the principle water strike in the weathered intergranular zone Examples: Deposits along most of the rivers although too insignificant to indicate on the map. Three areas near Lydenburg are shown on the map as well as Tertiary to Quaternary dune and marine sediments.				Sedimentary rocks of arenaceous origin. Acid volcanic rocks and other igneous rocks with very limited overlying residual weathered products. Examples: Black Reef Formation, Pretoria Group (quartzite), Dwyka Group, Eccca Group, Lebombo Group, Tshokwane Granophyre			Carbonate rocks including dolomite, limestone of marine origin Examples: Undifferentiated Black Reef Formation and Chuniespoort Group			Sedimentary. Igneous and metamorphic rocks with significant thicknesses of overlying saturated residual weathering. Examples: Undifferentiated Barberton Super G, Undifferentiated Tjakastad Sub G, Undifferentiated Onverwacht G, Fig Tree G, Moodies G, Basement gneissic and granitoid rocks, Diapiric domes and plutons, Various intrusive rocks of the Mozaan G and Nsuze G, Undifferentiated rocks of the Mozaan G, Amsterdam F and Usushwana Complex, Rocks of the Bushveld C, Diabase and Dolerite, Timbavati Gabbro, Zululand G.					
INTERGRANULAR				FRACTURED			KARST			INTERGRANULAR AND FRACTURED					

1.3 Mapping Methodology

1.3.1 Data sources, quality and quantity:

Data used in the compilation of the map sheet (1996) was predominantly obtained from the National Groundwater Data Base (NGDB) and Water Management System (WMS). For the brochure (2013) the same data (pre-1996) was used as well as data up to November 2012. New data were obtained from the National Groundwater Archive (NGA), WMS, and Groundwater Resource Information Programme (GRIP) and from consultants such as In Situ Groundwater Consulting.

Table 2: Number of borehole records extracted and evaluated for the brochure from the NGDB, NGA, WMS and other sources.

BOREHOLE RECORDS EXTRACTED AND EVALUATED					
Data up to November 2012		WMS			
Total number of borehole records	Total number of borehole yields used	Total number of EC values	Total number of nitrate values	Total number of fluoride values	Number of chemical analyses used for stiff diagrams
18711	2632	2316	1940	2255	1242

The total number of borehole records reflects all available data joined together into a single file that was obtained from various sources. It is estimated that 30-50% of the data is duplications. The reasons for the duplications are mainly that the bulk of the data is GRIP data files. The GRIP files originated from a desk study project where all information available at the time (2010) was captured on the Mpumalanga GRIP website. Up to date no follow up project was launched to verify the GRIP information and to confirm the data in the field. The result is duplications of NGDB data and other data that was already captured in data systems before the addition of the GRIP data. Yield data of approximately 1500 data points were checked with original hard copy files before it was used for the yield frequency diagrams. Before using the chemical data, duplications was eliminated, the harmonic mean of time series data at various monitoring points was calculated to use it as a single analysis and the data was evaluated by doing various quality checks. For instance 22.8% of the data in the original chemical data file have ionic balances greater than $\pm 10\%$ and 59.5% less than $\pm 5\%$.

1.3.2 Main map:

The lithostratigraphy of the area, obtained from the 1: 250 000 published Geological Map Series i.e. 2530 Barberton, 2630 Mbabane and 2632 Kosibaai, was regrouped and, where necessary, simplified to lithological types to form the base of the main map. It is displayed as grey ornaments on the map. The geological units are provided with black codes, which, for reasons of countrywide uniformity, do not always coincide with the codes on the said published geological maps, but are internal Departmental adaptations. The geological units and codes are listed on the map sheet as a chronostratigraphic column.

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 (refer Table 1, p14 and the legend shown on the main map), over the lithological base map and determining the median yield of the different lithology. 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 hydrogeological reports as well as the geology and related structures. Where supported by sufficient evidence and reason

based on experience, the aquifer characteristics of hydrogeologically well-defined areas were extrapolated into areas of data scarcity.

1.3.3 Inset maps:

The following inset maps have been included on the 1:500 000 Nelspruit Hydrological map sheet 2530:

Two hydrogeological cross-sections, based on limited geological information and the author's own interpretation of the available information. The cross-sections display the third dimension and regional hydrogeological relationships discussed on the map as points 1-9. The static water level (red line) is included to show its relationship with surface topography.

Distribution of borehole data: scale 1:2 000 000, representative of the available groundwater source information distribution at the time of map compilation (1996). The yellow represents no data points, light pink represents one data point, light blue 2-10 data points, violet 11-20 data points and purple represents more than 20 data points.

Elevation above sea level: scale 1:2 000 000, at varying contour intervals of 200, 400 and 500m. The elevation in the map area varies from sea level to 2500mamsl.

Mean annual precipitation: scale 1:2 000 000, contour intervals at 100 to 200mm/a. The rainfall in the area varies from approximately 400 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 with problematic chemical species, nitrate (concentration > 10mg/l) and fluoride (concentration > 1.5mg/l). The EC intervals as well as the nitrate and fluoride values shown are based on the prescribed guidelines for domestic water quality.

1.3.4 Brochure:

The purpose of the explanatory brochure is to give information on the methodology followed in compiling the map, to highlight important groundwater topics and to discuss groundwater occurrences in more detail as that could be depicted on the map. The occurrence of groundwater is very heterogeneous in South Africa while the mapping standards, legend, etc. demanded a high degree of conformity. Aspects of groundwater that are important, which could not be shown on the map, will vary dramatically from region to region and the brochure provides opportunities to reflect this variability. Included in the brochure are frequency diagrams on borehole yields and stiff diagrams giving information on groundwater chemistry for various lithology. These are guideline values with the accuracy a function of available data and quality of data.

2. PHYSICAL ENVIRONMENT

2.1 Climate

The area covered by the map sheet varies considerably in climate in line with variations in altitude and relief. It is a summer rainfall area divided by the Drakensberg Escarpment into the Highveld with cold frosty winters and moderate summers and the Lowveld with mild winters and subtropical climate. In the south-eastern part of the map area within the KwaZulu-Natal Province the annual precipitation decreases over the Makatini flats from approximately 1000mm/a near Kosibay westwards to 600-800mm/a at the Lebombo Mountain Range. Along the Drakensberg escarpment the rainfall is higher than 1000mm/a decreasing to 400-600mm/a in the lowveld area in the north-eastern sector of the map area. The temperature varies from 10-12° to 20-22° on the Highveld and escarp to a yearly average of 22° in the Lowveld. The

Highveld area in the eastern sector of the map receives an annual rainfall of between 600-800mm/a.

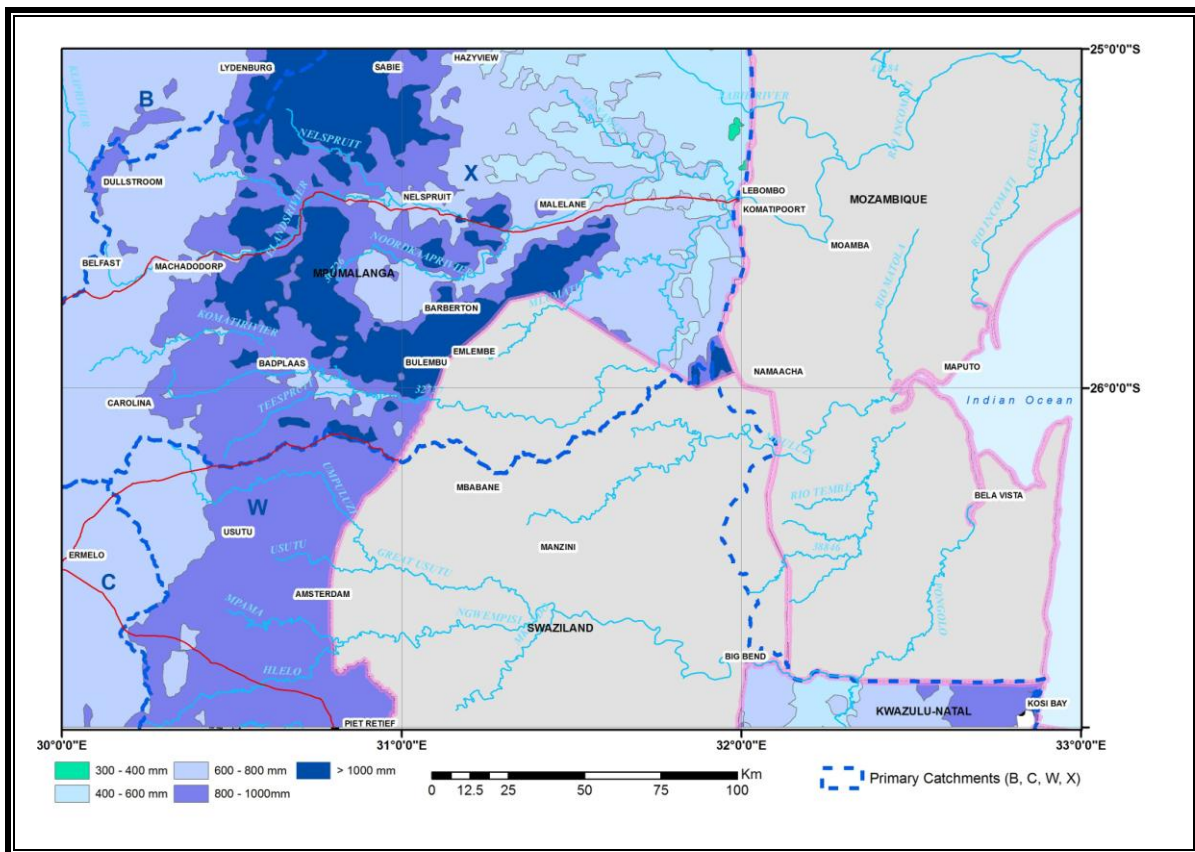


Figure 1: Mean annual precipitation (MAP).

2.2 Topography

The topography in the eastern sector of the map sheet, in particular the northern part of Kwa-Zulu Natal (Makatini flats), comprises flat coastal plains with average elevations of less than 200mamsl. To the west of the Makatini flats the coastal flats are abruptly terminated by the north-south striking Lebombo Mountain Range with heights of up to 800mamsl. On the rest of the map sheet topographical features are closely related to the underlying geology; the north to south striking Drakensberg Escarpment along the resistant Black Reef quartzite divides the map sheet into a high plateau in the north-west characterized by low to high mountains and the lowveld in the north-east characterized by slightly to strongly undulating plains.



The high plateau and mountain ridges have elevations of 1200-2500mamsl with the resistant quartzite of the Pretoria Group forming the high ground. The lowveld area is underlain by Swazian granitoid and gneissic rocks with elevations varying from 200mamsl in the east to 800mamsl towards the west. The area underlain by rocks of the Karoo Super Group ranges from slightly undulating plains and pans to strongly undulating plains with elevations between 1200mamsl in the east to 2000mamsl to the west.

Photo 2: The eastern escarpment is characterised by numerous waterfalls. The most spectacular one is the Mac-Mac Falls in the Mac-Mac River where resistant Black Reef Quartzite forms a thick ledge over which this 65m-high waterfall tumbles, cutting back a deep gorge into the escarpment (photo W.H. Du Toit, 2006).

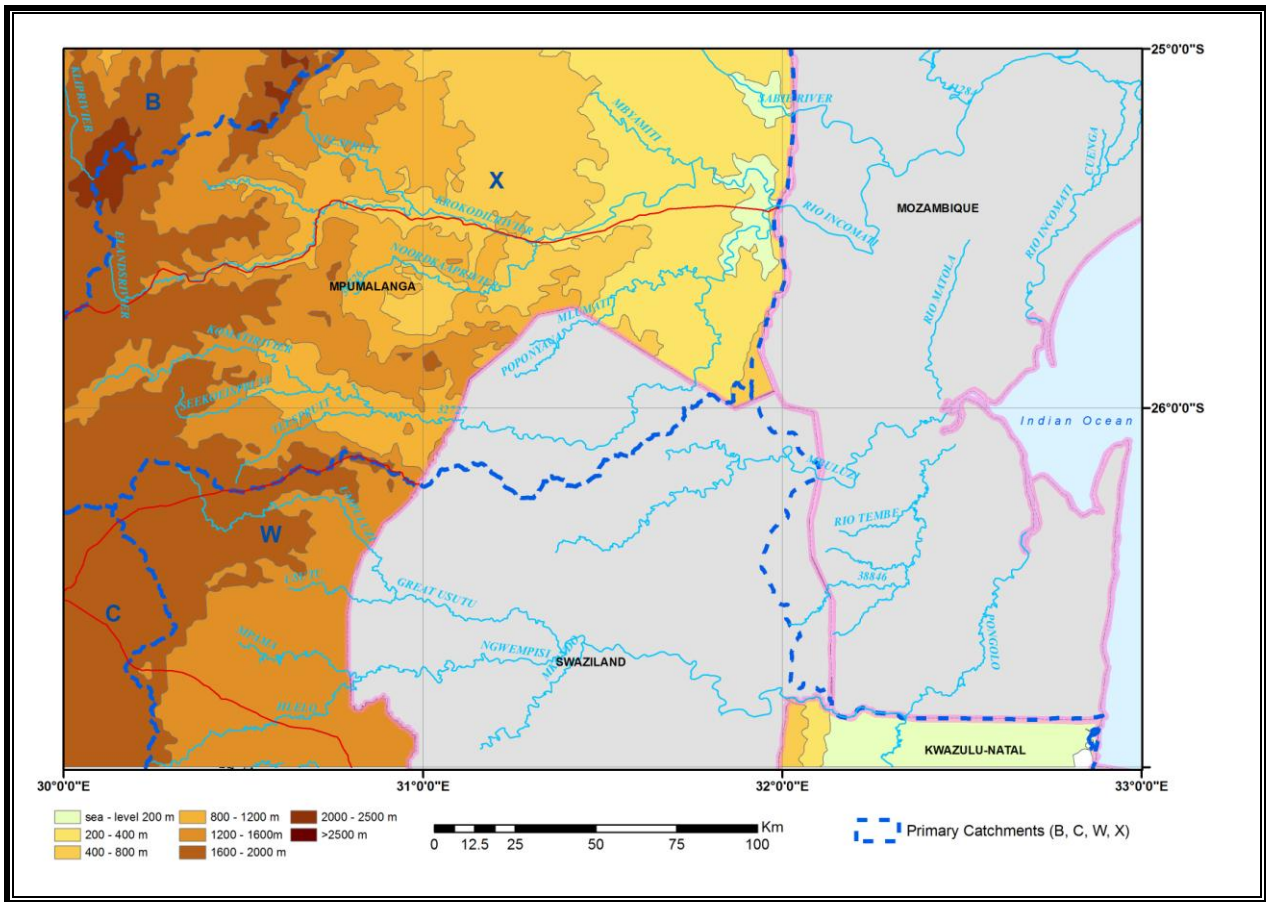


Figure 2: Elevation above sea level.

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

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

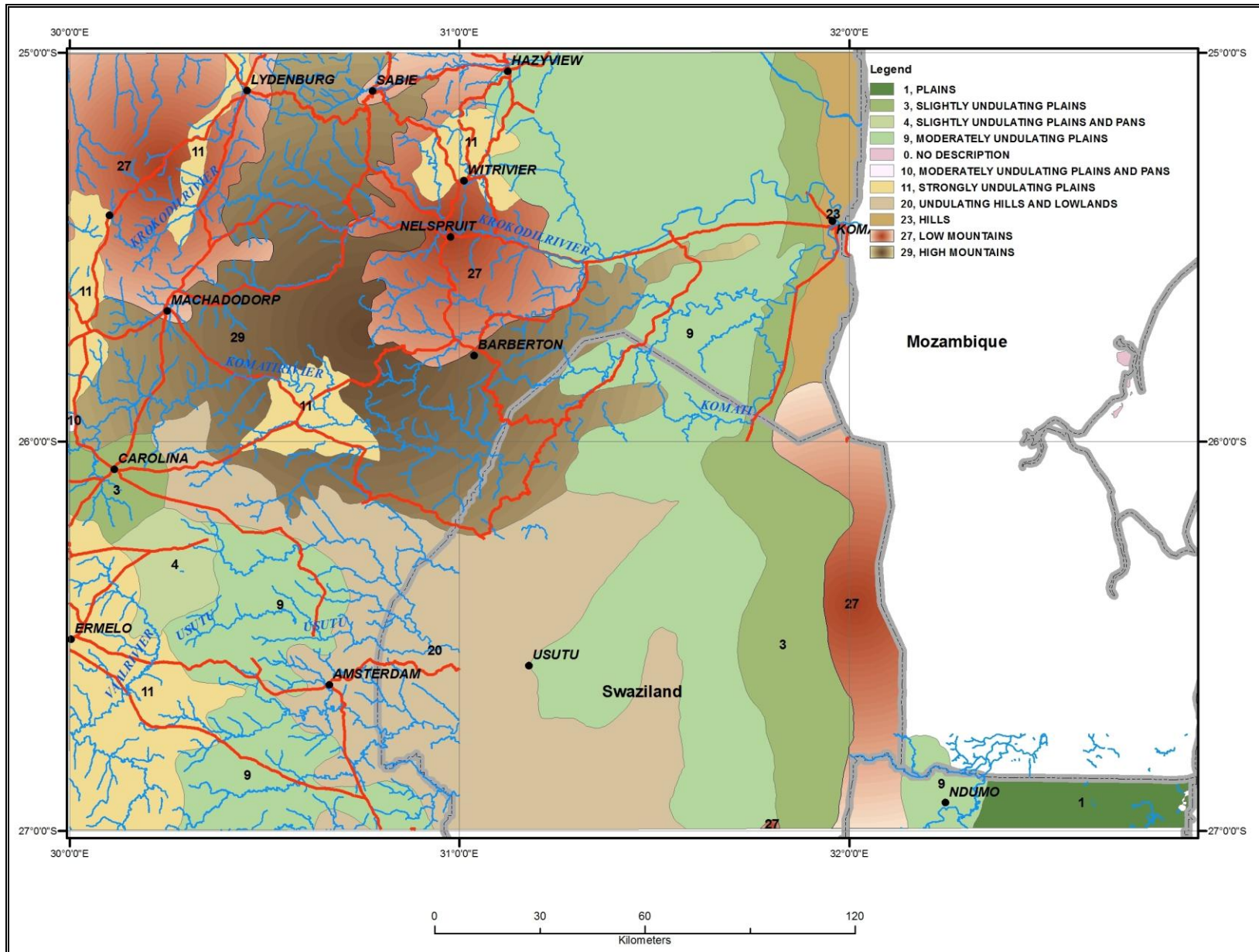


Figure 3: Terrain Morphology (Kruger, 1983)

Table 3: Explanation for Figure 3, Terrain Morphology

BROAD DIVISION	MAP SYMBOL	DESCRIPTION	DRAINAGE DENSITY* (km/km ²)	% OF AREA WITH SLOPES <5%
Plains with low relief	1	Plains	low - medium 0 - 2	> 80%
	3	Slightly undulating plains		
	4	Slightly undulating plains and pans		
	9	Moderately undulating plains		
	10	Moderately undulating plains and pans		
	11	Strongly undulating plains		
	7	Extremely irregular plains (almost hilly)		
Lowlands, hills and mountains with moderate to high relief	20	Undulating hills and lowlands	low - medium 0.5 - 2	20 - 50%
Closed hills and mountains with moderate and high relief	23	Hills	Medium-high 1.5-10.5	< 20%
	27	Low mountains		
	29	High mountains		

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

2.3 Surface Water

The map area is divided into four primary drainage regions (Figure 4, p22), the Olifants (B), Crocodile/Komati (X), Vaal (C) and Mfolozi/Usutu/Phongolo (W). Within the map sheet area the Olifants River System is represented by the north flowing Klip River. The Crocodile/Komati River System with its headwaters in the north-western Highveld and Drakensberg escarpment flows predominantly eastwards. The Crocodile- and Komati Rivers joins near Komatipoort before flowing through the Lebombo Mountain range into Mozambique where it is subsequently joined by the Sabi River. The headwater of the Vaal River is near Ermelo and it flows predominantly south-west. The Usutu River system starts on the Highveld area flowing predominantly eastwards with the bulk of the system within Swaziland. In KwaZulu-Natal the Pongola River joins this system to continue as the north-east flowing Rio Pongolo in Mozambique.

In areas underlain by rocks of the Karoo Supergroup fresh water lakes are formed in shallow depressions with Chrissiesmeer the largest. In a report on the state of the rivers, mining-related disturbances are given as one of the main causes of impairment of river health. Other factors

are extensive invasion by alien vegetation (especially Black Wattle) and to a lesser extent alien fauna. In a report by the Department of Agriculture on land degradation it is stated that 14% of the runoff in Mpumalanga is used by alien vegetation and commercial forestry may reduce runoff in dry periods by up to 18%. Drainage regions and major dams are listed in *Table 4*, p23.



Photo 3: *The area around Chrissiesmeer and Lothair, which is underlain by sediments of the Vryheid Formation, are characterized by the occurrence of numerous fresh water lakes where the interaction between surface and groundwater is an important parameter in the existence of these lakes. Chrissiesmeer is one of the biggest fresh water lakes in the country (photo W. H. Du Toit, 2006)*

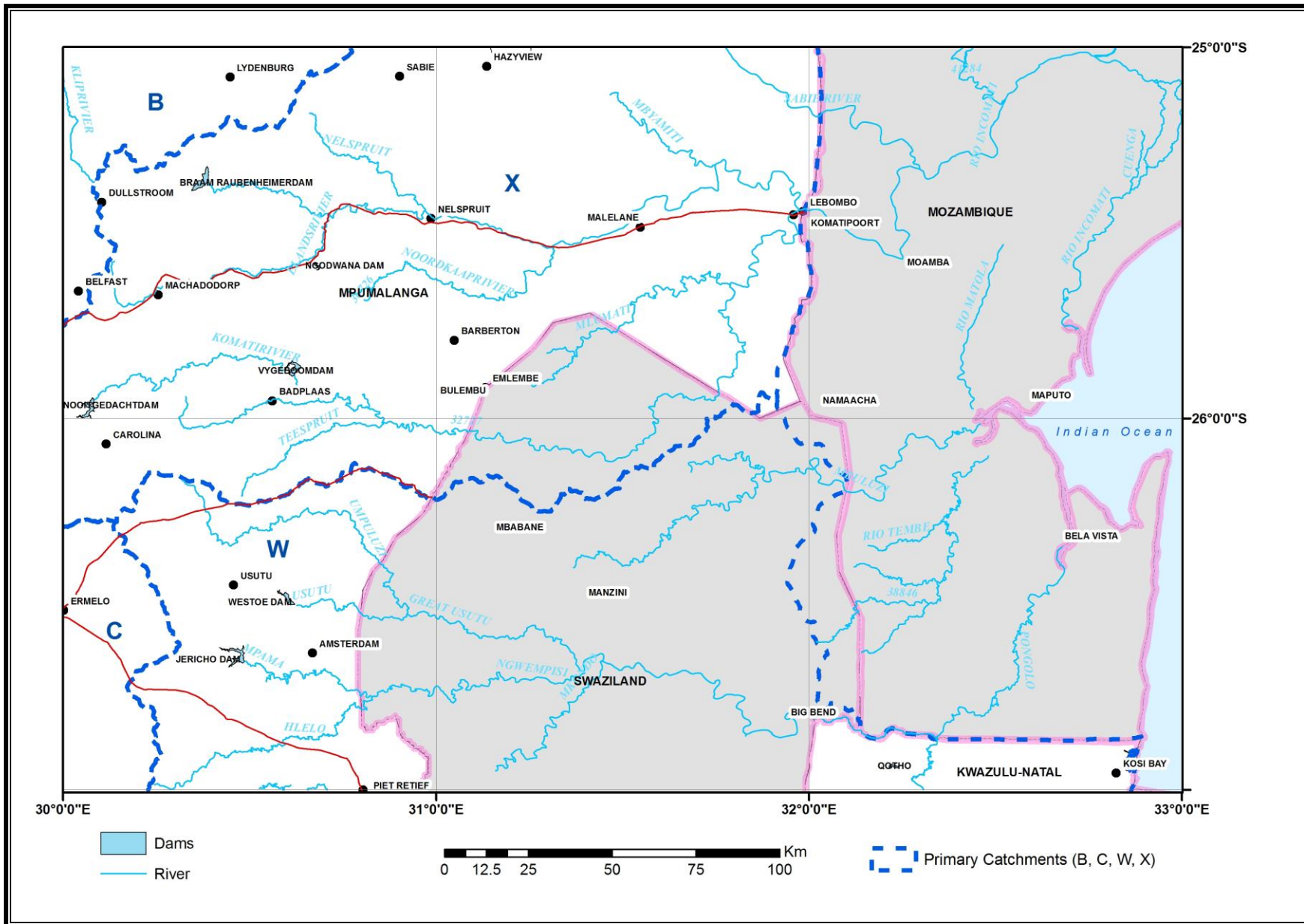


Figure 4: Primary Catchments, rivers and major dams.

Table 4: Drainage and dams

Primary drainage region	Secondary drainage	Tertiary drainage	Dams	Capacity Megalitre	Latitude	Longitude
Mfolozi	Usutu	Assegaai River	Heyshope Dam	451,300	26° 59'' 45'	30° 31'' 50'
		Hlelo River				
		Ngwempisi River/Mpama River	Jericho Dam	59,500	26°39'' 15'	30° 29'' 10'
			Morgenstond Dam	100,773	26° 45'' 57'	30° 22'' 10'
		Usutu River	Westoe Dam	61,900	26° 30'' 15'	30° 37'' 05'
		Mbuluzi River				
		Small Usutu River				
Olifants		Pongola	Josini Dam	2,267,100	27°25'' 15'	32° 04'' 30'
		Klip River				
Vaal						
Crocodile/Komati	Crocodile	Crocodile	Kwena Dam/Braam Raubenheimer Dam	158,900	25° 21'' 45'	30° 22'' 30'
		Ngodwana/Elands	Ngodwana Dam	10,400	25° 35'' 01'	30° 40'' 05'
		Nelspruit				
		Mbyamiti				
	Komati	Noordkaap				
		Upper Komati	Nooitgedacht Dam	18,800	25° 57'' 01'	30° 05'' 01'
		Seekoei Spruit				
		Komati River				
		Lomati River				
		Mlumati				
	Sabi	Teespruit				
		Sabie River	Witklip Dam	12,970	25° 14'' 10'	30° 54'' 01'
		Sand River				
		Onder Sabie River				
Witwatersrivier/White River		Da Gama Dam	13,578	25° 08'' 30'	31° 01'' 01'	
	Klipkoppie Dam	12,256	25° 13'' 01'	31° 01'' 10'		

2.4 Geology

2.4.1 Regional geology

The geology of the map area includes rocks of a wide variety of lithology and represents the geological history from Swazian to recent. A simplified geological map (Figure 5, p28) was compiled from the following 1:250 000 published geological map sheets and explanatory booklets (Council for Geosciences):

- 2530 Barberton
- 2630 Mbabane
- 2632 Kosibaai

The major stratigraphic units formed the basis for the delineation of the hydrological units that were chosen according to hydrogeological similarities. The boundaries of the hydrological units do not always follow the geological boundaries and the names may differ from the names used for the South African geological map series. The major divisions and stratigraphic groups in the map area are as follows:

- The Barberton Mountain Land
- Gneisses, migmatites and granitoid rocks of the Swazian Basement
- Diapiric domes and plutons of Swazian and Radian age
- The Pongola Sequence and associated Usushwana Complex
- The Transvaal Supergroup
- Diabase dykes and sills
- The Bushveld Complex
- Karoo Supergroup
- Dolerite dykes and sills
- Cretaceous to Quaternary

2.4.1.1 The Barberton Mountain Land

The Barberton Mountain Land is mainly underlain by a sequence of metavolcanics and sediments grouped together under a distinctive and well defined unit, the Barberton Sequence. This greenstone belt is approximately 8-16km thick, 130km in length and 50km wide trending north-easterly from Badplaas to Komatipoort. It is the oldest, best preserved, and least metamorphosed volcano-sedimentary succession known (Saager and Koppel, 1976). It is divided into three groups, Onverwacht, Fig Tree and Moodies Groups (SACS, Handbook 8, 1980). The hydrogeological units on the map sheet corresponding to the geological lithology of the Barberton Sequence is referred to as the undifferentiated Barberton Super Group (Zr), the undifferentiated Tjakastad Subgroup (Zot-Zoo), and the undifferentiated Onverwacht, Fig Tree and Moodies Group (Zo-Zd).

2.4.1.2 Gneisses, migmatites and granitoid rocks of the Swazian Basement

North and south of the Barberton Mountain Land intrusive granite gneisses and migmatite form part of the pre-Transvaal basement and is of Swazian to Randian age. Similar hydrogeological characteristics resulted in these rocks being grouped into two units referred to as unnamed Swazian rocks (Zz) and Nelspruit Suite (Ze). The age relationship of the gneissic and granitoid rocks to the Barberton Sequence is not yet fully understood and various researchers differ in opinion.

2.4.1.3 Diapiric domes and plutons of Swazian and Radian age

Smaller diapiric domes and plutons such as the Kaap Valley Granite (Zka), Dalmein Granite (Zda) and Salisbury Kop Granodiorite (Rsk) occur along the southern and northern boundary of the Barberton Mountain Land. The Hebron Granodiorite (Zhe) and Mpangeni (Rmp) intruded into the Nelspruit Suite. Various smaller intrusions into older granitoid rocks were grouped on the map sheet as unnamed Radian intrusions (Rz) and the Boesmanskop Syenite (Rbs).

2.4.1.4 Pongola Sequence and the associated Usushwana Complex

In the south-eastern part of the map sheet, the Pongola Sequence in association with the Usushwana Complex dominate the underlying geology of an area from Amsterdam trending south-easterly in a 20km wide elongated belt up to the Swaziland border. The Pongola Sequence and Usushwana Complex overlay the Swazian basement gneissic and granitoid rocks unconformably. The Pongola Sequence is divided into a lower Nsuze and upper Mozaan Group. The boundaries of the Nsuze Group (Zn) are the same on the hydrogeological map sheet as on the geological map sheet, 2630 Mbabane. The most southern occurrence of the Mozaan Group (Rm) is described as a hydrogeological unit while the other occurrences as depicted on the geological map are grouped under the undifferentiated rocks of the Mozaan Group, Amsterdam Formation and Usushwana Complex (Rm-Ru). The hydrogeological unit named undifferentiated rocks of the Thole and Piet Retief Suite (Rth-Rup) relates to basic and ultramafic intrusives into the Swazian basement rocks. South of the Pongola Sequence leucocratic biotite granite is grouped as a hydrogeological unit named 'various intrusive rocks of the Mozaan and Nsuze Group (Zn)'

2.4.1.5 Transvaal Super Group

The rocks of the Transvaal Super Group represent a tectono-sedimentary phase of clastic, volcanic, and chemical sedimentation within a large sedimentary basin resting unconformably on Swazian basement rock (SACS, Handbook 8, p187). The higher ground is formed by the more resistant rocks such as the quartzites of the Steenkampsberg, Magaliesberg, Lakenvallei and Daspoort Formations. The hydrogeological unit described as Wolkberg Group (Vw) represents the Godwan Formation while the hydrogeological unit named Black Reef Formation (Vbl) represents the Wolkberg Group as depicted on the geological map sheet, 2530 Barberton. The undifferentiated Black Reef Formation and Chuniespoort Group (Vh-Vbl) represents the continuous quartzite along the escarpment as well as the overlaying chemical sediments. The Pretoria Group (Vp) represents the tidal and deep water sediments and volcanic rocks.

2.4.1.6 Diabase dykes and sills

The diabase intrusions occur mainly as dykes and to a limited extent as sills in all the pre-Karoo rocks within the map sheet. Sills within the Swazian basement rocks are restricted to a few localities within the rocks of the Nelspruit Suite (Ze). Diabase sills are predominantly intruded within the rocks of the Transvaal Supergroup. The emplacement of these sills is generally considered part of the whole magmatic evolution of the Bushveld Complex. Petrogenetically it relates to various magmatic events and volcanic activities that preceded the emplacement of the plutonic rocks of the Complex which range in composition from basalt to rhyolite (SACS, Handbook 8, p225).

In the northern part of the map sheet within the gneissic and granitoid rocks of the Nelspruit Suite (Ze) the prominent strike of diabase dykes is east-west. In the vicinity of the Crocodile River more to the south, the prominent strike is south-easterly. South of the Barberton Mountain Land the strike is predominantly northerly within the rocks of the Nelspruit Suite (Ze). The frequency of occurrence increases within the Kaap Valley Granite (Zka) and Unnamed Swazian Rocks (Zz). Strike is predominantly north-westerly and north easterly within these units.

Diabase dykes within the Undifferentiated Onverwacht, Fig Tree and Moodies Groups strike predominantly north, north-west and occasionally to the east. West of the Drakensberg escarpment within the rocks of the Pretoria Group (Vp) strike is mainly northerly and occasionally easterly. In the southern part of the map occasional north-east or west-north-west orientated dykes occur within the rocks of the Pongola Sequence.

2.4.1.7 Bushveld Complex

The Bushveld Igneous Complex occurs in the north-western sector of the map sheet. The Complex is mainly represented in the map area by the Rustenburg Suite (Vr), a succession of mafic and ultramafic layered rocks. The Lebowa Suite (Mle), representing a younger felsic phase occurs as a single granite pluton in the north-western corner of the map. In contrast with the western limb of the Complex (Rustenburg area) where the topography is more flat, covered with 'turf' and with isolated hills, the eastern limb is characterized by the Leola mountain range where the complete layered succession of rock types is exposed.

The layered character of the Complex is generally believed to be the result of crystals settling out from magma during slow cooling. The process is described as the gravitative settling of cumulus crystals and subsequent crystallization of the 'intercumulus liquid' (occupies the space between cumulus crystals, which crystallize in place to cement the settled particles together). This process will, during conditions of lengthy quiescence and slow cooling of the magma, result in the accumulation of thick homogenous rock units in which the only signs of bedding will be displayed by the igneous lamination (SACS, Handbook 8, p224).

2.4.1.8 Timbavati Gabbro

The Timbavati Gabbro (Nti) occurs as intrusive sills within Swazian basement rocks. The occurrence is restricted to the area north of the Barberton Sequence in the north-eastern sector of the map sheet.

2.4.1.9 Karoo Super Group

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 migration 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 break-up of the Gondwana continent (Brandl, 2002). The Super Group is divided in a few geographical areas with two well defined areas within the map sheet.

The sediments underlying the south-western sector of the map sheet represent the northern part of the **Main Karoo Basin**. Sediments deposited in this basin underlie almost 60% of South Africa. The north-south-trending **Lebombo Basin**, which links up with the main basin, is underlain by rocks of the Lebombo Group (Jl) representing the final magmatic phase. It is divided into the Jozini Formation, a fractured aquifer due to its resistance to weathering and the Letaba Basalt Formation classed as an intergranular and fractured aquifer. It overlays the Clarens Formation (Trc) consisting predominantly of sandstone occurring as a thin strip along the western slope of the Lebombo Mountain Range. In turn it overlays the Eccca Group (Pe) consisting of undifferentiated grit, sandstone, shale and coal seams with interlayered siltstone and mudstone. The lowest unit is represented by the Dwyka Group (C-Pd) consisting of rock fragments in a fine grained matrix.

2.4.1.10 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). Dolerite outcrop occurring as sills are abundant in the south-western sector of the map sheet overlying younger Karoo sedimentary rock.

Dyke clusters with limited extent that intruded into the sediments of the Karoo Supergroup south of Sheepmoor are depicted on the 1:250000 2630 Mbabane geological map. Prominent northerly striking dolerite dykes occur within the Lebombo Group (Jl), and within the fractured aquifers of the Ecca Group (Pe). These units occur along the Mozambique border in the eastern part of the map sheet. The frequency of these occurrences increases in the Komatipoort area. East of the Dwarsrivier a prominent cluster of northerly striking dykes occur within the rocks of the Rustenburg Suite (Vr) and near Lydenburg within the rocks of the Pretoria Group (Vp). A very prominent northerly striking dyke (approximately 70km in extent) is indicated on the above referenced geological map that transects the hydrogeological units Undifferentiated Black Reef Formation and Chuniespoort Group (Vh-Vbl), the Black Reef Formation (Vbl), the Wolkberg Group (Vw) and the Nelshoogte Pluton (part of the unit referred to as Unnamed Swazian Rocks, Zz). Less frequently occurring dykes, striking predominantly north-easterly are found within the rocks of the Undifferentiated Onverwacht, Fig Tree and Moodies Groups (Zo-Zd) and Unnamed Swazian rocks (Zz).



Photo 4: *Dykes of various compositions and orientations are a common occurrence within the basement rocks of the area. North-east appears to be the more dominant orientation. This dolerite dyke occurs in a road cutting in the Kruger National Park on the northern bank of the Sabie River. Fractured dolerite and/or its contact with the host rock are important targets for successful groundwater supplies (photo W.H. Du Toit, 2006).*

2.4.1.11 Cretaceous to Quaternary

Cretaceous to Tertiary deposits within the map sheet are represented by the Zululand Group (K-Tu) which underlay the western part of the Makatini Flats in KwaZulu-Natal. The origin of the group is attributed to a period of marine transgression from the north during the fragmentation of the Gondwana continent. Tertiary to Quaternary deposits occurs to the east of the Zululand Group forming coastal flats up to 80km inland from the coast. The Maputaland Group (T-Qm) consists of deposits and reworked deposits of marine origin, coastal dunes, lagoons, estuaries, and coastal swamps. Quaternary deposits in the rest of the map consist mainly of alluvial deposits, residual soils and scree deposits. Alluvial deposits occur along most of the streams in the area with prominent alluvial fans and prominent scree deposits along the Drakensberg Escarpment.

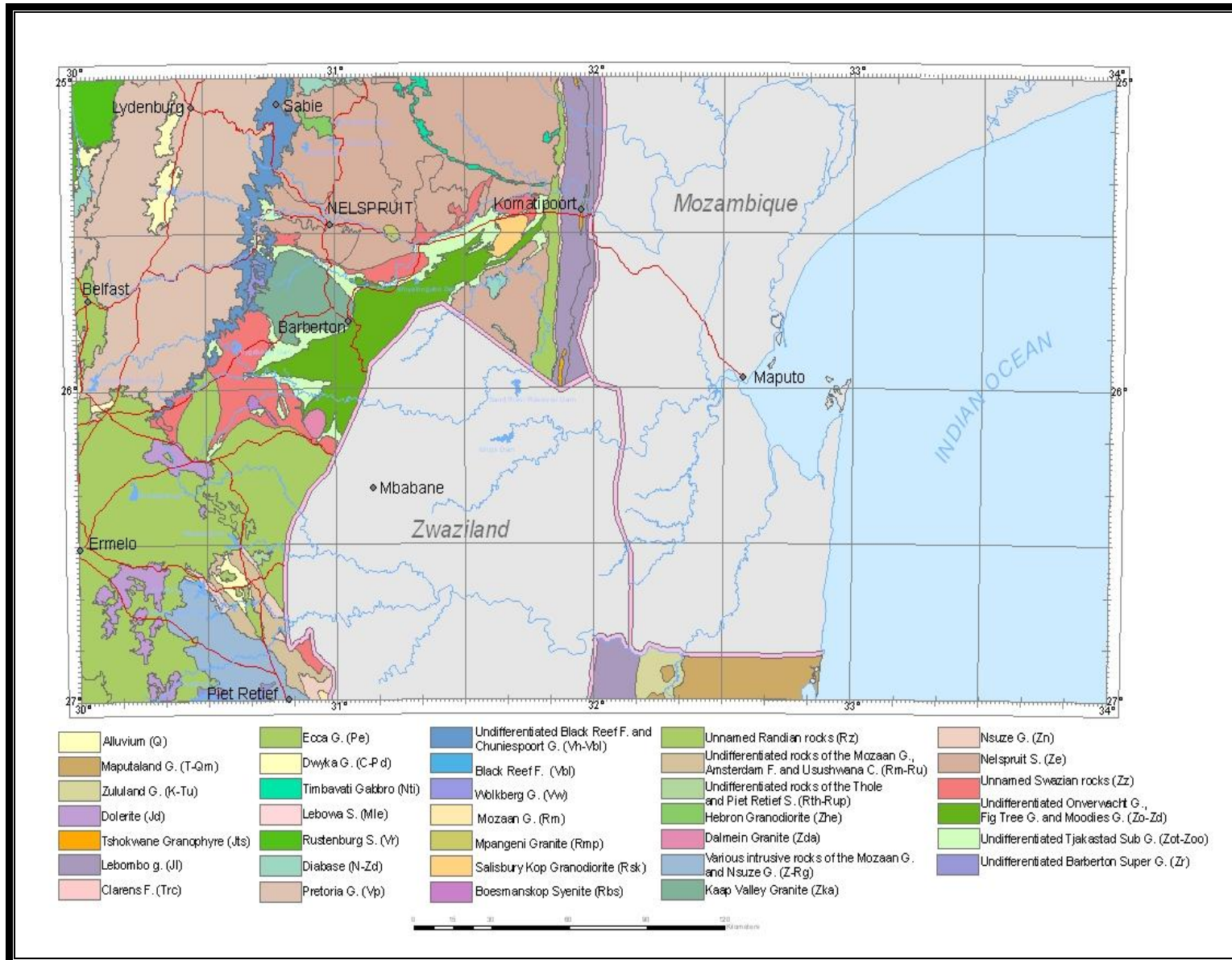


Figure 5: Simplified regional geology of the map area (after DWA, 2011).

2.4.2 Structural geology

2.4.2.1 Dykes and sills

North of the Barberton Sequence, diabase dykes are frequently found in the granitoid, gneissic and migmatite rocks of the Nelspruit Suite. The strike is predominantly easterly especially in the northern part of the map sheet, south-easterly and south near the Barberton Sequence which is more to the centre of the map sheet. Diabase intruded as sills dominate in the north in the area west of Hazyview and in an area between Swaziland and the Barberton Mountain Land. A prominent gabbro sill occurs in a wide arc in the north-eastern sector of the map sheet.

Diabase dyke intrusions are much more frequently occurring within the diapiric domes and plutons of Swazian age, trending south-easterly and lesser in a southern direction. Intrusions into the Barberton Sequence are more frequent in the southern and middle part of the sequence than in the northern part towards Komatipoort. Minor diabase dyke intrusions occur in rocks of the Pongola Sequence. In the Pretoria Group diabase dyke intrusions and sills related to the Bushveld Complex occurs more frequently than in any other unit of the map sheet.

Numerous dolerite dykes striking predominantly south intruded into the rocks of the Pretoria Group and Bushveld Complex. In rocks of the Karoo Super Group dolerite dykes are frequently found striking southerly especially in the vicinity of Komatipoort. In the south-western part of the map within the rocks of the Karoo Super Group dolerite sills dominate in two areas namely around Sheepmoor and in an area north-east of Chrissiesmeer. Dolerite dykes are less frequent except for a dyke cluster south of Sheepmoor striking southerly transecting sills and striking predominantly south.

2.4.2.2 Faults and shear zones

The map area is characterized by the lack of major fault zones in most of the geological units as depicted in (Figure 6, p30). Faulting occurs predominantly within the rocks of the Pretoria Group (Vp), in the north-western sector of the map sheet and to a lesser degree in the rocks of the Undifferentiated Onverwacht, Fig Tree and Moodies Groups (Zo-Zd). Within the Pretoria Group (Vp) the strike is predominantly northerly and lesser to the south-east. In the latter the strike is predominantly north-easterly and lesser to the north and north-west.

Shear zones occur in the granitoid and gneissic rocks of the Nelspruit Suite (Ze), in an area more or less bounded by the rocks of the undifferentiated Black Reef Formation and Chuniespoort Group (Vh-Vbl) in the west, the Kaap Valley Granite (Zke) in the south, and the Nsikazi River in the east. The strike is predominantly north-north-west and north-north-east transecting the intermediate to younger phases of the Nelspruit Suite (Ze).

The contribution of the fault and shear zones to the occurrence of groundwater could not be established due to a lack of data and hydrogeological reports.

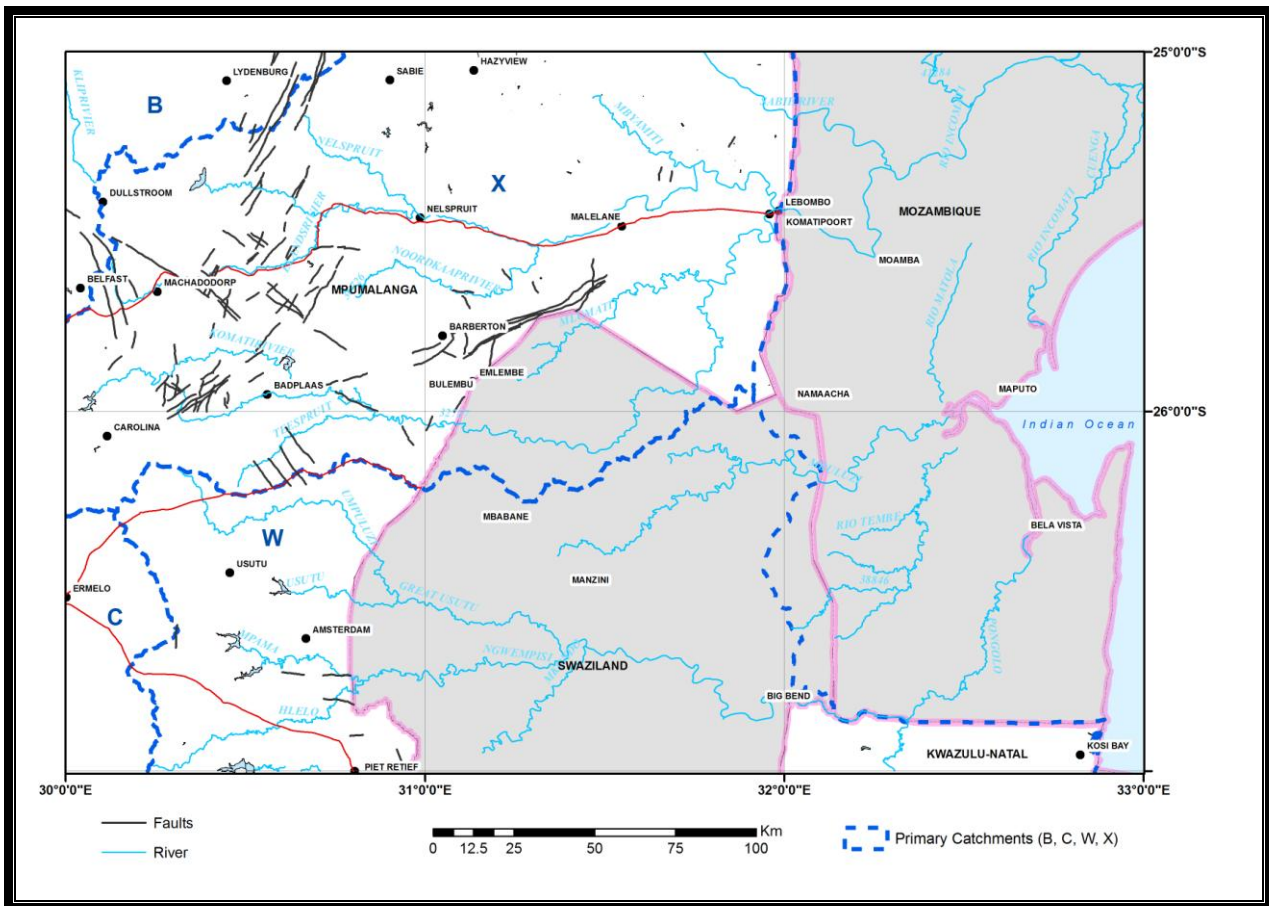


Figure 6: Faults inferred and observed (after DWA, 2012).

2.5 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 leading to a decrease in water quality.

In order to characterise and compare the chemical composition of groundwater in the various rock formations, the chemical results of 1494 analysed groundwater samples taken during the period from 1995 to 2012 was used. The samples were carefully chosen from a total of 3439 using the following criteria: Incomplete or questionable analyses were not used and in cases where sample points had more than one analysis (time series data), the harmonic mean was calculated for each parameter and the results used as a single analysis for that particular sample point. This reduced the total available sample data that was used to compile the stiff diagrams.

The accuracy of the results for the chemical analysis was further evaluated by the plausibility of the electrical conductivity (EC) and the electro neutrality (E.N) of the chemical analysis. The calculation used for plausibility of EC is by comparing the $\sum \text{anions (meq/L)} = \sum \text{cations (meq/L)} = \text{EC}/100(\mu\text{S/cm})$ for $\text{EC} < 2000 \mu\text{S/cm}$. The electro neutrality was calculated as follows: $[\sum \text{cations (meq/L)} + \sum \text{anions (meq/L)}] / [\sum \text{cations (meq/L)} - \sum \text{anions (meq/L)}] * 100\% \leq \pm 5\%$.

Chemical analyses are usually only accepted when the electro neutrality is $\pm 5\%$. The overall reduced data set had very good to acceptable electro neutrality (EN $\pm 5\%$) for 59.5% of the data

samples and less acceptable in 17.7% ($EN \pm 10\%$) of the samples. The remaining 22.8% that is usually discarded were used selectively in certain units with limited data. This data was plotted on Schoeller diagrams for each unit to eliminate samples not following the predominant trend.

Keeping to strict guidelines would have resulted in a greater number of units not having enough chemical data for characterization. Another reason for allowing EN differences above $\pm 5\%$ to be used is that improvements in technology for the analytical instrumentation used by laboratories result in more parameters analysed to a greater accuracy. Not all element concentrations were previously taken into account when applying electro neutrality as a basis for accuracy evaluation. There is a difference when using all the available parameters in calculation or only when using the major ones. The electro neutrality is more readily influenced in water samples which reflect class 0 and class 1 quality samples (DWA guideline classifications, 1995). The inaccuracy of a single major ion can result in the discarding of that specific sample's entire parameter range, when analysing large volumes of data. CAT/ANI balances are regarded as true, only when concentrations of all major ion groups have been determined. In cases of acidic samples, the acid capacity and micro elemental concentrations are also to be determined, prior to assuming the cat/ani balances as inaccurate.

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 in most of the brochures of the hydrogeological map series. 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 listed. Most of the units are a combination of water dominated by calcium-magnesium-sodium-bicarbonate or calcium-magnesium-chloride or sodium-chloride, or calcium-magnesium-bicarbonate or magnesium-sodium-bicarbonate.

- **Calcium Magnesium bicarbonate water**

Bicarbonate water is usually characterised by a high content of HCO_3^- and $\text{Ca}^{2+}/\text{Mg}^{2+}$. Groundwater encountered in the Undifferentiated Black Reef Formation (Vh-Vbl), Pretoria Group (Vp), Rustenburg Suite (Vr) show a tendency to this water type.

- **Sodium bicarbonate water**

This water type has predominantly been present in the geological units of the study area. 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^- . In most of the cases Ca^{2+} and Mg^{2+} is also dominant. Units exhibiting a prominence to this water type includes the Dwyka Group (C-Pd), Undifferentiated Tjakastad Sub Group Zot-Zoo), Undifferentiated Onverwacht Group (Zo-Zd), Unnamed Swazian rocks (Zz), Nelspruit Suite (Ze), Nsuze Group (Zn), Kaap Valley Granite (Zka), various intrusive rocks of the Mozaan Group and Nsuze Group (Z-Rg), Dalmein Granite (Zda), Eccca Group (Pe) fractured and intergranular aquifers, Dolerite (Jd), Undifferentiated rocks of the Mozaan Group, Amsterdam Formation and Usushwana Complex (Rm-Ru), Unnamed Randian rocks (Rz) and the Timbavati Gabbro (Nti).

- **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 quaternary alluvial deposits (Q), Lebombo Group (Jl), Ecca Group (Pe), and Clarens Formation (Trc). A predominance of Na^+ and Cl^- indicates an end point of discharge or stagnation of water.

Table 5, p32 provides some guidelines on the suitability of water quality based on electrical conductivity (EC) measurements for domestic, livestock and irrigation purposes (DWA 1996). Figure 7, p41 gives an overview of the area for EC values, nitrate and fluoride concentrations. The quality ranges referenced in Table 6 to Table 9, p34 - 39 is as per SANS 241:2005 specification.

Table 5: Guideline sheet using electrical conductivity as indicator for the suitability of groundwater for domestic, livestock and irrigation usage (DWA 1996).

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

2.6 Aquifer Hydrochemistry

Chemical data was obtained from various sources, but predominantly from the National Water Quality Database (WMS). This was used 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 data points were grouped to represent the different hydrogeological units.

The hydrochemical results were averaged by calculating the harmonic mean value for each of the major elements and groundwater parameters. These values are summarized for each aquifer unit in Table 6, p34. The first column gives the symbol of each unit and the third the total sample points used. The total samples in each unit can be put into perspective when compared with the unit aerial extent in relation to the map. The percentage coverage of each unit in relation to the map extent is given in column 2 of Table 10, p43. For spatial distribution

of the sample points the reader is referred to the geographical distribution map for each unit. In general Table 6 gives an overview of the expected concentrations of the major chemical elements in mg/l for each unit. Where the concentration displayed in the table exceeds the maximum allowed limit (SANS 241, 2005), it is displayed in bold red.

Table 7 to Table 9, p35 to p39 was compiled using the percentages of samples grouped into different domestic water classes for each major element. The classification (ideal, acceptable, maximum allowed and unacceptable) is according to the South African National Standards for domestic water use (SANS 241, 2005) document. The number of samples used in the statistical analysis is more than the total that passed the quality check ($EN \pm 5\%$). The samples failing the quality check $EN > \pm 5\%$ were systematically evaluated before inclusion. Further in the document, under the discussion for each unit, the hydrochemistry is presented as a stiff diagram showing the major anions and cations.

Ten of the units did not have any chemistry data available for analysis. They are the Black Reef Formation (Vbl); Pretoria Group fractured aquifer (Vp), Undifferentiated Barberton Super Group (Zr), Hebron Granodiorite (Zhe), Undifferentiated rocks of the Thole and Piet Retief Suite (Rth-Rup), Salisbury Kop Granodiorite (Rsk), Mpangeni Granite (Rmp), Mozaan Group (Rm), Wolkberg Group (Vw) and the Lebowa Suite (Mle).

Some of the units had 5 or less sample points with chemistry data. They are the units Alluvium (Q), Dwyka Group (C-Pd), Tshokwane Granophyre (Jts), Nsuze Group (Zn), Boesmanskop Syenite (Rbs), Diabase (N-Zd), Rustenburg Suite (Vr) and the Zululand Group (K-Tu)

Table 6: Summary table, calculated harmonic mean values for various chemical parameters for each unit.

Symbol	E.N. $\leq \pm 10\%$	Total samples used in analysis	pH	EC	NO ₃	F	TAL as (CaCO ₃)	Na	Mg	SO ₄	Cl	K	Ca
				mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
SANS 241			4-10	370	20	1.5		400	100	600	600	100	300
Q	0	2	Category A: Intergranular aquifers										
T-Qm	8	8	6.7	15.3	6.2	0.1	no data	4.7	9.4	23.2	3.4	0.4	12.4
			7.7	39.7	0.05	0.12	68.2	38.8	6.9	9.5	53.6	4.6	17.3
			Category B: Fractured aquifers										
Vbl			Black Reef Formation, no data available										
Vp			Pretoria Group, no data available										
C-Pd	3	4	7.4	13.8	0.54	0.2	51.4	6.7	5.5	4	5.3	1.5	6.4
Pe	63	68	7.9	176.2	0.09	0.49	185.5	197.7	25.3	19.2	217.2	2.8	66.9
JI	19	27	7.5	65.6	0.24	0.46	87.5	95.7	5.3	11.2	92.9	1.6	15.8
Jts	1	1	8	71	1.5	0.5	210	63.8	30	27	100.4	1.5	46
			Category C: Karst aquifers										
Vh-Vbl	18	23	7.9	12	0.11	0.16	50.1	3	4.1	4.1	3.4	0.4	6.4
			Category D: Intergranular and fractured aquifers										
Zr			Undifferentiated Barberton Super Group, no data available										
Zot-Zoo	74	81	7.9	64.2	0.79	0.3	222.5	27.9	24.3	12	18	0.6	26.3
Zo-Zd	54	62	7.8	35.9	0.13	0.14	134.7	14.5	16.7	8	9.3	1.5	21.1
Zz	78	93	7.6	21.1	0.57	0.3	83	18.3	4.7	4.4	7.2	1.4	9.3
Ze	377	472	7.7	34.1	0.5	0.48	117.4	30.9	6.6	3	17.3	1.5	12.5
Zn	2	5	7.0	8.6	0.16	0.12	40.6	6.4	2.6	1.9	5.2	1.0	9.9
Zka	33	60	7.3	37.1	1.3	0.5	119.1	18.8	15.9	11.5	10.8	0.9	24.5
Z-Rg	5	10	7.4	11.1	0.07	0.13	47.0	6.6	1.4	2.5	2.2	1.3	7.4
Zda	10	10	7.9	30.8	0.3	0.43	138.4	24.8	10.5	5.9	7.3	1.0	18.9
Zhe			Hebron Granodiorite, no data available										
Rth-Rup			Undifferentiated rocks of the Thole and Piet Retief Suite, no data available										
Rm-Ru	13	17	7.6	10	0.16	0.14	32.4	4.7	2.1	2.0	5.4	0.8	3.9
Rz	85	138	7.2	7.1	0.23	0.14	31	6.8	1.5	1.0	3.0	1.3	2.7
Rbs	1	1	7.6	20	0.4	1.2	90	14	8	1.3	4	1	12
Rsk			Salisbury Kop Granodiorite, no data available										
Rmp			Mpangeni Granite, no data available										
Rm			Mozaan Group, no data available										
Vw			Wolkberg Group, no data available										
Vp	46	68	7.6	16.3	0.1	0.23	64.8	4.5	7.4	3.9	3.6	0.5	10.3
N-Zd	1	1	6.4	23	0.75	0.4	100	13	14	4	4	1	11
Vr	3	5	7.8	37.4	0.12	0.1	239.7	17.1	18.8	7.2	5.3	0.4	35.0
Mle			Lebowa Suite, no data available										
Nti	6	6	8.5	112.2	0.06	0.56	525.5	84.2	80.1	5.0	80.5	1.2	35.2
Pe	65	80	7.3	14.6	0.08	0.22	51.8	9.1	3.1	3.6	2.1	1.5	7.5
Trc	6	9	7.7	214.9	0.34	0.9	335.0	247.5	74.9	76.4	348.4	5.1	91.8
JI	41	59	7.6	91.3	0.09	0.37	160.2	66.1	17.2	7.9	65.3	0.8	18.2
Jd	8	13	6.9	5.0	0.21	0.1	8.2	2.4	1.6	3.2	3.1	0.7	2.2
K-Tu	4	5	8.1	160.0	0.04	0.7	272.0	261.1	11.4	23.7	335.5	4.9	31.4

Note: (Q: Alluvium), (T-Qm: Maputaland G), (Vp: Pretoria G), (C-Pd: Dwyka G), (Pe: Ecça G), (JI: Lebombo G), (Jts: Tshokwane Granophyre), (Vh-Vbl: Undifferentiated Black Reef F and Chuniespoort G), (Zot-Zoo: Undifferentiated Tjakastad Sub G), (Zo-Zd: Undifferentiated Onverwacht G, Fig Tree G and Moodies G), (Zz: Unnamed Swazian rocks), (Ze: Nelspruit S), (Zn: Nsuze G), (Zka: Kaap Valley Granite), (Z-Rg: Various intrusive rocks of the Mozaan G and Nsuze G), (Zda: Dalmein Granite), (Rm-Ru: Undifferentiated rocks of the Mozaan G, Amsterdam F and Usushwana G), (Rz: Unnamed Randian rocks), (Rbs: Boesmanskop Syenite), (Vp: Pretoria G), (N-Zd: Diabase), (Vr: Rustenburg S), (Nti: Timbavati Gabbro), (Pe: Ecça G), (Trc: Clarens F), (JI: Lebombo G), (Jd: Dolerite), (K-Tu: Zululand G).

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 SO ₄ (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	2	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%
T-Qm	8	62.5%	12.5%	25%	0%	87.5%	0%	12.5%	0%	100%	0%	0%	0%
Category B: Fractured aquifers													
Vp	0												
C-Pd	4	100%	0%	0%	0%	75%	0%	25%	0%	100%	0%	0%	0%
Pe	68	7.35%	11.76%	27.94%	52.94%	66.67%	4.76%	15.87%	12.7%	97.06%	0%	0%	2.94%
Jl	27	37.04%	14.81%	37.04%	11.11%	51.85%	0%	14.81%	33.33%	96.3%	0%	3.7%	0%
Category C: Karst aquifers													
Vh-Vbl	23	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Category D: Intergranular and fractured aquifers													
Zr	0												
Zot-Zoo	81	83.95%	3.7%	4.94%	7.41%	54.67%	14.67%	17.33%	13.33%	97.44%	0%	0%	2.56%
Zo-Zd	62	93.55%	1.61%	0%	4.84%	66.13%	4.84%	9.68%	19.35%	100%	0%	0%	0%
Zz	93	83.87%	9.68%	5.38%	1.08%	74.07%	7.41%	9.88%	8.64%	100%	0%	0%	0%
Ze	472	67.58%	23.31%	5.08%	4.03%	72.83%	6.52%	9.57%	11.09%	99.13%	0.87%	0%	0%
Zn	5	100%	0%	0%	0%	60%	20%	20%	0%	100%	0%	0%	0%
Zka	60	100%	0%	0%	0%	55%	5%	5%	35%	98.33%	1.67%	0%	0%
Z-Rg	10	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Zda	10	100%	0%	0%	0%	90%	0%	10%	0%	100%	0%	0%	0%
Zhe	0												
Rth-Rup	0												
Rm-Ru	17	100%	0%	0%	0%	82.35%	5.88%	11.76%	0%	100%	0%	0%	0%

Note: (Q: Alluvium), (T-Qm: Maputaland G), (Vp: Pretoria G), (C-Pd: Dwyka G), (Pe: Ecca G), (Jl: Lebombo G), (Vh-Vbl: Undifferentiated Black Reef F and Chuniespoort G), (Zr: Undifferentiated Barberton Super G), (Zot-Zoo: Undifferentiated Tjakastad Sub G), (Zo-Zd: Undifferentiated Onverwacht G, Fig Tree G and Moodies G), (Zz: Unnamed Swazian rocks), (Ze: Nelspruit S), (Zn: Nsuze G), (Zka: Kaap Valley Granite), (Z-Rg: Various intrusive rocks of the Mozaan G and Nsuze G), (Zda: Dalmein Granite), (Zhe: Hebron Granodiorite), (Rth-Rup: Undifferentiated rocks of the Thole and Piet Retief S), (Rm-Ru: Undifferentiated rocks of the Mozaan G, Amsterdam F and Usushwana C).

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 D: Intergranular and fractured aquifers													
Rz	138	100%	0%	0%	0%	78.26%	7.97%	6.52%	7.25%	100%	0%	0%	0%
Rbs	1	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Rsk	0												
Rmp	0												
Rm	0												
Vw	0												
Vbl	0												
Vp	68	100%	0%	0%	0%	93.75%	4.69%	1.56%	0%	100%	0%	0%	0%
N-Zd	1	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Vr	5	100%	0%	0%	0%	80%	20%	0%	0%	100%	0%	0%	0%
Mle	0												
Nti	6	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Pe	80	97.3%	1.35%	1.35%	0%	94.52%	5.48%	0%	0%	98.68%	0%	0%	1.32%
Trc	9	11.1%	11.1%	11.1%	66.7%	66.67%	0%	0%	33.3%	100%	0%	0%	0%
Jl	59	28.81%	32.3%	30.51%	8.47%	44.1%	1.7%	3.4%	50.9%	96.6%	3.4%	0%	0%
Jts	1	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Jd	13	100%	0%	0%	0%	84.62%	0%	15.38%	0%	100%	0%	0%	0%
K-Tu	4	0%	0%	100%	0%	100%	0%	0%	0%	100%	0%	0%	0%

Note: (Rz: Unnamed Randian rocks), (Rbs: Boesmanskop Syenite), (Rsk: Salisbury Kop Granodiorite), (Rmp: Mpangeni Granite), (Rm: Mozaan G), (Vw: Wolkberg G), (Vbl: Black Reef F), (Vp: Pretoria G), (N-Zd: Diabase), (Vr: Rustenburg S), (Mle: Lebowa S), (Nti: Timbavati Gabbro), (Pe: Eccca G), (Trc: Clarens F), (Jl: Lebombo G), (Jts: Tshokwane Granophyre), (Jd: Dolerite), (K-Tu: Zululand G).

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 (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable
Limit Ranges		80	150	300	>300	25	50	100	>100	30	70	100	>100	100	200	400	>400
Category A: Intergranular aquifers																	
Q	2	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
T-Qm	8	75%	25%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	75%	0%	25%	0%
Category B: Fractured aquifers																	
Vp	0																
C-Pd	4	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Pe	68	41.2%	20.6%	29.4%	8.8%	95.6%	4.4%	0%	0%	14.7%	30.9%	22.1%	32.3%	5.9%	20.6%	27.9%	45.6%
Jl	27	88.9%	3.7%	7.4%	0%	100%	0%	0%	0%	70.4%	22.2%	3.7%	3.7%	40.7%	14.8%	40.7%	3.7%
Category C: Karst aquifers																	
Vh-Vbl	23	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Category D: Intergranular and fractured aquifers																	
Zr	0																
Zot-Zoo	81	88.9%	9.9%	1.2%	0%	100%	0%	0%	0%	28.4%	39.5%	18.5%	13.6%	71.6%	12.4%	13.6%	2.5%
Zo-Zd	62	95.2%	4.8%	0%	0%	100%	0%	0%	0%	35.5%	51.6%	12.9%	0%	93.6%	1.6%	0%	4.8%
Zz	93	96.8%	3.2%	0%	0%	98.9%	1.1%	0%	0%	74.2%	23.7%	2.2%	0%	78.5%	16.1%	4.3%	1.1%
Ze	472	97.7%	1.3%	1%	0%	99.8%	0.2%	0%	0%	65.7%	27.8%	5.3%	1.3%	59.6%	26.7%	9.2%	4.5%
Zn	5	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Zka	60	98.3%	1.7%	0%	0%	100%	0%	0%	0%	66.7%	33.3%	0%	0%	100%	0%	0%	0%
Z-Rg	10	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Zda	10	100%	0%	0%	0%	100%	0%	0%	0%	90%	10%	0%	0%	100%	0%	0%	0%
Zhe	0																
Rth-Rup	0																
Rm-Ru	17	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%

Note: (Q: Alluvium), (T-Qm: Maputaland G), (Vp: Pretoria G), (C-Pd: Dwyka G), (Pe: Ecqa G), (Jl: Lebombo G), (Vh-Vbl: Undifferentiated Black Reef F and Chuniespoort G), (Zr: Undifferentiated Barberton Super G), (Zot-Zoo: Undifferentiated Tjakastad Sub G), (Zo-Zd: Undifferentiated Onverwacht G, Fig Tree G and Moodies G), (Zz: Unnamed Swazian rocks), (Ze: Nelspruit S), (Zn: Nsuze G), (Zka: Kaap Valley Granite), (Z-Rg: Various intrusive rocks of the Mozaan G and Nsuze G), (Zda: Dalmein Granite), (Zhe: Hebron Granodiorite), (Rth-Rup: Undifferentiated rocks of the Thole and Piet Retief S), (Rm-Ru: Undifferentiated rocks of the Mozaan G, Amsterdam F and Usushwana C).

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 (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable	Class 0 (Ideal)	Class I (Acceptable)	Class II (Max Allowed)	Un-acceptable
Limit Ranges		80	150	300	>300	25	50	100	>100	30	70	100	>100	100	200	400	>400
Category D: Intergranular and fractured aquifers																	
Rz	138	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	98.6%	1.4%	0%	0%
Rbs	1	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Rsk	0																
Rmp	0																
Rm	0																
Vw	0																
Vbl	0																
Vp	68	100%	0%	0%	0%	100%	0%	0%	0%	90.9%	9.1%	0%	0%	100%	0%	0%	0%
N-Zd	1	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Vr	5	80%	20%	0%	0%	100%	0%	0%	0%	60%	40%	0%	0%	100%	0%	0%	0%
Mle	0																
Nti	6	100%	0%	0%	0%	100%	0%	0%	0%	0%	0%	100%	0%	33.3%	66.7%	0%	0%
Pe	80	98.7%	0%	1.3%	0%	100%	0%	0%	0%	96.1%	3.9%	0%	0%	97.4%	2.6%	0%	0%
Trc	9	33.3%	55.6%	11.1%	0%	100%	0%	0%	0%	0%	33.3%	11.1%	55.6%	22.2%	0%	22.2%	55.6%
Jl	59	49.1%	45.8%	5.1%	0%	100%	0%	0%	0%	27.1%	40.7%	28.8%	3.4%	32.2%	45.8%	15.2%	6.8%
Jts	1	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Jd	13	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
K-Tu	4	100%	0%	0%	0%	100%	0%	0%	0%	75%	25%	0%	0%	0%	25%	50%	25%

Note: (Rz: Unnamed Randian rocks), (Rbs: Boesmanskop Syenite), (Rsk: Salisbury Kop Granodiorite), (Rmp: Mpangeni Granite), (Rm: Mozaan G), (Vw: Wolkberg G), (Vbl: Black Reef F), (Vp: Pretoria G), (N-Zd: Diabase), (Vr: Rustenburg S), (Mle: Lebowa S), (Nti: Timbavati Gabbro), (Pe: Eccca G), (Trc: Clarens F), (Jl: Lebombo G), (Jts: Tshokwane Granophyre), (Jd: Dolerite), (K-Tu: Zululand G).

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	2	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%
T-Qm	8	62.5%	12.5%	25%	0%	0%	100%	0%	0%	100%	0%	0%	0%
Category B: Fractured aquifers													
Vp	0												
C-Pd	4	100%	0%	0%	0%	0%	100%	0%	0%	75%	25%	0%	0%
Pe	68	4.4%	25%	35.3%	35.3%	0%	100%	0%	0%	58.8%	19.1%	7.4%	14.7%
Jl	27	100%	0%	0%	0%	0%	100%	0%	0%	92.3%	7.7%	0%	0%
Category C: Karst aquifers													
Vh-Vbl	23	100%	0%	0%	0%	0%	100%	0%	0%	95%	5%	0%	0%
Category D: Intergranular and fractured aquifers													
Zr	0												
Zot-Zoo	81	42%	40.7%	14.8%	2.5%	0.8%	100%	0%	0%	83.3%	11.5%	3.9%	1.3%
Zo-Zd	62	58%	37%	5%	0%	0%	100%	0%	0%	91.9%	8.1%	0%	0%
Zz	93	76.3%	16.1%	7.5%	0%	1.5%	98.5%	0%	0%	46.6%	19.7%	13.8%	19.9%
Ze	472	55.9%	35%	6.6%	2.5%	0%	100%	0%	0%	33.3%	33.3%	0%	33.3%
Zn	5	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%
Zka	60	90%	10%	0%	0%	0%	100%	0%	0%	61.7%	33.3%	5%	0%
Z-Rg	10	100%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%
Zda	10	100%	0%	0%	0%	0%	100%	0%	0%	60%	10%	30%	0%
Zhe	0												
Rth-Rup	0												
Rm-Ru	17	94.1%	0%	5.9%	0%	0%	88.2%	11.8%	0%	81.3%	6.2%	0%	12.5%

Note: (Q: Alluvium), (T-Qm: Maputaland G), (Vp: Pretoria G), (C-Pd: Dwyka G), (Pe: Eccca G), (Jl: Lebombo G), (Vh-Vbl: Undifferentiated Black Reef F and Chuniespoort G), (Zr: Undifferentiated Barberton Super G), (Zot-Zoo: Undifferentiated Tjakastad Sub G), (Zo-Zd: Undifferentiated Onverwacht G, Fig Tree G and Moodies G), (Zz: Unnamed Swazian rocks), (Ze: Nelspruit S), (Zn: Nsuze G), (Zka: Kaap Valley Granite), (Z-Rg: Various intrusive rocks of the Mozaan G and Nsuze G), (Zda: Dalmein Granite), (Zhe: Hebron Granodiorite), (Rth-Rup: Undifferentiated rocks of the Thole and Piet Retief S), (Rm-Ru: Undifferentiated rocks of the Mozaan G, Amsterdam F and Usushwana C).

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
Limits Ranges		70	150	370	>370	4.0 -5.9	6.0-9.0	9.1 - 10.0	>10 & <4	0.7	1	1.5	>1.5
Category D: Intergranular and fractured aquifers													
Rz	138	100%	0%	0%	0%	4.3%	95.7%	0%	0%	89.9%	7.2%	2.9%	0%
Rbs	1	100%	0%	0%	0%	100%	0%	0%	0%	0%	0%	100%	0%
Rsk	0												
Rmp	0												
Rm	0												
Vw	0												
Vbl	0												
Vp	68	98.5%	1.5%	0%	0%	0%	100%	0%	0%	88%	9%	0%	3%
N-Zd	1	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Vr	5	80%	20%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%
Mle	0												
Nti	6	0%	100%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%
Pe	80	93.8%	6.2%	0%	0%	2.5%	97.5%	0%	0%	83.1%	9.1%	3.9%	3.9%
Trc	9	0%	22.2%	33.3%	44.5%	0%	100%	0%	0%	11.1%	44.5%	44.4%	0%
Jl	59	25.2%	39%	40.7%	5.1%	0%	100%	0%	0%	62.7%	22%	8.5%	6.8%
Jts	1	100%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%
Jd	13	100%	0%	0%	0%	0%	100%	0%	0%	92.3%	7.7%	0%	0%
K-Tu	4	0%	50%	50%	0%	0%	100%	0%	0%	25%	50%	25%	0%

Note: (Rz: Unnamed Randian rocks), (Rbs: Boesmanskop Syenite), (Rsk: Salisbury Kop Granodiorite), (Rmp: Mpangeni Granite), (Rm: Mozaan G), (Vw: Wolkberg G), (Vbl: Black Reef F), (Vp: Pretoria G), (N-Zd: Diabase), (Vr: Rustenburg S), (Mle: Lebowa S), (Nti: Timbavati Gabbro), (Pe: Eccca G), (Trc: Clarens F), (Jl: Lebombo G), (Jts: Tshokwane Granophyre), (Jd: Dolerite), (K-Tu: Zululand G).

3. HYDROGEOLOGY OF THE DIFFERENT GEOLOGICAL UNITS

3.1 Characteristics and description of the hydrogeological units

In this chapter the characteristics of the various hydrogeological units are briefly described in terms of their geographical location, lithology, general use, quality, quantity, results of previous research and its importance as groundwater aquifers. Available data for each unit was statistically analysed and presented in a pre-described format as required for the hydrogeological map series. Quantity and quality for each unit are presented as borehole yield frequency and stiff diagrams. Table 10, p43 summarizes statistics for each unit obtained from the various yield frequency diagrams.

3.2 Aquifers

An aquifer can be defined as “a stratum which contains intergranular interstices, or a fissure/fracture or a system of interconnected fissures/fractures capable of transmitting groundwater rapidly enough to directly supply a borehole or a spring” (Vegter, 2001).

For the purposes of the 1:500 000 hydrogeological map series aquifers are divided into four types namely:

- Intergranular
- Fractured
- Fractured and intergranular
- Karst

3.3 Aquifer classes and Yields

Relatively small areas of Karst and Intergranular aquifers occur on the map sheet. The intergranular aquifers are consisting mainly of alluvium. The most prevalent aquifer type (*Figure 33, p66*) is the Intergranular and Fractured type with the intergranular part the result of extensive chemical weathering of the relatively flat areas of Pre-Cambrian rocks. The fractured part is mainly of secondary origin due to geological events after the formation of the rock which relates to geological lineaments, stress release, etc. It is therefore not surprising that much of the Fractured only aquifer type is found in the Drakensberg and Lebombo Mountains, whose higher relief is related to its resistance to weathering.

Table 10: Summary yield frequency analysis for each unit.

Aquifer Unit	Unit extent as % of map area	Total number wet boreholes	80 Percentile (l/s)	Max yield (l/s)	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	1.04%	43	3.78	7.57	2.3%	18.6%	51.2%	14%	14%
T-Qm	2.54%	239	239		13%	31%	38.9%	12.1%	5.1%
Category B: Fractured aquifers									
Vbl	0.04%	No data							
Vp	0.94%	29	1.99	5.1	13.8%	27.6%	37.9%	13.8%	6.9%
C-Pd	0.48%	12	1.42	3.78	0%	33.3%	50%	16.7%	0%
Pe	1.35%	51	5	18	0%	27.5%	35.2%	15.7%	21.6%
Jl	1.38%	38	0.81	25	34.2%	34.2%	21.1%	5.3%	5.3%
Jts	0.11%	2	0.75	0.91	50%	0%	50%	0%	0%
Category C: Karst aquifers									
Vh-Vbl	2.52%	31	3	35	6.5%	22.6%	29%	19.4%	22.6%
Category D: Intergranular and Fractured aquifers									
Zr	0.17%	4	4.19	5.05	0%	25%	50%	0%	25%
Zot-Zoo	7.75%	124	5.5	38	16.1%	13.7%	20.2%	26.6%	23.4%
Zo-Zd	4.88%	59	3.5	27.2	13.6%	28.8%	28.8%	15.3%	13.6%
Zz	4.62%	142	1.6	20.5	28.2%	27.5%	33.1%	10.6%	0.7%
Ze	16.99%	749	1.7	35	19.1%	30.4%	32.8%	11.5%	6.1%
Zn	0.64%	13	1.4	3.6	15.4%	7.7%	53.8%	23.1%	0%
Zka	2.42%	120	2.53	15	11.7%	25.8%	32.5%	19.2%	10.8%
Z-Rg	3.09%	21	1.6	5.89	9.5%	23.8%	42.9%	19%	4.8%
Zda	0.21%	9	0.45	1.7	11.1%	66.7%	22.2%	0%	0%
Zhe	0.21%	No data							
Rth-Rup	0.07%	No data							
Rm-Ru	1.55%	34	2.13	3.84	5.9%	29.4%	41.2%	23.5%	0%
Rz	5.96%	197	1	6	26.9%	43.1%	21.8%	7.6%	0.5%
Rbs	0.09%	2	1.6	1.6			100%		
Rsk	0.42%	12	4.4	8	8.3%	41.7%	25%	8.3%	16.7%
Rmp	0.08%	1	0.27	0.27		100%			
Rm	0.03%	1	0.1	0.1	100%				
Vw	0.01%	6	2.25	2.71	16.7%	0%	33.3%	50%	0%
Vp	17.54%	207	2.13	35	6.8%	27.1%	44%	20.8%	1.4%
N-Zd	0.39%	3	5.95	10	0%	0%	66.7%	0%	33.3%
Vr	1.45%	11	3.65	10	0%	9.1%	54.5%	27.3%	9.1%
Mle	0.01%	No data							
Nti	0.40%	8	2.5	6	25%	12.5%	37.5%	12.5%	12.5%
Pe	13.92	169	2	7.99	20.7%	28.4%	33.1%	14.8%	3%
Trc	0.30%	5	3.95	7.1	0%	60%	20%	0%	20%
Jl	3.61%	157	4.64	30	21%	21.7%	23.6%	15.3%	18.5%
Jd	2.02%	21	1.8	3.33	9.5%	47.6%	33.3%	9.5%	0%
K-Tu	0.76%	112			58%	15.2%	23.2%	3.6%	0%
Total	99.9%	2632							

Note: (Q: Alluvium), (T-Qm: Maputaland G), (Vbl: Black Reef F), (Vp: Pretoria G), (C-Pd: Dwyka G), (Pe: Eccca G), (Jl: Lebombo G), (Jts: Tshokwane Granophyre), (Vh-Vbl: Undifferentiated Black Reef F and Chuniespoort G), (Zr: Undifferentiated Barberton Super G), (Zot-Zoo: Undifferentiated Tjakastad Sub G), (Zo-Zd: Undifferentiated Onverwacht G, Fig Tree G and Moodies G), (Zz: Unnamed Swazian rocks), (Ze: Nelspruit S), (Zn: Nsuze G), (Zka: Kaap Valley Granite), (Z-Rg: Various intrusive rocks of the Mozaan G and Nsuze G), (Zda: Dalmein Granite), (Zhe: Hebron Granodiorite), (Rth-Rup: Undifferentiated rocks of the Thole and Piet Retief Suite), (Rm-Ru: Undifferentiated rocks of the Mozaan G, Amsterdam F and Usushwana G), (Rz: Unnamed Randian rocks), (Rbs: Boesmanskop Syenite), (Rsk: Salisbury Kop Granodiorite), (Rmp: Mpangeni Granite), (Rm: Mozaan G), (Vw: Wolkberg G), (Vp: Pretoria G), (N-Zd: Diabase), (Vr: Rustenburg S), (Mle: Lebowa S), (Nti: Timbavati Gabbro), (Pe: Eccca G), (Trc: Clarens F), (Jl: Lebombo G), (Jd: Dolerite), (K-Tu: Zululand G).

3.3.1 Intergranular Aquifers

Intergranular describes aquifers in which groundwater occurs in openings between granules and grains of unconsolidated material such as sand and gravel. Such openings can either be of a primary or secondary nature. Primary openings refer to the voids left during the deposition of the material. The “intergranular” aquifers on the map refer to this type and are primarily comprised of alluvium. The capacity of intergranular aquifers to store or yield water is influenced by factors such as grain size, roundness of grains, ratio of different grain sizes, clay content and the density of compaction. The greatest restricting factors on intergranular aquifers within the map area are considerable clay content and limited recharge. The geographical distribution of the intergranular aquifers is shown in Figure 8, p44.

The Intergranular aquifers cover approximately 3.58% of the total map area and are made up of the following hydrogeological units.

- Alluvium (Q), p44
- Maputaland Group (T-Qm), p47

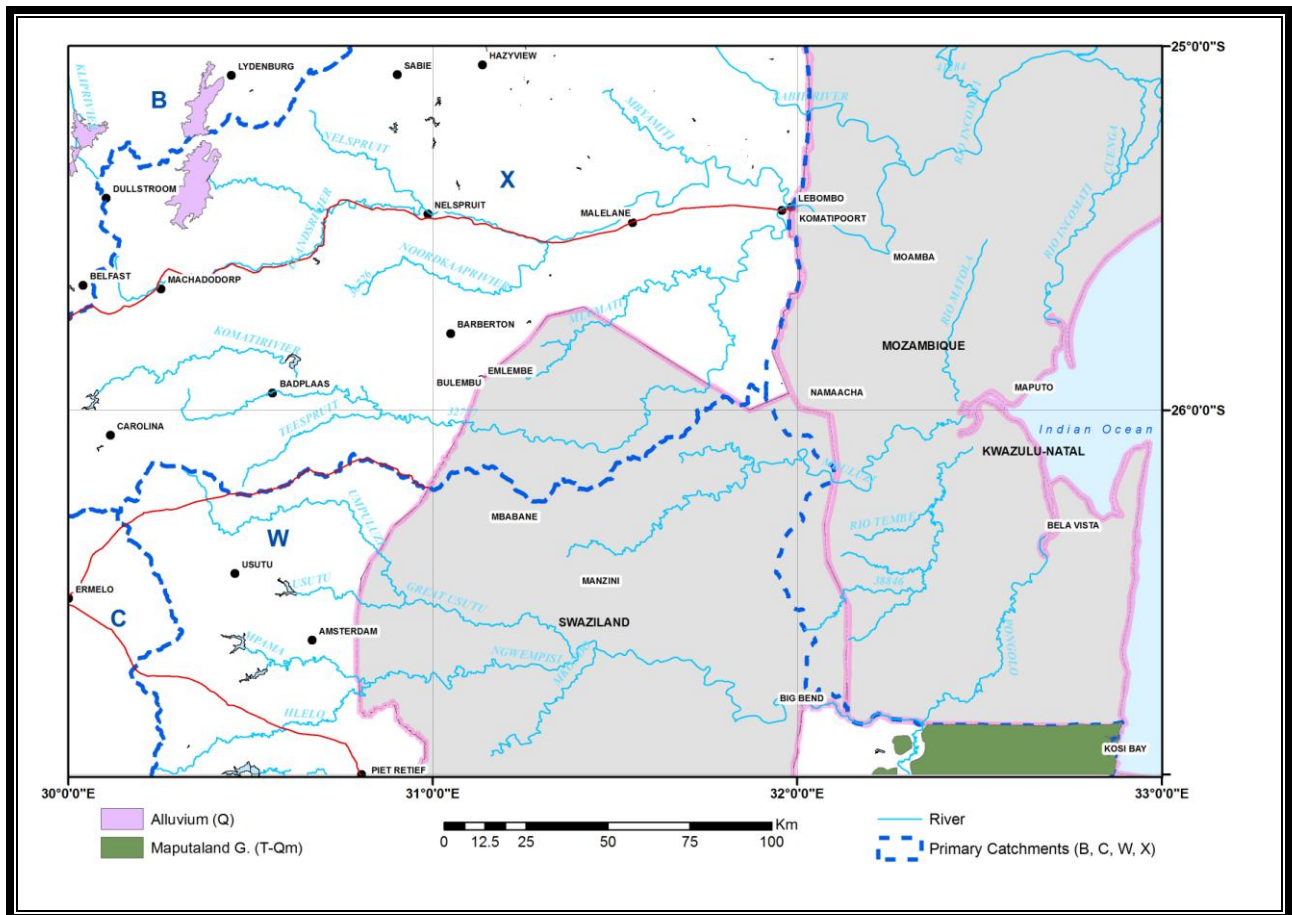


Figure 8: Geographical distribution of the Intergranular aquifers.

3.3.1.1 Alluvial deposits (Q)

This unit represents alluvial as well as colluvium deposits. Although alluvial deposits of variable lateral extent and thickness are found along most of the streams in the map area it was not included as part of the unit due to map scale and importance. Alluvial deposits relate to the upstream regional geology and the sorting, grain size distribution and the extent of the deposit is influenced by the flow of the river. 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. In the areas underlain by granitoid and gneissic rocks the alluvial deposits consists mostly of sand and pebbles.

Prominent scree deposits and very thick alluvial fans adjoin the Drakensberg escarpment. These deposits vary from very coarse and conglomeratic to fine grained and clayey (Walraven, 1989). The unit as depicted on the map sheet occurs in three areas within the north-western part of the map near Lydenburg, where it overlies rocks of the Pretoria Group (Vp), (Figure 9, p45).

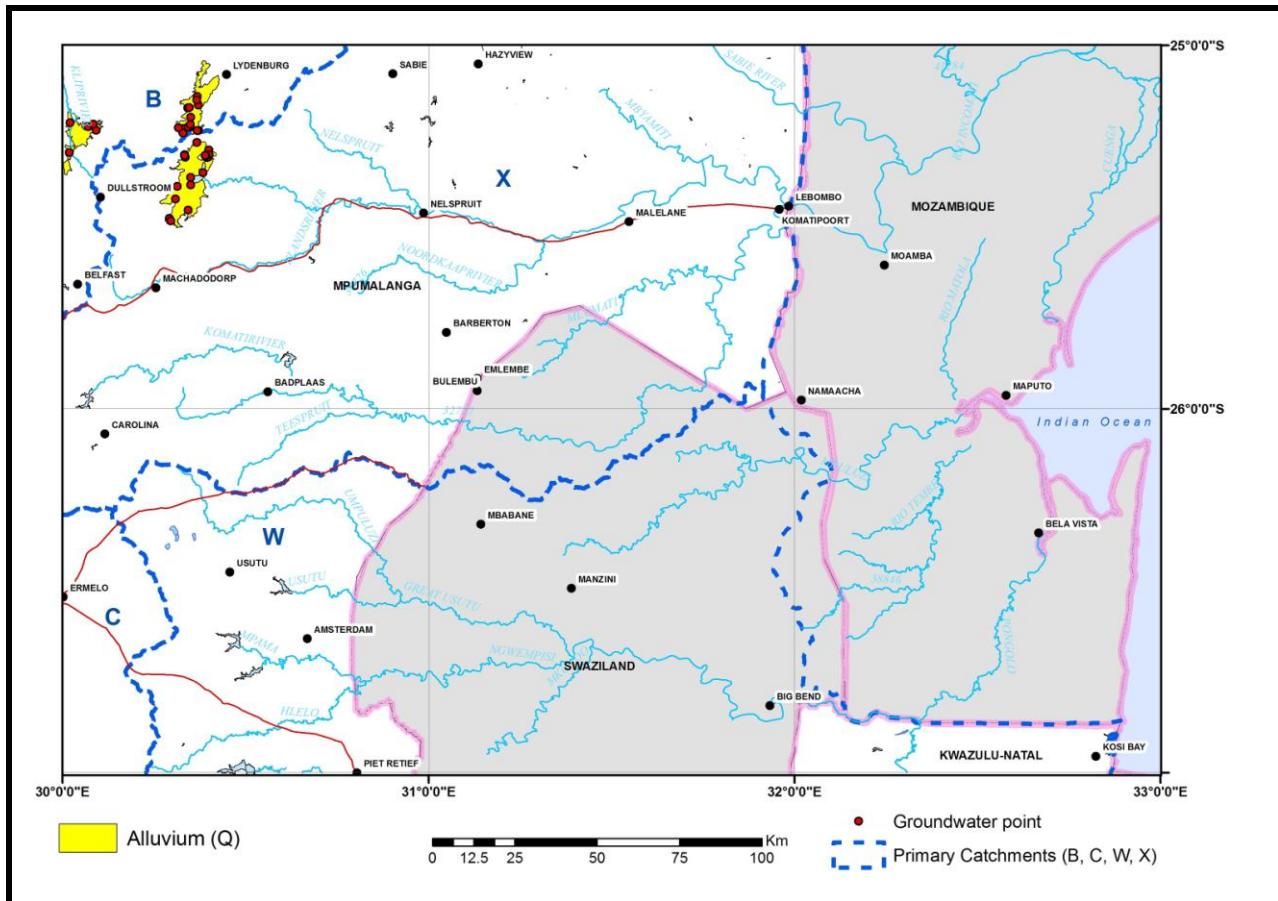


Figure 9: Geographical distribution of the Alluvium deposits (Q) and associated sampling points.

Figure 10, p46 represents the yield frequency diagram for the unit using yield data of 43 data points. Most of the maximum yields are within the range 0.5-2l/s (51.2%) with 28% of the yields higher than 2l/s. The boreholes with the highest maximum yields are located within low lying areas near streams. The alluvial consists of boulders, sand and clay with reported depths up to 15m. The development of groundwater sources is challenging and expensive as drilling conditions can be very difficult, requiring the use of the Odex drilling method. From the available data a relationship between strong boreholes and lineaments underlying the alluvium could not be established. From a hydrogeological perspective the ultimate targets in the area will be deep alluvial deposits near streams (recharged areas) underlain by lineaments. A scientific approach using remote sensing techniques followed by ground geophysical methods is recommended for source development.

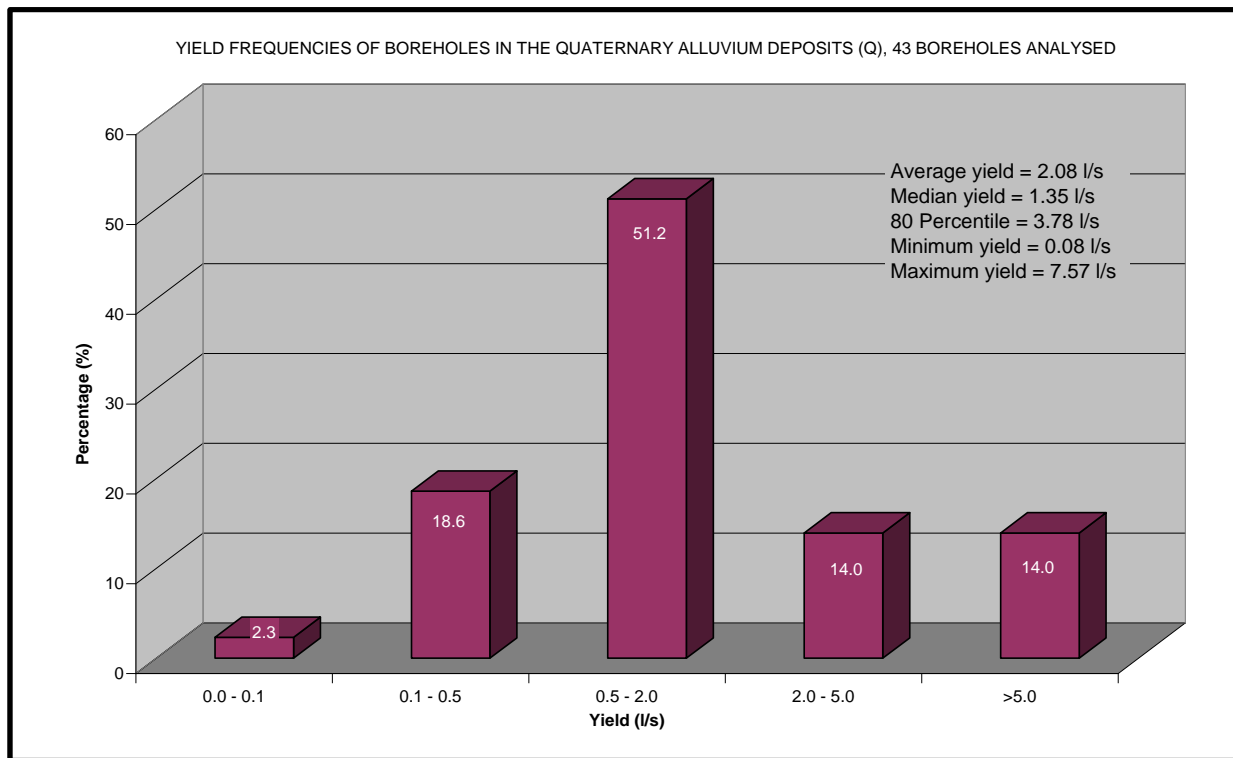


Figure 10: Yield frequency of boreholes in the alluvium deposits (Q).

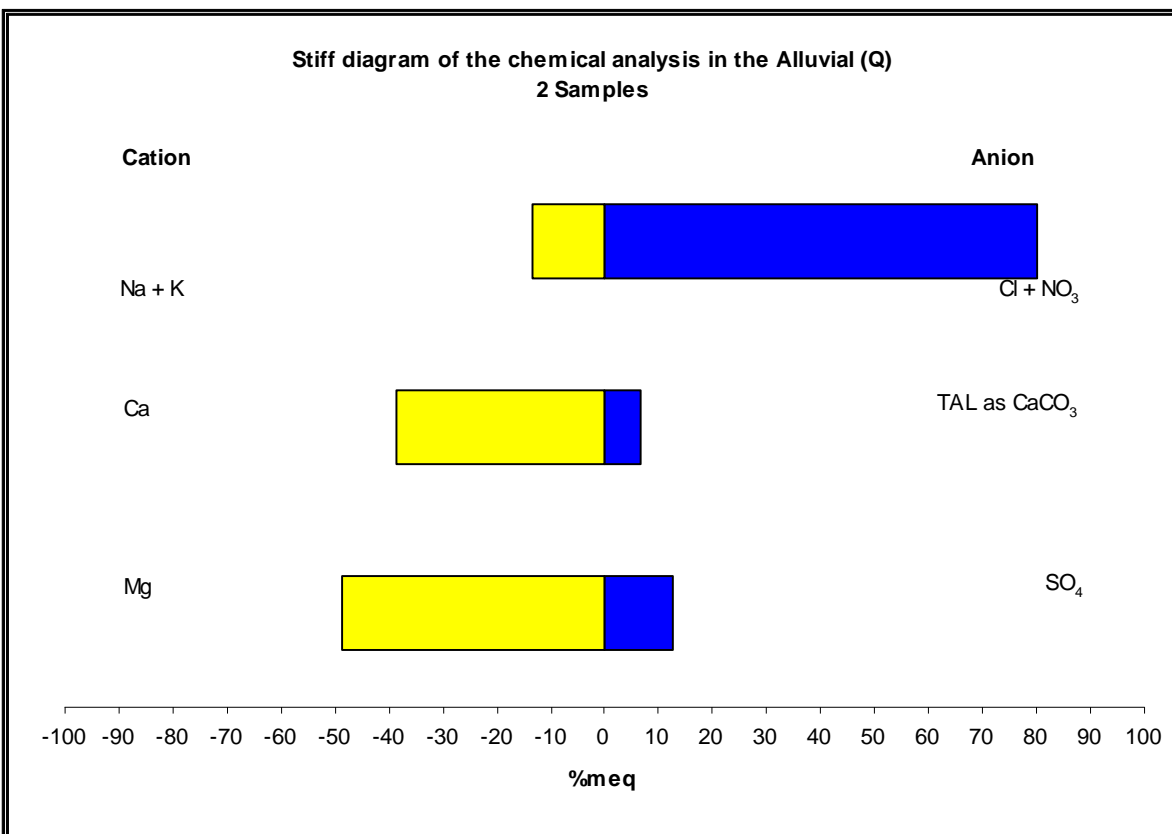


Figure 11: Stiff diagram representing chemistry for aquifers of the alluvium deposits (Q).

Figure 11, p46 represents the plot of the dominant anions and cations for the unit. Only two chemical analyses were available for analysis. Both were classified as dominantly calcium-

magnesium-chloride waters, indicating a water type related to reverse ion exchange (replacement of Na^+ with Ca^{2+} and Mg^{2+}); these samples failed the ionic balance for quality of data.

3.3.1.2 Maputaland Group (T-Qm)

This hydrogeological unit underlay the coastal flats of KwaZulu-Natal in the south-eastern section of the map sheet. Formations included in this hydrogeological unit are the Uloa Formation consisting of a thin layer of ferruginous gravelly claystone at the base followed by a bed of soft shell limestone and calcareous sandstone at the top with a total formation thickness of approximately 30m (King, 1953); the Bluff Sandstone Formation comprising of coastal and off-shore dune cordons of calcarenite and an inland bed of coral limestone with a total estimated thickness up to 180m (Krige, 1933); the Berea Formation comprising inland dune cordons usually composed of red decalcified sands (Davies, 1976); the Port Dunford Formation consisting of poorly consolidated sand, silt, clay and lignite containing marine molluscs and non-marine mammalian bones with a thickness of approximately 30m (Anderson, 1907) and the Muzi Formation consisting of mottled brown argillaceous sand with a total thickness of less than 50m (Du Preez, 1987).

Limited chemical analyses and no yield data was available for the unit within the map area. The description for the unit was obtained from the adjacent hydrogeological map sheet, 2730 Vryheid. It was reported that the static groundwater levels are generally shallow (swl < 10m) in low lying areas and that 50% of the sources have static water levels of less than 15mbgl. It concludes that the likelihood of drilling a successful borehole is very good, usually greater than 95%. It found that the Uloa Formation is the highest yielding aquifer in the unit with reported maximum yields up to 15l/s, but that its intermittent occurrence prevents extensive development. It states that the behaviour of this formation is similar to that of a dolomitic aquifer due to the carbonate content and that it has been classified as intergranular due to the presence of overlying sand, which provides storage for the secondary fractures. It reports that the water quality is usually ideal to acceptable ($\text{EC} < 100\text{mS/m}$) with lower EC values along the eastern parts of the coastal plain which can be attributed to the higher rainfall.

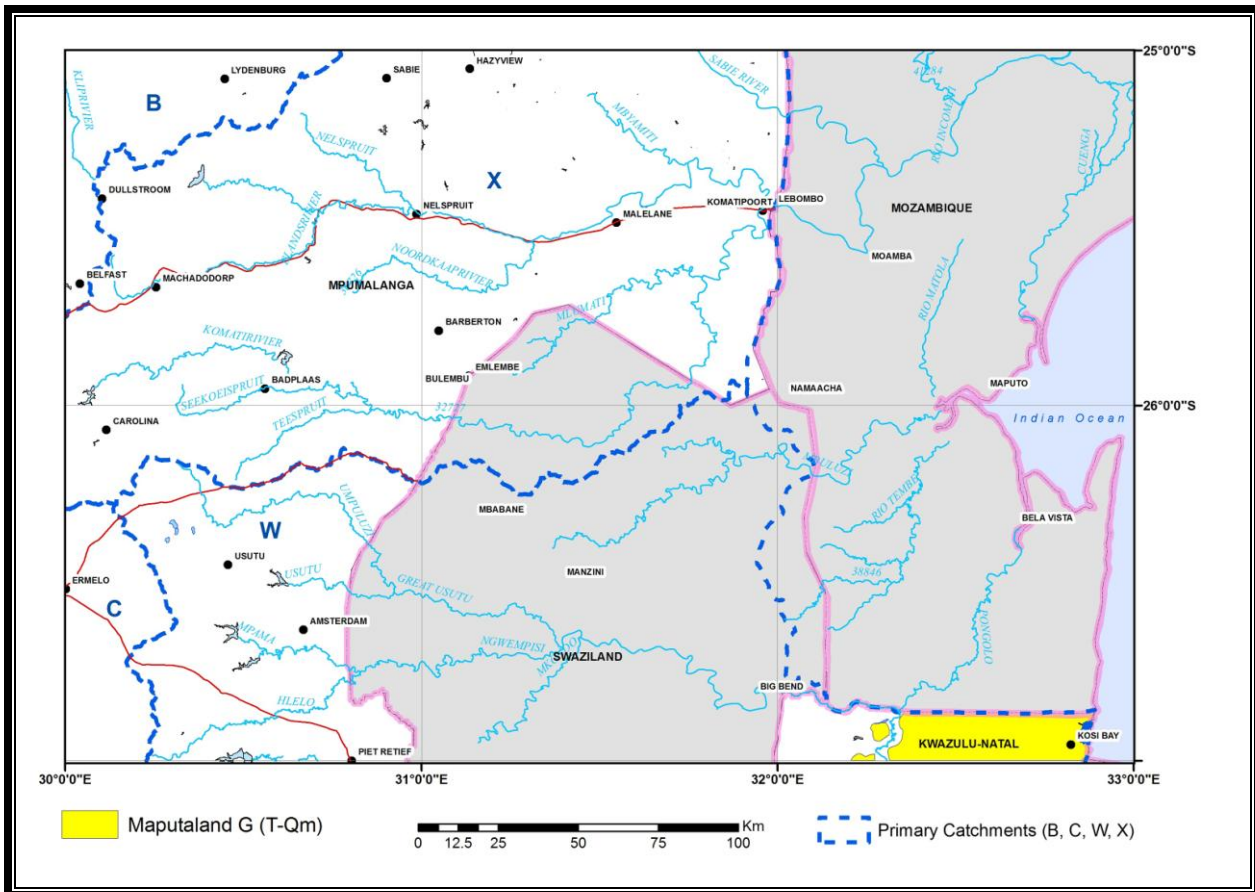


Figure 12: Geographical distribution of the Maputaland Group (T-Qm) and associated sampling points.

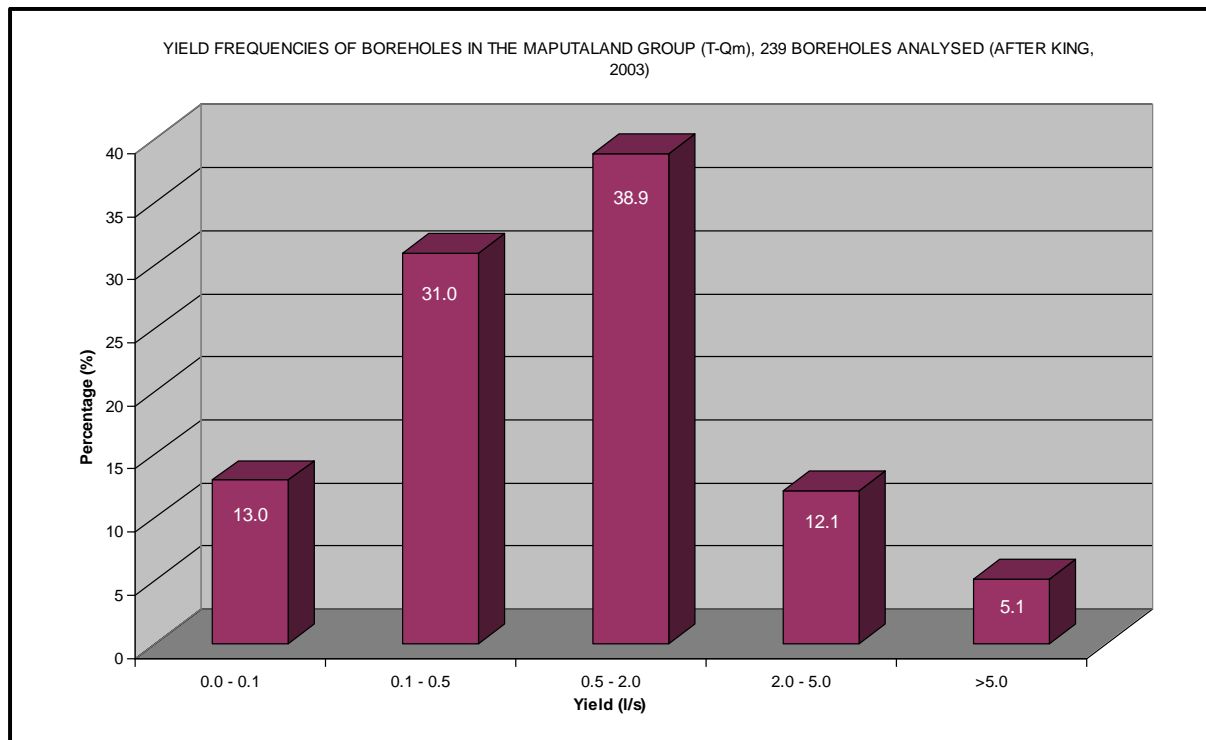


Figure 13: Yield frequency of boreholes in the Maputaland Group (T-Qm) after King, 2003.

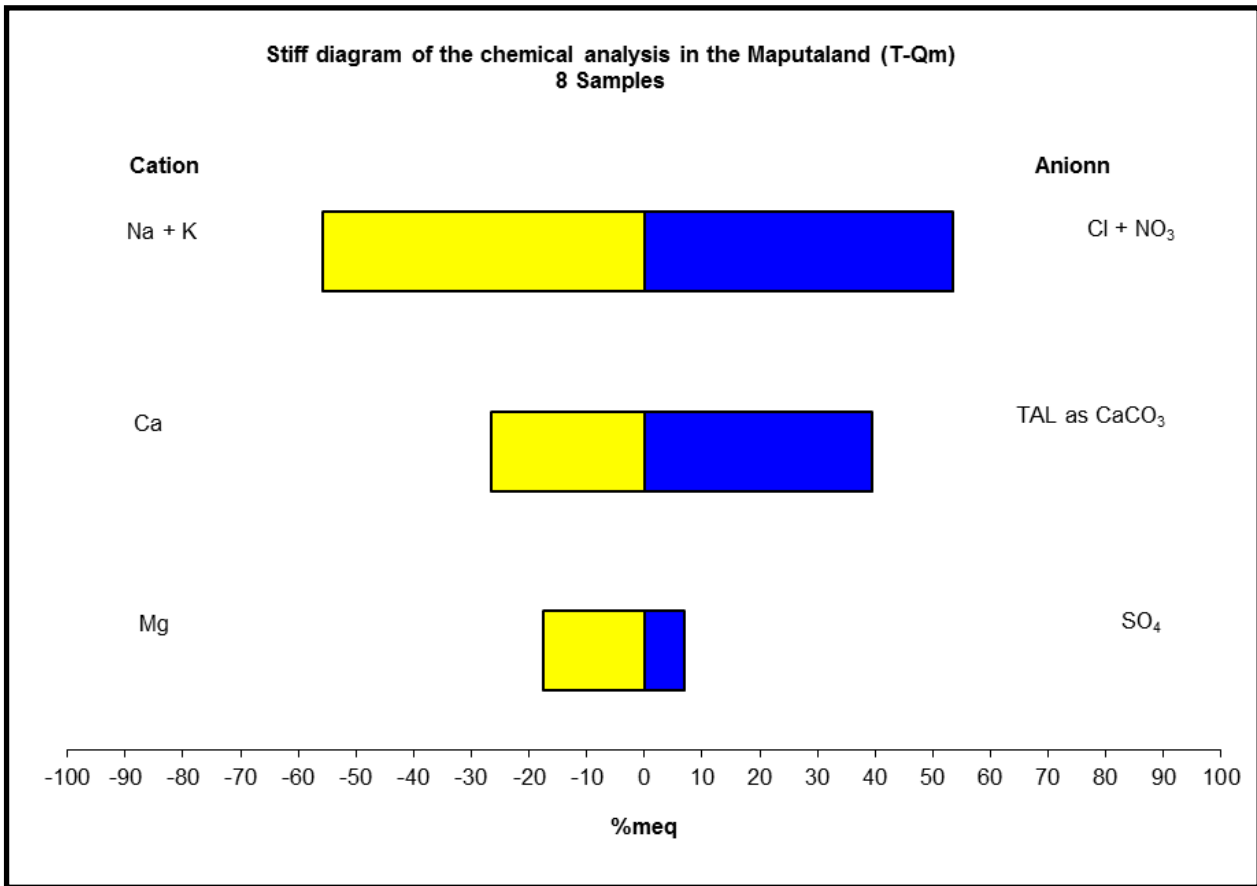


Figure 14: Stiff diagram representing chemistry for aquifers of the Maputaland Group (T-Qm).

3.3.2 Fractured Aquifers

Over geological time, rocks are subjected to forces largely related to gravity and the movement of large rock masses in the crust and upper mantle. With applied force, a set of stresses is produced. The action of an applied stress field will result in deformation (change in size and shape) of a body. Strain is the geometrical expression of the amount of deformation which is a function of type of material, temperature, pressure, fluids, period exposed to stress etc. In rock a combination of elastic and viscous strain exists when forces are applied. When elastic deformation leads to failure, the material loses cohesion by the development of a **fracture or fractures** across which the continuity of the material is broken. It is called brittle behaviour and leads to the development of **faults and joints** (Park, 1983).

When essentially no primary pore spaces exist and the water is stored in fractures, joints, bedding planes and cavities within the solid rock mass, the aquifer is called fractured or secondary. Fractured aquifers are found in sedimentary, igneous, and metamorphic rocks.

The fractured aquifers cover approximately 4.26% of the total map area and are made up of the following hydrogeological units.

- Black Reef Formation (Vbl), p51
- Pretoria Group (Vp), p51
- Dwyka Group (C-Pd), p53
- Eccca Group (Pe), p55
- Lebombo Group (Jl), p57
- Tshokwane Granophyre (Jts),60

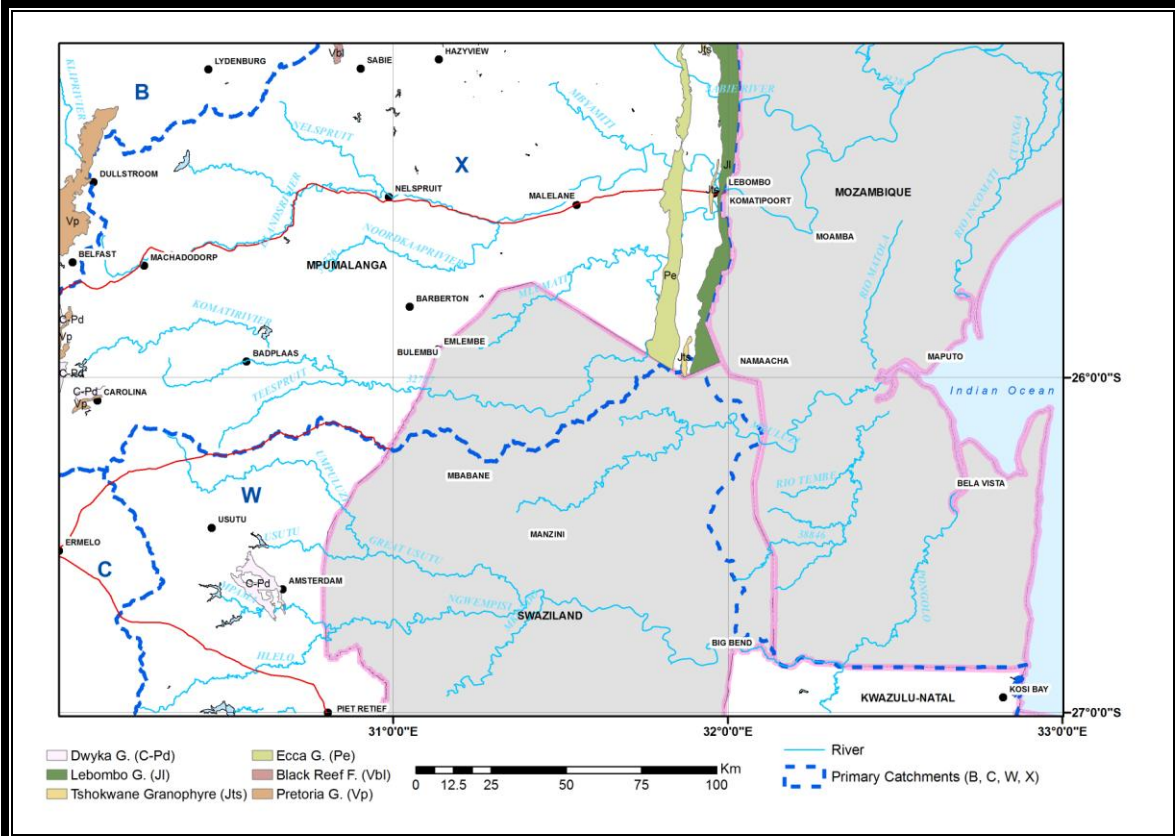


Figure 15: Geographical distribution of the fractured aquifers.

3.3.2.1 Black Reef Formation (Vbl)

This unit occurs at a single location in the northern part of the map near Sabie. The unit should not be confused with the predominantly resistant quartzite formation that occurs continuously along the length of the Drakensberg Escarpment. The unit shown on the hydrogeological map corresponds with the occurrence of the upper and lower members of the Wolkberg Group exclusive of the rocks of the Godwan Formation. The maximum thickness of the unit is less than 50m. It consists of two shale members separated by feldspathic quartzite with lava in the lower part of the unit.

Inadequate data prevented the proper analysis of the yield and quality characteristics of the unit.

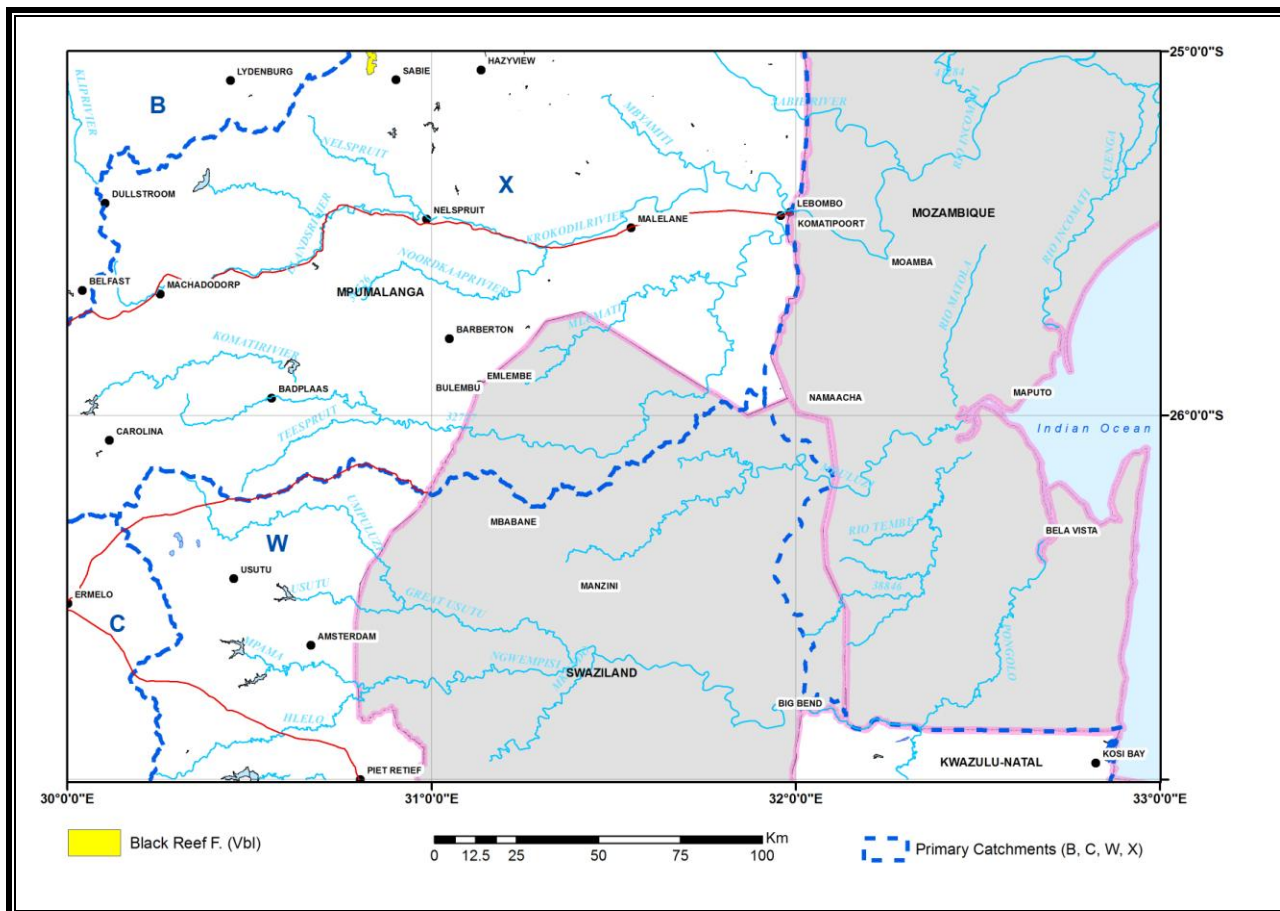


Figure 16: Geographical distribution of the fractured aquifers of the Black Reef Formation (Vbl).

3.3.2.2 Pretoria Group (Vp), fractured aquifers

Consisting predominantly of arenaceous sedimentary rocks of the Steenkampsberg Formation, the fractured aquifers of the Pretoria Group occur in a narrow south to north band in the north-western part of the map sheet. The rock is predominantly a clean, medium- to fine-grained, cross-bedded quartzite with interlayers of purple-weathering arsenate, shale and thin conglomerate layers (Walraven, 1986). Rocks of the Pretoria Group with fractured aquifer characteristics cover a tiny portion of the map area (0.94%), with the bulk of the Group being classified as intergranular and fractured (17.54%) as discussed in section 3.3.4.19, p100.

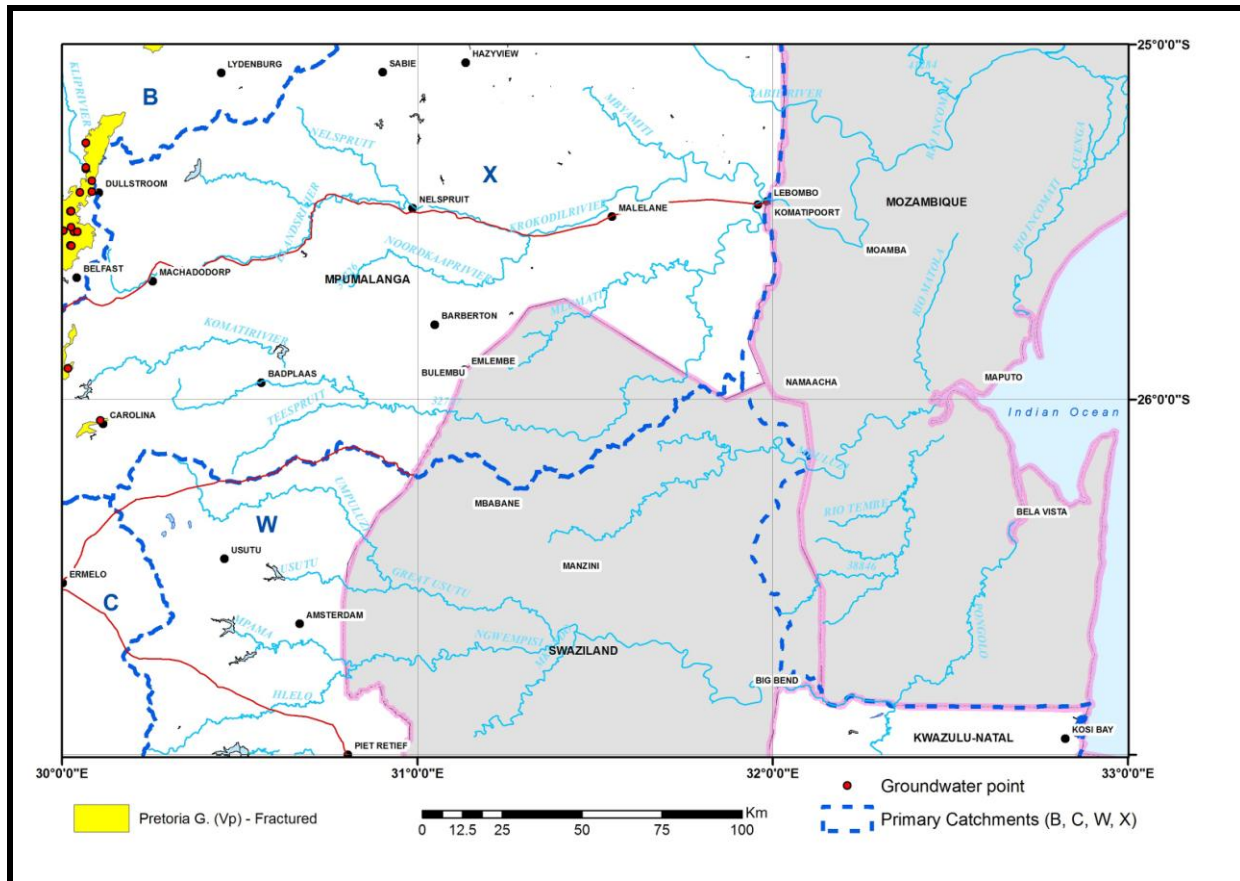


Figure 17: Geographical distribution of the fractured aquifers of the Pretoria Group (Vp) and associated sampling points.

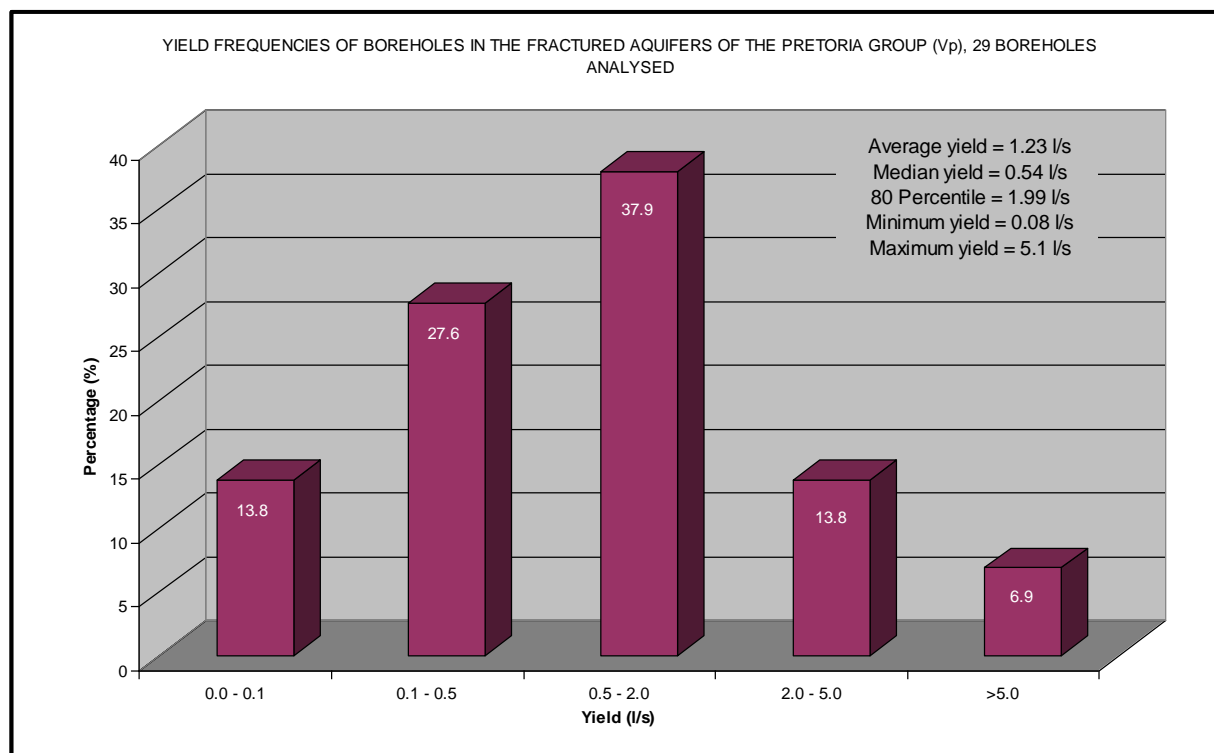


Figure 18: Yield frequency of boreholes in the fractured aquifers of the Pretoria Group (Vp).

The yield diagram (*Figure 18*, p52) for the fractured aquifers of the Pretoria Group was compiled using 29 data points. Of the total data points 37.9% have maximum yields ranging between 0.5-2l/s, 20.4% yield more than 2l/s with the remaining 41.4% yielding less than 2l/s. Most of the information is old NGDB data with borehole positions defaulted to the centre of the cadastral farm. The higher yielding boreholes can thus not be linked to any geological lineaments. Fractured zones within the quartzite will be the main targets in the unit followed by secondary fractures related to intrusive diabase dykes and sills. No water strike depths or borehole depths were available for analysis. From a hydrogeological perspective quartzite can be explored to feasible depths of 150m as there will always be a small chance of striking water with increasing depth ($\pm 10\%$), (Vegter, 1995). No chemical data was available for analysis.

3.3.2.3 Dwyka Group (C-Pd)

The Dwyka Group consists predominantly of diamictite and represents the oldest sedimentary deposit of the Karoo Supergroup. Exposure on the map sheet is poor, where observed it consists of pebbles and boulders in a groundmass of yellowish-green, argillaceous material and quartz grains (Walraven, 1989). Within the boundaries of the map, the unit is represented in four small areas, around Amsterdam and Carolina and north-west of Carolina. The small geographical extent (0.48%) and massive character of the rock makes the unit an insignificant aquifer.

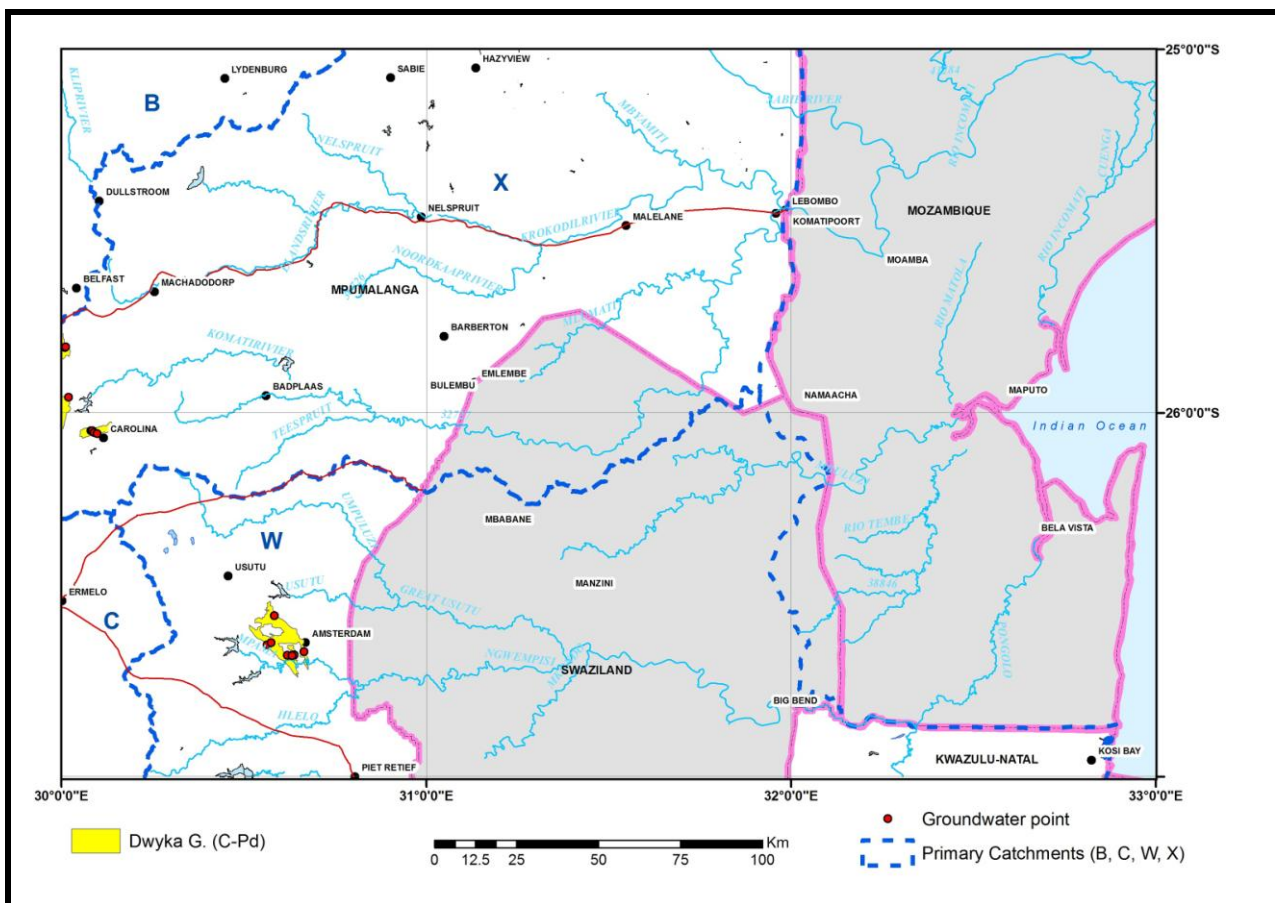


Figure 19: Geographical distribution of the Dwyka Group (C-Pd) and associated sampling points.

The yield diagram *Figure 20*, p54 represents the maximum yield data of 12 sample points. Eighty three percent of the yields are less than 2l/s. The coordinates of the available data points is not accurate as the positions are defaulted to the centre of the cadastral farms. The data is predominantly from the NGDB. The thickness of the unit is not known. The depths of 8 boreholes

are known, the average depth is 53m and the deepest hole listed is 66m. Drilling targets in the unit will be deep weathered and fractured zones.

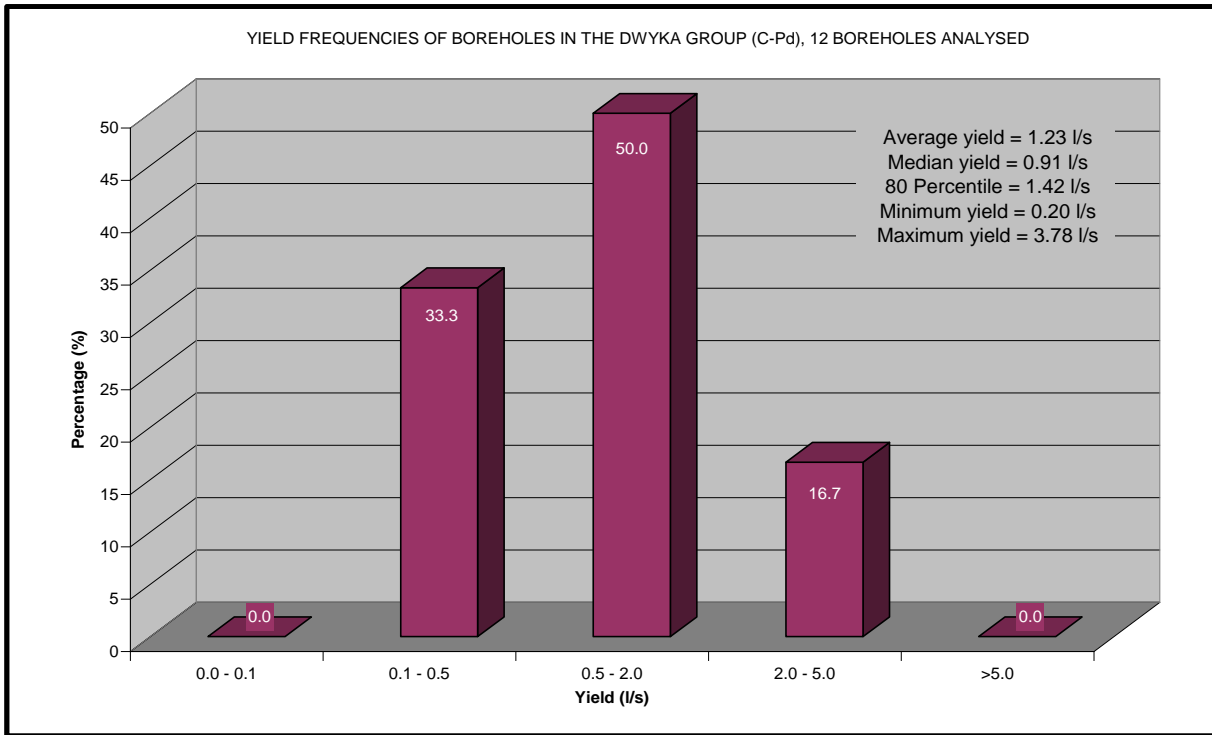


Figure 20: Yield frequency of boreholes in the Dwyka Group (C-Pd).

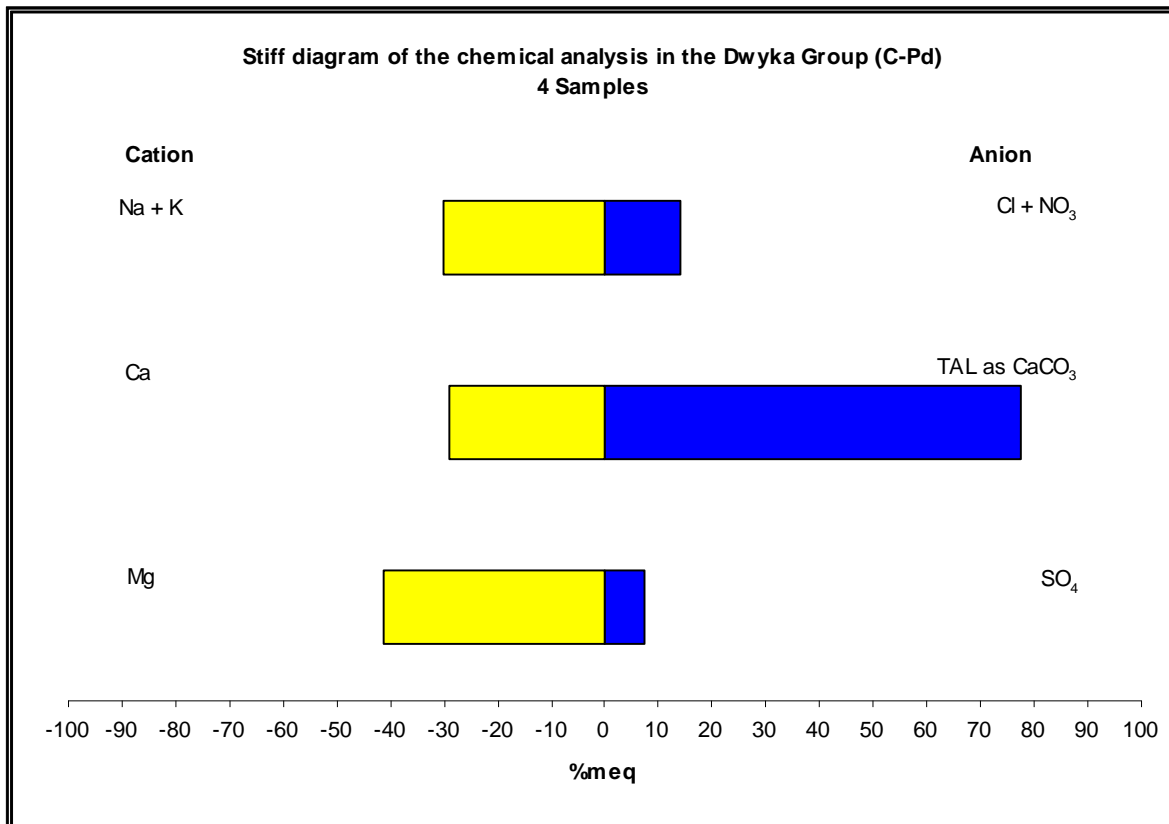


Figure 21: Stiff diagram representing chemistry for aquifers of the Dwyka Group (C-Pd).

Only 4 chemical analyses were available for the chemical characterization of the Dwyka Group (C-Pd). The groundwater quality of three falls within the ideal domestic water quality range (Table 7 to Table 9, p35 - 39). The fourth sample falls within the maximum allowable limit for domestic use due to the nitrate concentration of 17.97mg/l, (10mg/l < N >20mg/l). The water is classified as a magnesium-sodium-calcium-bicarbonate type.

3.3.2.4 Ecca Group (Pe), fractured aquifers

The aquifers of the Ecca Group are classed as fractured as well as fractured and intergranular. The fractured aquifers of the Ecca Group occur as a narrow south to north strip along the eastern part of the mapped area. It forms a relatively flat area along the western side of the Lebombo mountain range covering 1.35% of the map area. Due to the topography most of the rural villages occurs along this strip up to the border of the Kruger National Park in the north. The unit is therefore significant in supplying water for domestic use.

The stratigraphic knowledge of the area is not sufficient for a detailed lithostratigraphic nomenclature but it is known that the Clarens Sandstone Formation is present in the area (SACS, Handbook 8). Rocks of the unit with intergranular and fractured characteristics covers 13.97% of the map area and are discussed in section 3.3.4.24, p109.

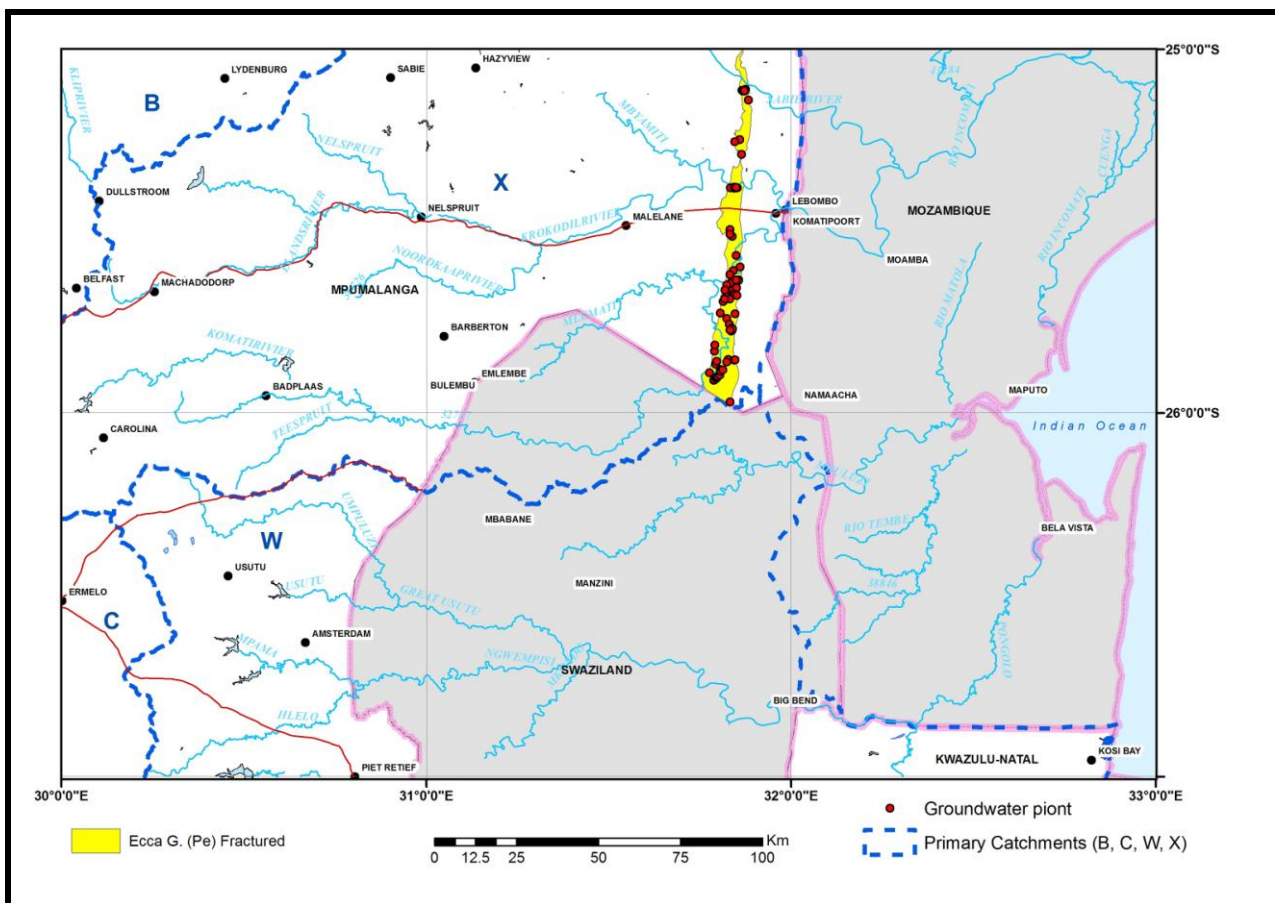


Figure 22: Geographical distribution of the fractured aquifers of the Ecca Group (Pe) and associated groundwater sampling points.

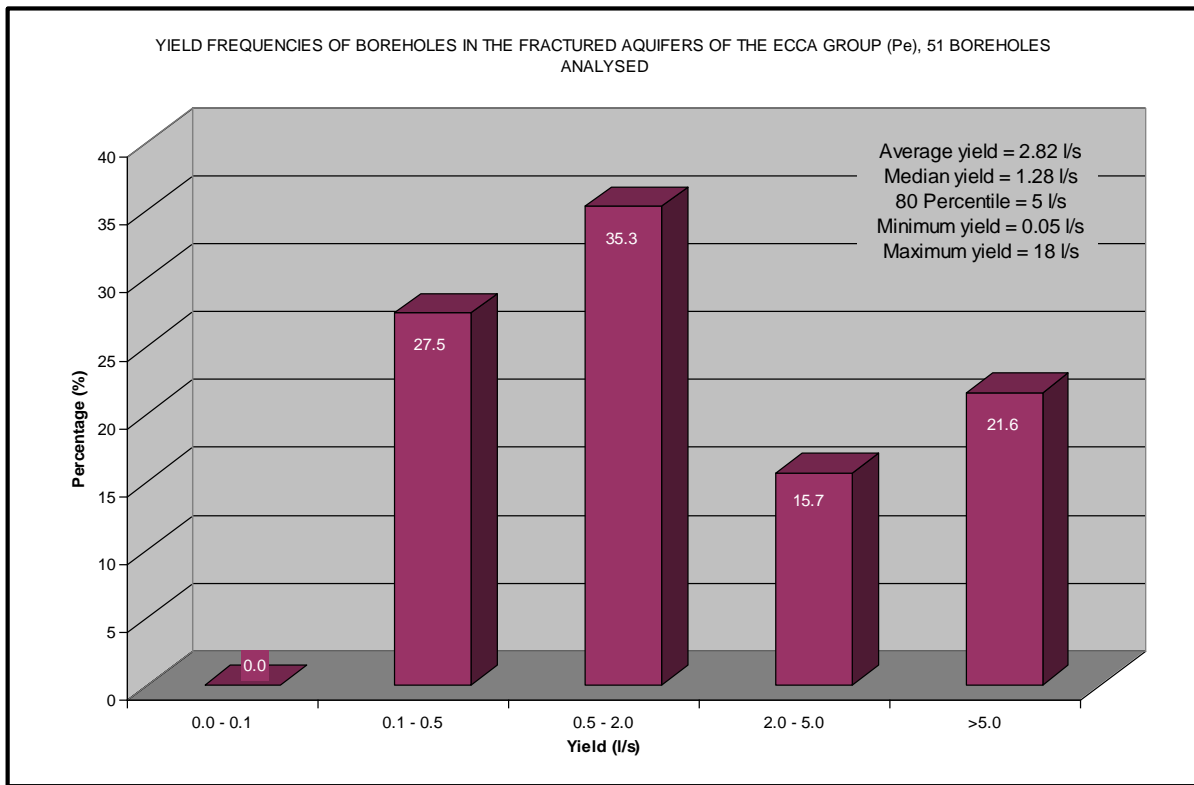


Figure 23: Yield frequency of boreholes in the fractured aquifers of the Eccca Group (Pe).

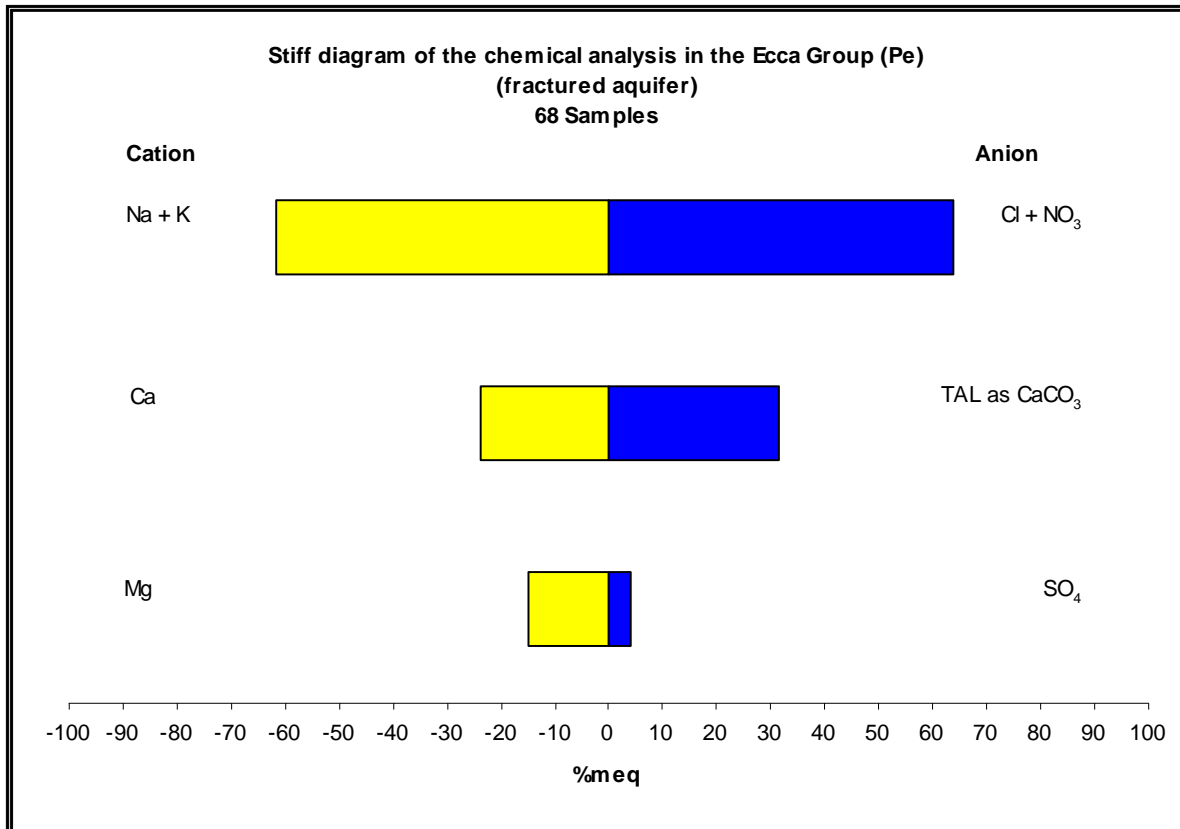


Figure 24: Stiff diagram representing chemistry for the fractured aquifers of the Eccca Group (Pe).

Maximum yield data is available for fifty one boreholes (Figure 23, p56). Of these 35.3% falls within the range 0.5-2l/s, and 37.3% yield more than 2l/s. No yield data for the range 0-0.1l/s was available and no dry boreholes are listed. Forty nine boreholes are listed without any yield data that is either destroyed or not in use. If these boreholes are assumed to be low yielding the diagram changes completely with 75.3% of the boreholes yielding less than 2l/s. Fifty two boreholes have data on final drilled depths, the deepest reported borehole is 98m deep and the average depth is 59m. Water strike data was available on eight boreholes, the average water strike is 45.6m and the deepest reported strike is 85m. Burger (1949) concluded that chances of obtaining adequate supplies are more favourable where interlayered coal layers occur in the sediments than where only sandstone and ordinary shale layers occur. A few boreholes drilled next to dolerites dykes intrusive in sediments of the Ecca Group, indicated that yields get progressively smaller the closer boreholes are drilled to the contact (Burger, 1949). The poor yields generally obtained in the Ecca Group can be ascribed to the fact that small potential water bearing fractures are filled up with secondary material. This was observed in dry riverbeds where the different layers are exposed. Dolerite intrusions as well as fractured sediments occurring at depth are the better targets for successful groundwater development in this geohydrological unit

The water is a sodium-chloride water type indicating an end point of discharge or stagnation of water. A high number of unacceptable chemical concentration values are found in this unit for the elements chloride (Cl > 600mg/l), nitrate (N > 20mg/l), fluoride (F > 1.5mg/l), calcium (Ca > 300mg/l), magnesium (Mg > 100mg/l) as well as sodium (Na > 400mg/l). In 35% of the samples the Electric Conductivity are unacceptable (EC > 370mS/m).

3.3.2.5 Lebombo Group (Jl) (Rhyolite)

The outpouring of lava marked the end of the sedimentary deposits of the Karoo Supergroup. Two formations of the Lebombo Group occur within the map sheet. The **Jozini Formation** representing the youngest formation of the Lebombo Group is the most resistant to weathering and forms the bulk of the Lebombo Mountain Range. Due to the resistive character of the formation, it was classed as a fractured aquifer. The unit consists of a succession of acid volcanic rocks predominantly light cream to red and purple rhyolite and minor lava flows. The thickness is between 80 and 350m thick (Bristow and Cleverly, 1979). The formation is a poor aquifer with dewatering of fractures due to limited recharge a common reported problem in production boreholes. The **Letaba Formation** is classed as a fractured and intergranular aquifer and covers 3.61% of the map area compared to the 1.38% of the map area underlain by the fractured aquifer unit.

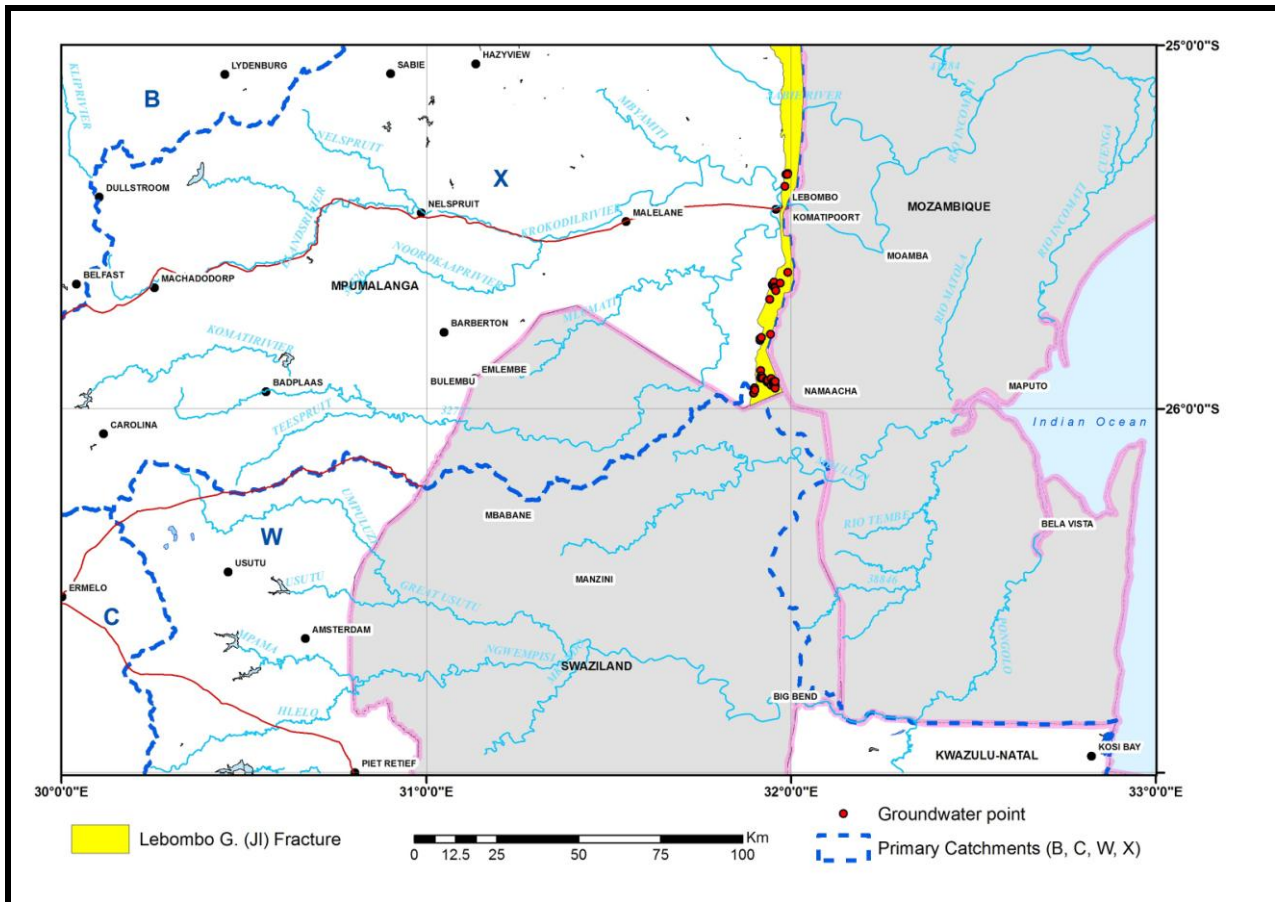


Figure 25: Geographical distribution of the fractured aquifers of the Lebombo Group (JI) and associated groundwater sampling points.

The maximum yield data for thirty eight boreholes falling within the fractured aquifers of the Lebombo Group (JI) was available for the characterization of the unit. Of this total, 89.5% are yielding less than 2l/s. The median yield of boreholes in the rhyolite is only 0.03 l/s and is generally regarded as having a very low development potential (Du Toit, 1998). A hundred and two data points have recorded drilling depths; the average depth is 82m with the deepest reported as 158m. Six boreholes have reported water strike depths; the average strike depth is 39m with the deepest recorded strike as 69m. Most of the water occurs in fractured rhyolite and to a lesser extent in fractured dolerite intrusions or on the contact with the host rock (Du Toit, 1998). Reports that some production boreholes decreased in deliverable yields over time can be attributed to inadequate recharge; this unit is therefore not regarded as an important production aquifer.

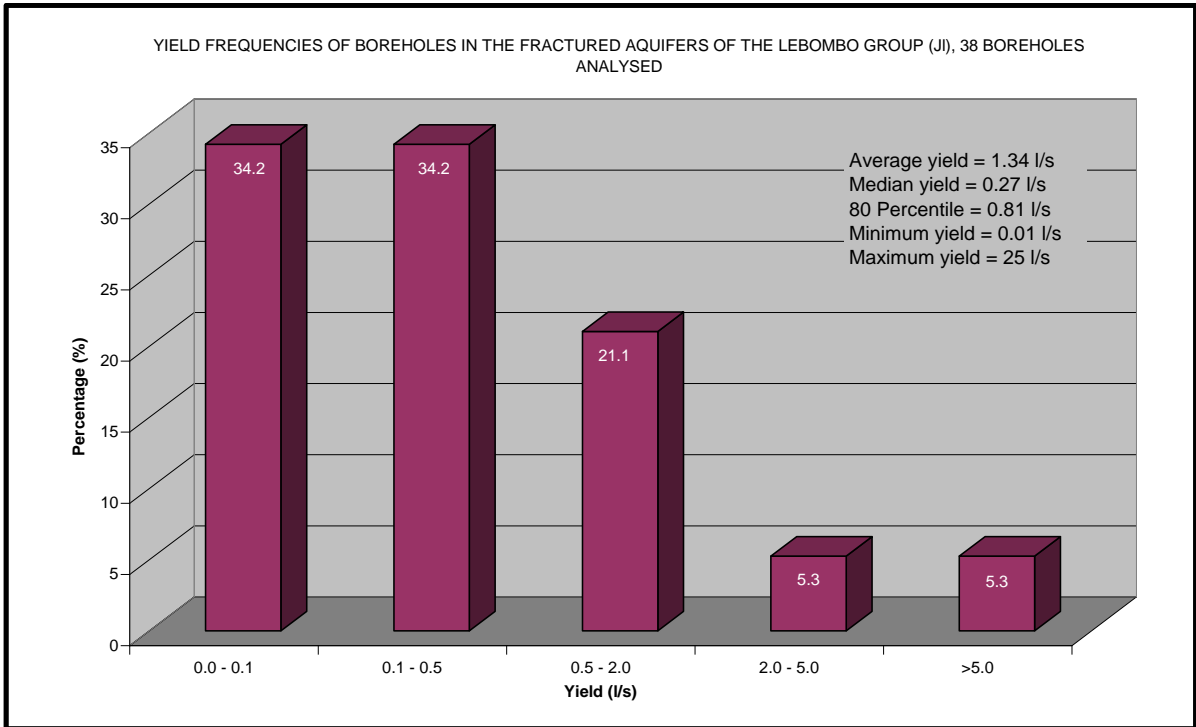


Figure 26: Yield frequency of boreholes in the fractured aquifers of the Lebombo Group (JI).

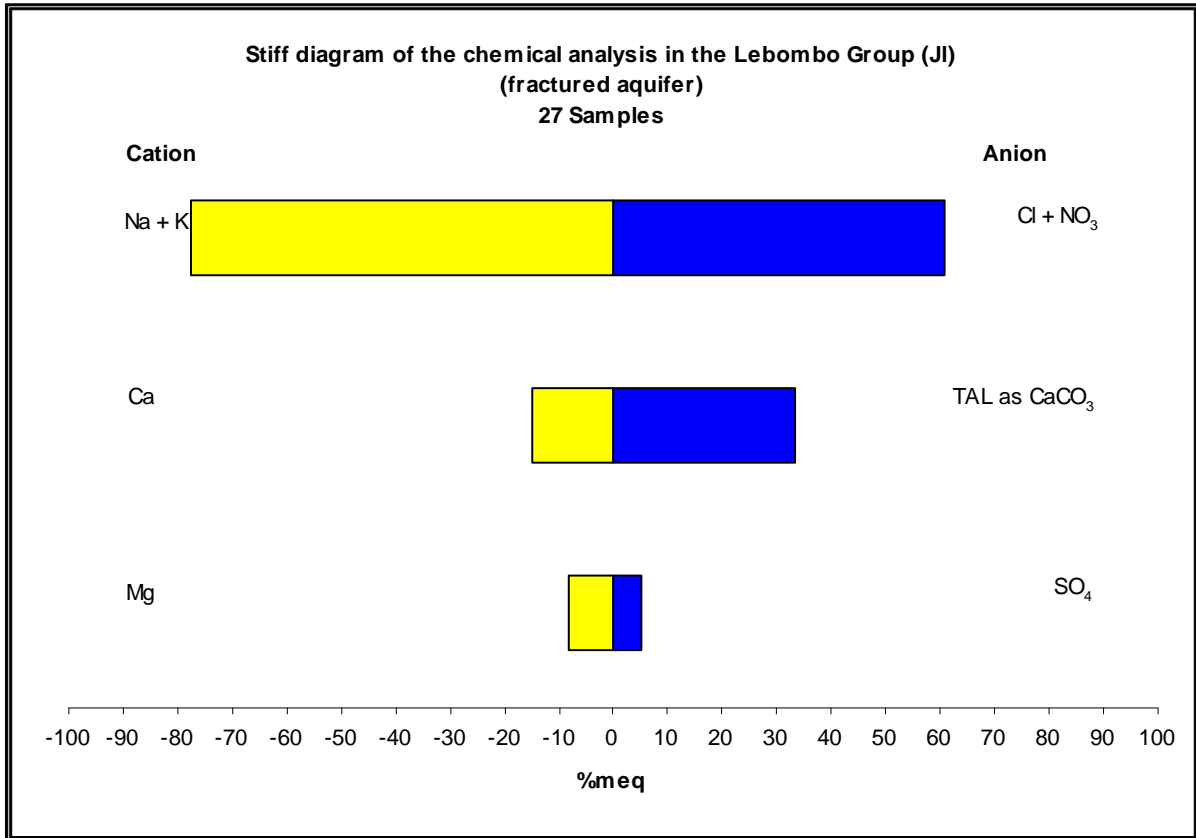


Figure 27: Stiff diagram representing chemistry for the fractured aquifers of the Lebombo Group (JI).

The Stiff diagram, (Figure 27) shows the unit to be dominated by a sodium-chloride type of water or natural saline water. A predominance of Na^+ and Cl^- indicates an end point of discharge or stagnation of water. Elevated nitrate concentrations exceeds the maximum allowable limit ($\text{N} > 20\text{mg/l}$) in 33% of the samples. The chloride as well as sodium concentration values exceed the maximum allowable limits in 40% of the samples ($\text{Cl} > 600\text{mg/l}$), ($\text{Na} > 400\text{mg/l}$).

3.3.2.6 Tshokwane Granophyre (Jts)

Intrusive into the Jozini- and Letaba Formations the Tshokwane Granophyre forms irregular and sill-like bodies of granophyres and monzonite to microgranitic dykes (SACS, Handbook 8, p 629). Three occurrences along the Mozambique border are depicted on the map sheet.

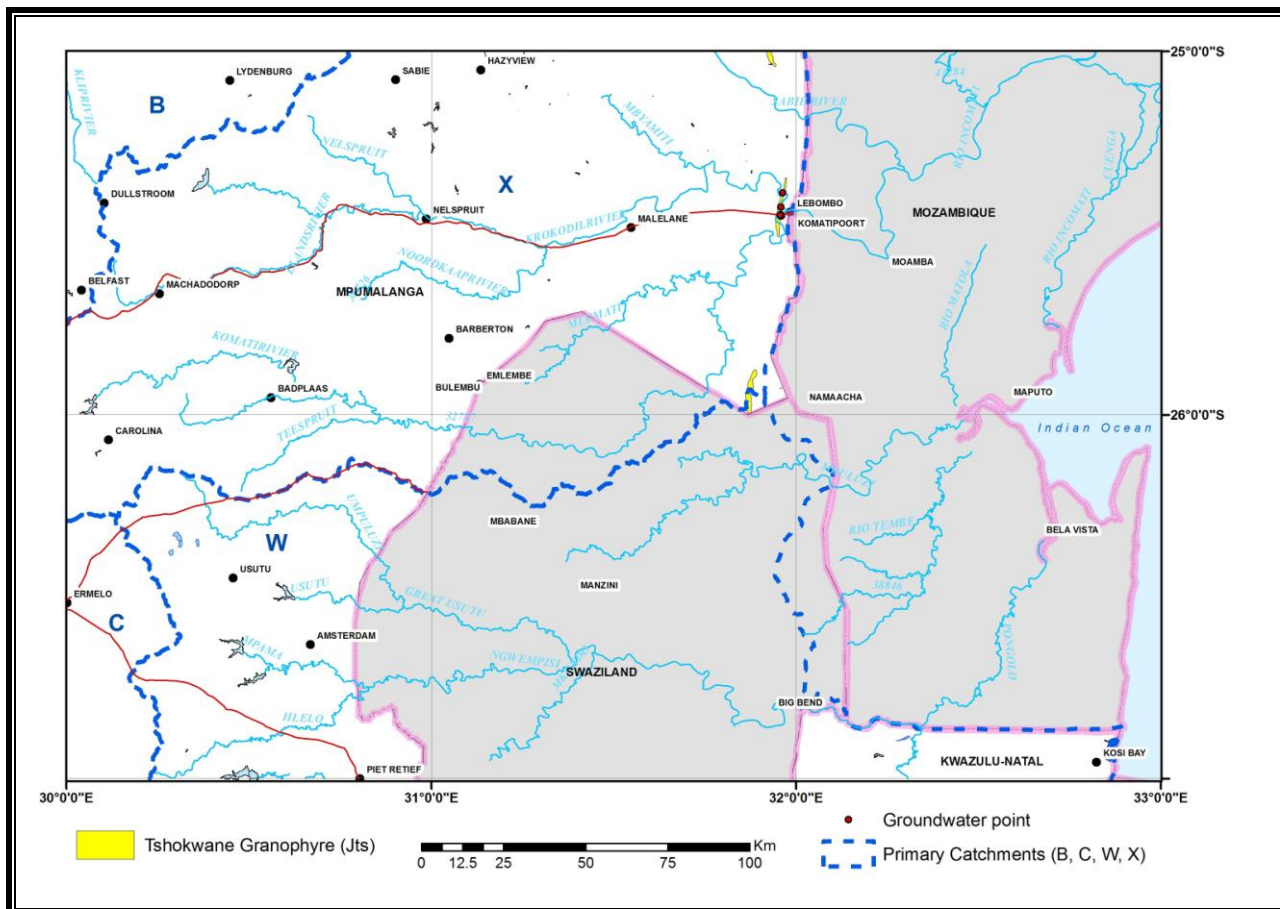


Figure 28: Geographical distribution of the Tshokwane Granophyre (Jts) and associated groundwater sampling points.

The available data is inadequate for a proper analysis of the yield and quality characteristics of the unit. However, considering yield data of boreholes drilled in Tshokwane Granophyre outside of the map area permitted limited characterization of this hydrogeological unit. Water is generally intercepted within the first 50m where it occurs in either fractured granophyre or along dolerite dyke contacts. Drilling results indicated that fractured granophyre and fractures associated with dyke intrusions are equally important targets for successful groundwater development.

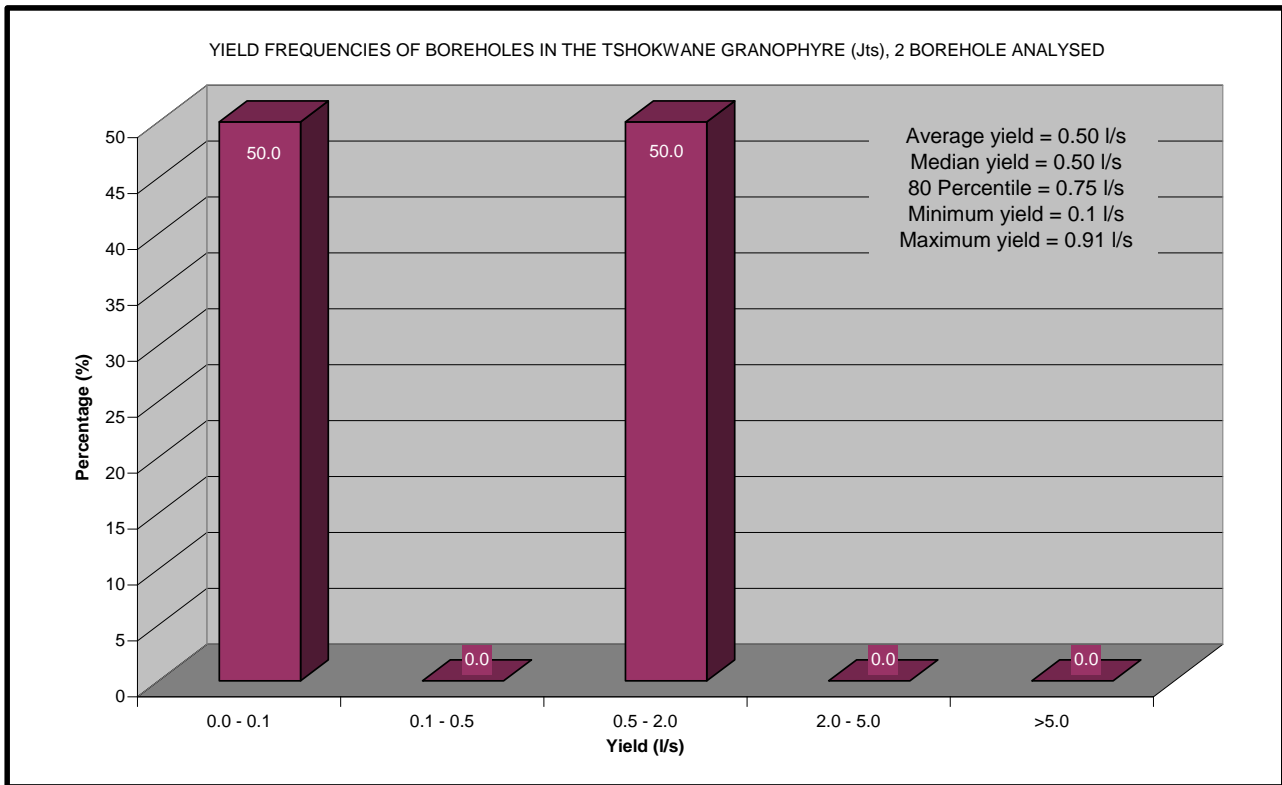


Figure 29: Yield frequency of boreholes in the Tshokwane Granophyre (Jts).

According to Hem's (1970) classification groundwater from the Tshokwane Granophyre is moderate brackish and based on the dominant ion relations a sodium-magnesium-calcium-chloride-bicarbonate water type. The water is high in Cl, which has built up with time and could it thus be classified according to the Davis & DeWiest (1966) classification, as old water. The only analysis available for the Tshokwane Granophyre indicates an EC value of 249 mS/m whilst the fluoride and sulphate exceed maximum recommended limits for domestic use. The water is also of alkaline nature with total alkalinity exceeding the maximum limit.

3.3.3 Karst Aquifers

Karst is the term used to describe distinctive surficial and subterranean features developed by the chemical dissolving action of slightly acidic water on highly soluble rocks, most notably limestone and dolomite, and to a lesser degree, gypsum, anhydrite, and halite. For the processes of Karst to be active, water must dynamically circulate through these soluble rocks, therefore exposing the rock to interaction with water and enabling transportation of solutes. For dissolution to occur the circulating water must be under-saturated with respect to the soluble chemical constituents of the rock. This interplay of flow (hydrology) and dissolution (geochemistry), removes rock thereby creating increasingly larger voids along the pathways. The resulting dissolution of rocks can form huge interstices such as the extensive Sudwala cave system.

Karst aquifers are water-bearing, soluble rock layers at or near the earth's surface in which groundwater flow is concentrated along secondary enlarged fractures, fissures, conduits, and other interconnected openings.

Karst aquifers cover approximately 2.52% of the total map area and are made up of only one unit on the map sheet, the Undifferentiated Black Reef Formation and Chuniespoort Group (Vh-Vbl) indicated in Figure 30, p62.

3.3.3.1 Undifferentiated Black Reef Formation and Chuniespoort Group (Vh-Vbl)

The Chuniespoort Group is a succession of grey and greyish blue to pink, compact poorly bedded dolomite and limestone with chert layers overlaying the very resistant quartzitic Black Reef Formation. A transitional zone consisting of red, yellow and green shale with minor fine-grained sandstone, chert and dolomitic limestone lentils mark this contact. Regional dip is shallow and everywhere towards the inside of the Transvaal basin (SACS Handbook 8). The unit underlies mountainous area with the Black Reef Formation forming a spectacular escarpment which is an important feature for Mpumalanga tourism. The main agricultural activity within the unit is forestry.

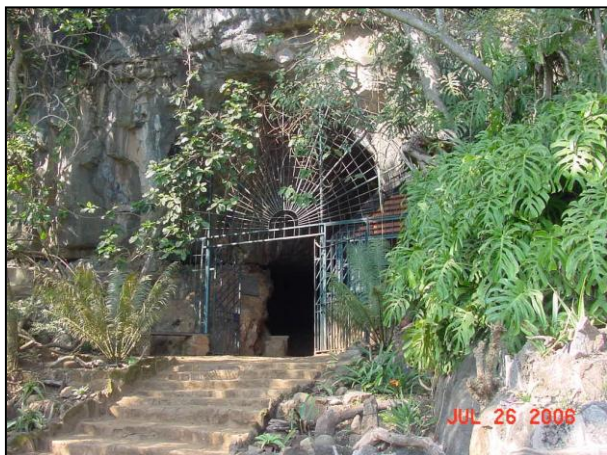


Photo 5: The entrance to the Sudwala Caves located about 30km west of Nelspruit. The caves, which extend for several kilometres into the mountain, are located high up on the slopes of a mountain consisting of dolomite of the Malmani Subgroup. It is not far below the contact with the overlying shales and quartzites of the Pretoria Group. The caves developed as the result of the dissolution of the dolomite ($MgCO_3$) by a weak carbonic acid derived from carbon dioxide (CO_2), (photo W.H. Du Toit, 2006)

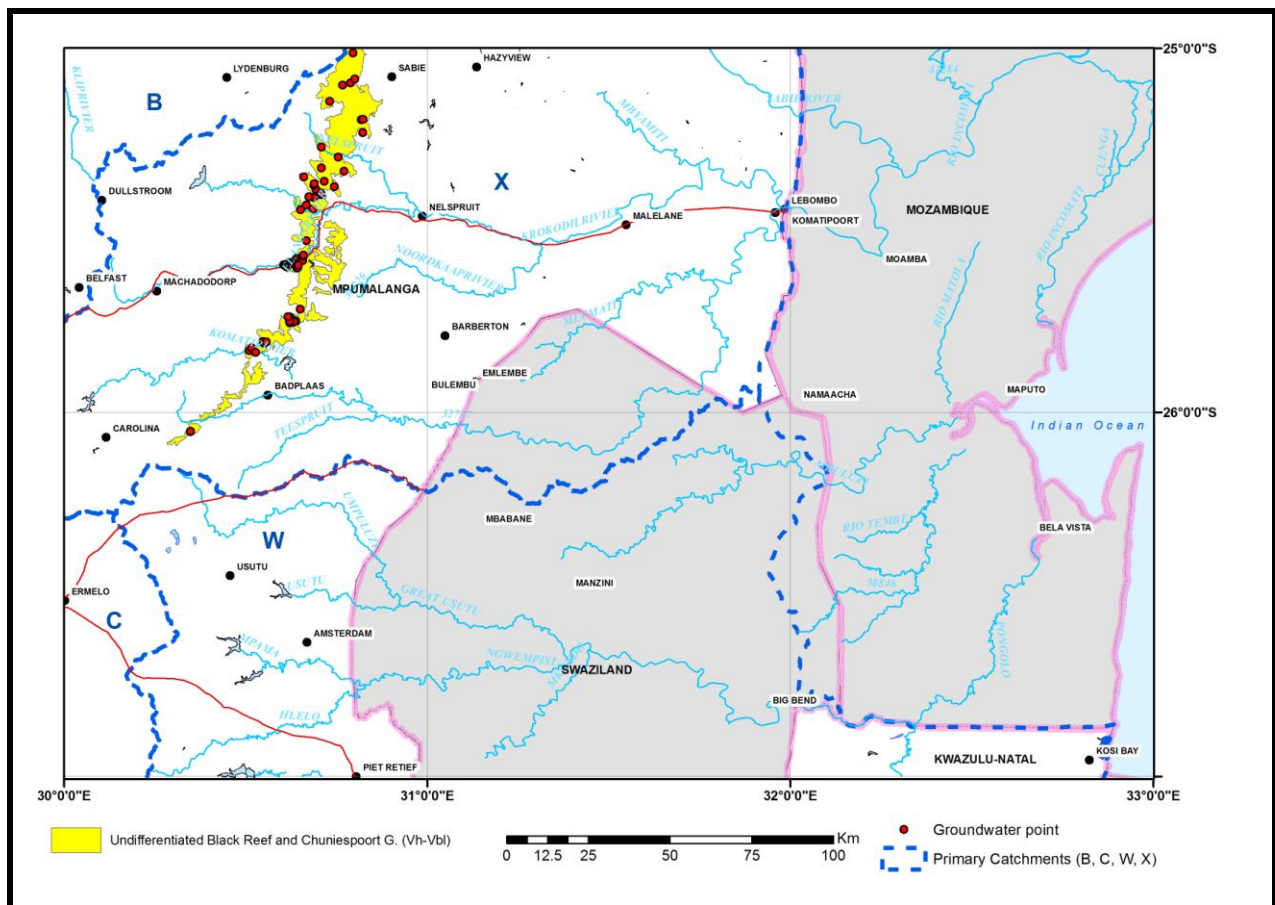


Figure 30: Geographical distribution of the undifferentiated Black Reef Formation and Chuniespoort Group (Vh-Vbl) and associated groundwater sampling points.

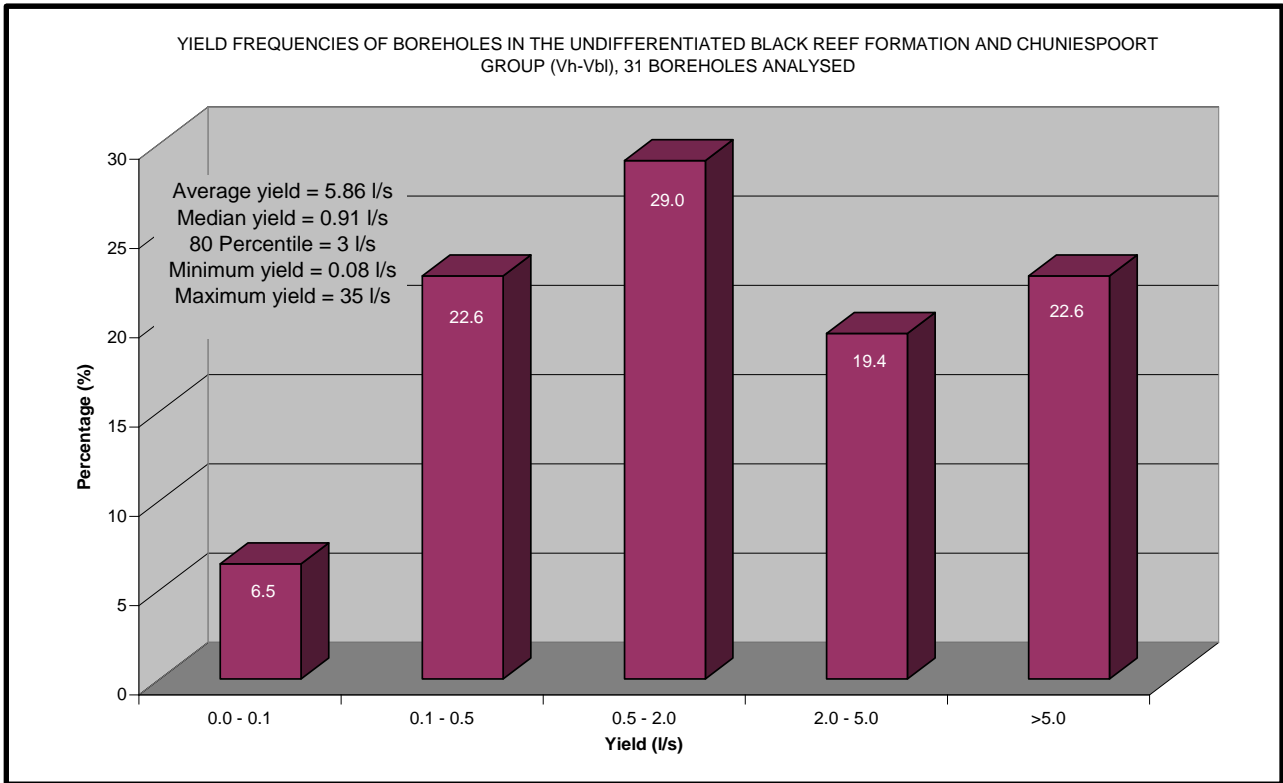


Figure 31: Yield frequency of boreholes in the undifferentiated Black Reef Formation and Chuniespoort Group (Vh-Vbl).

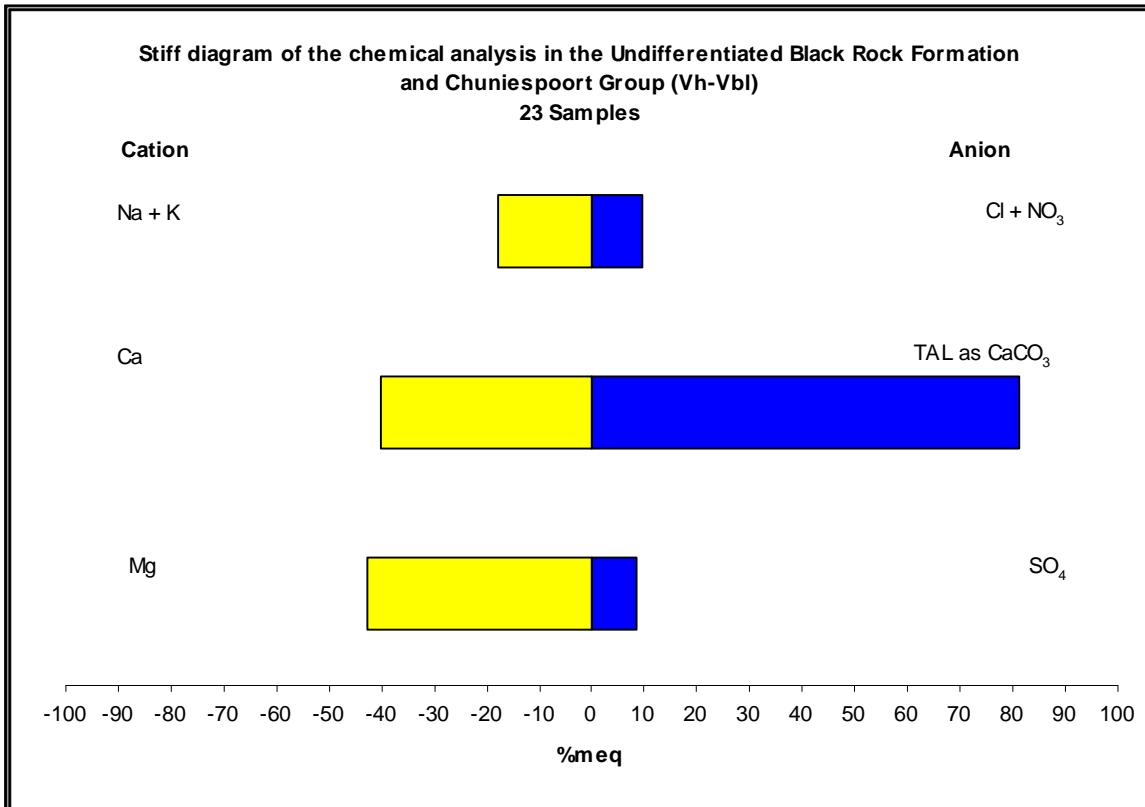


Figure 32: Stiff diagram representing chemistry for the undifferentiated Black Reef Formation and Chuniespoort Group (Vh-Vbl).

Figure 32, p 63 shows the dominant anions and cations presented as a stiff diagram compiled from 23 available chemical records. The water displays a calcium-magnesium-bicarbonate character, with elevated sodium levels; HCO_3^- is the dominant anion. This type of water is often associated with dolomitic aquifers, which corresponds to the geology of the unit. All the available chemical analyses within the unit fall within the ideal water quality class, (Table 7, p35 to Table 9, p39).



Photo 6: *Stromatolites in the dolomites of the Malmani Subgroup at the Sudwala Caves. Stromatolites are finely layered, concentric, mound-like structures found in dolomite and formed by microscopic algal organisms (W.H. du Toit, 2006).*

The yield frequency diagram (Figure 31, p63) represents 31 data points with maximum yield data. Of these 58% have yields that are less than 2l/s and 22.6% have yields that exceed 5l/s. Twenty six data points have recorded drilling depths; the deepest depth is 90m and the average is 68m. Static water level depths are reported at 20 data points, ranging from 1-60m with an average depth of 20m. The deeper static water levels are probably related to the effect of agriculture as it is reported that fountains dried up as plantations matured. Water is found in dissolution channels, at the contact zones of dykes and sills, and in fractures of diverse origin.

3.3.4 Intergranular and fractured aquifers

“Intergranular and fractured”, as depicted on this map, describe aquifers within the same lithology, in which groundwater occur in both the above modes with the exception that the intergranular interstices are secondary of nature. Secondary intergranular interstices normally result where the less resistant material in a medium to coarse-grained hard rock lithology, such as granite and gneiss, is removed by weathering, leaving intergranular interstices between the remaining more resistant granules. The same restricting factors as mentioned above are valid for this type of aquifer within the map area. Limited information regarding water levels and depth of weathering rendered it impossible to accurately delineate aquifers of this type within the map area. This type, as indicated on the map, rather refers to the property of the lithology to contain groundwater in both modes than to the actual condition at any given locality.

The hydrogeological units of the map sheet are predominantly exhibiting intergranular and fractured aquifer characteristics. It covers approximately 89.64% of the total map area and is made up of the following hydrogeological units:

- Undifferentiated Barberton Super Group (Zr), p67
- Undifferentiated Tjakastad Subgroup (Zot-Zoo), p68
- Undifferentiated Onverwacht Group, Fig Tree Group, Moodies Group (Zo-Zd), p71
- Unnamed Swazian Rocks (Zz), p73
- Nelspruit Suite (Ze), p75
- Nsuze Group (Zn), p78
- Kaap Valley Granite (Zka), p80
- Various intrusive rocks of the Mozaan Group and Nsuze Group (Z-Rg), p83
- Dalmein Granite (Zda), p85
- Hebron Granodiorite (Zhe), p87
- Undifferentiated rocks of the Thole and Piet Retief Suite (Rth-Rup), p87
- Undifferentiated rocks of the Mozaan Group, Amsterdam Formation, and Usushwana Complex (Rm-Ru), p88
- Unnamed Randian Rocks (Rz), p90
- Boesmanskop Syenite (Rbs), p92
- Salisbury Kop Granodiorite (Rsk), p94
- Mpangeni Granite (Rmp), p95
- Mozaan Group (Rm), p97
- Wolkberg Group (Vw), p98
- Pretoria Group (Vp), intergranular and fractured, p100
- Diabase Intrusions (N-Zd), p102
- Rustenburg Suite (Vr), p104
- Lebowa Suite (Mle), p106
- Timbavati Gabbro (Nti), p106
- Ecca Group (Pe), intergranular and fractured aquifers, p109
- Clarence Formation (Trc), p111
- Lebombo Group (Jl), intergranular and fractured, p113
- Dolerite (Jd), p115
- Zululand Group (K-Tu), p117

The distribution of the intergranular and fractured aquifers is shown in *Figure 33*, p66.

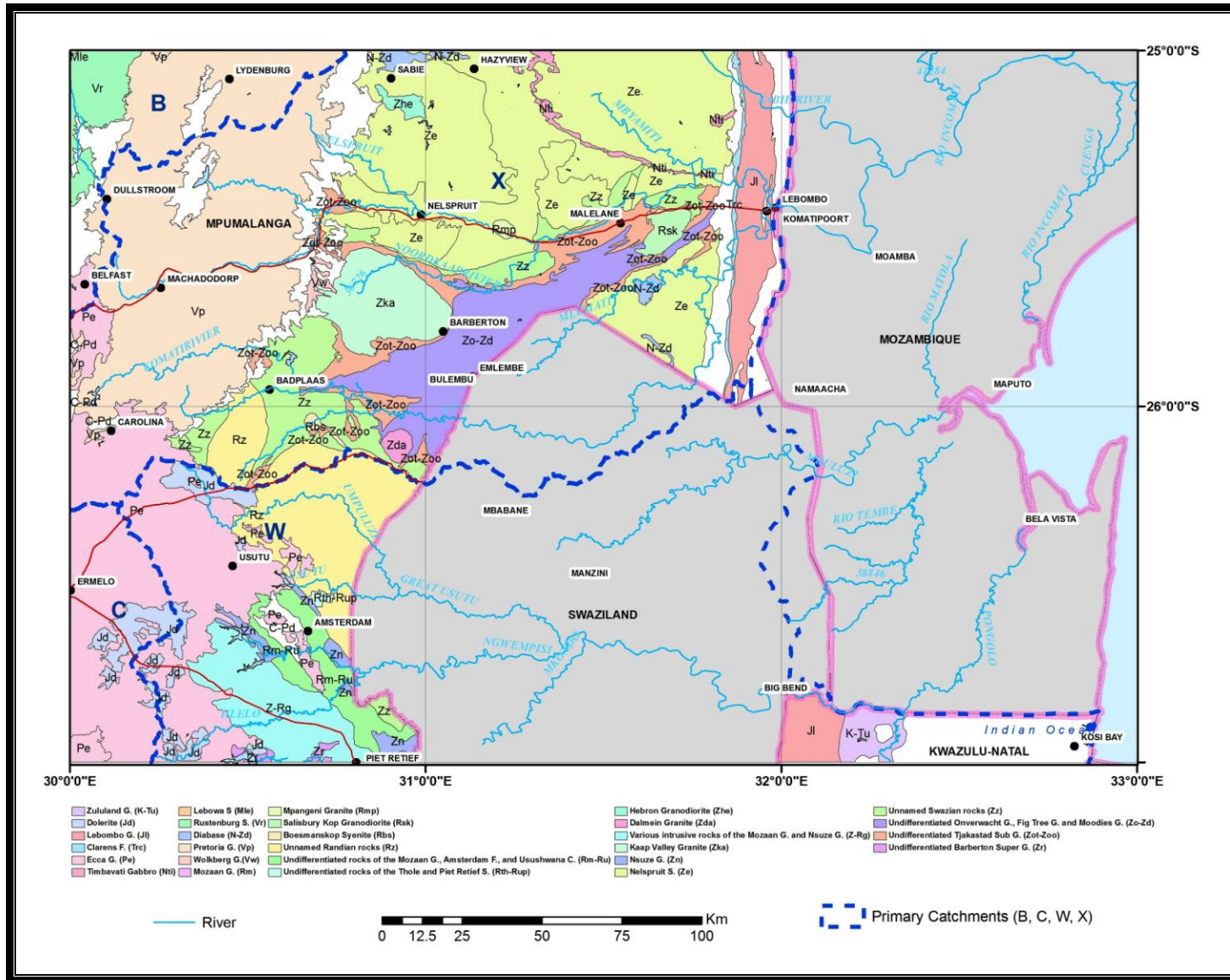


Figure 33: Geographical distribution of the intergranular and fractured aquifers.

3.3.4.1 Undifferentiated Barberton Super Group (Zr)

Geographically isolated from the main occurrence of the Barberton Sequence the unit occurs in three areas in the southern portion of the map sheet just west of Piet Retief. Rocks of this unit represent the lower formations of the Onverwacht Group and consist of a succession of mostly undifferentiated volcanic rocks. *Figure 35*, p68 represents the maximum yield data of four boreholes. Due to inadequate data the yield diagram is not discussed further. Static water levels are available for two sources; 10.5mbgl and 14.5mbgl, only one borehole has a recorded depth of 72m. As the static water level is shallow it is assumed that drilling targets in the area will be related to the weathered and fractured zone.

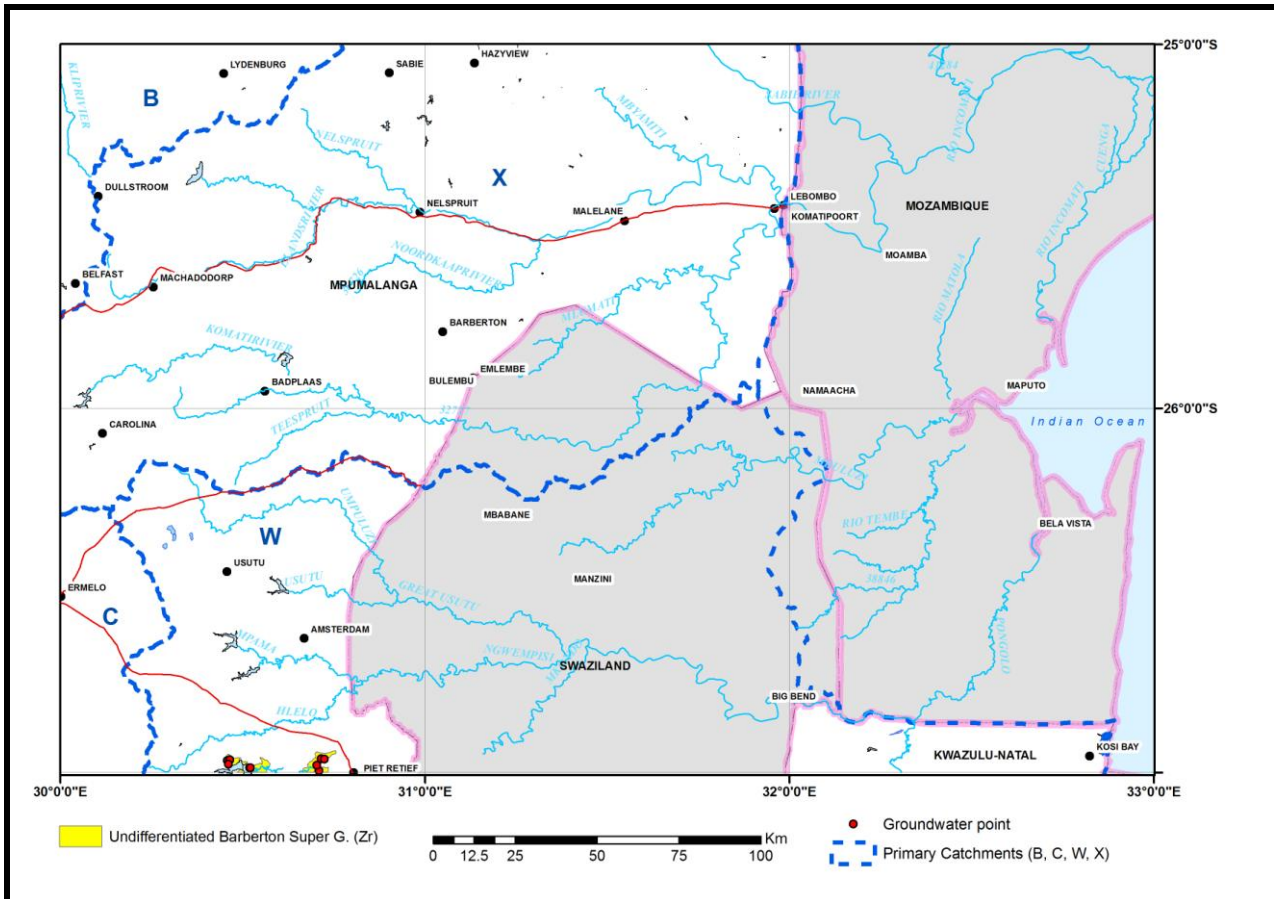


Figure 34: Geographical distribution of the undifferentiated Barberton Super Group (Zr) and associated groundwater sampling points.

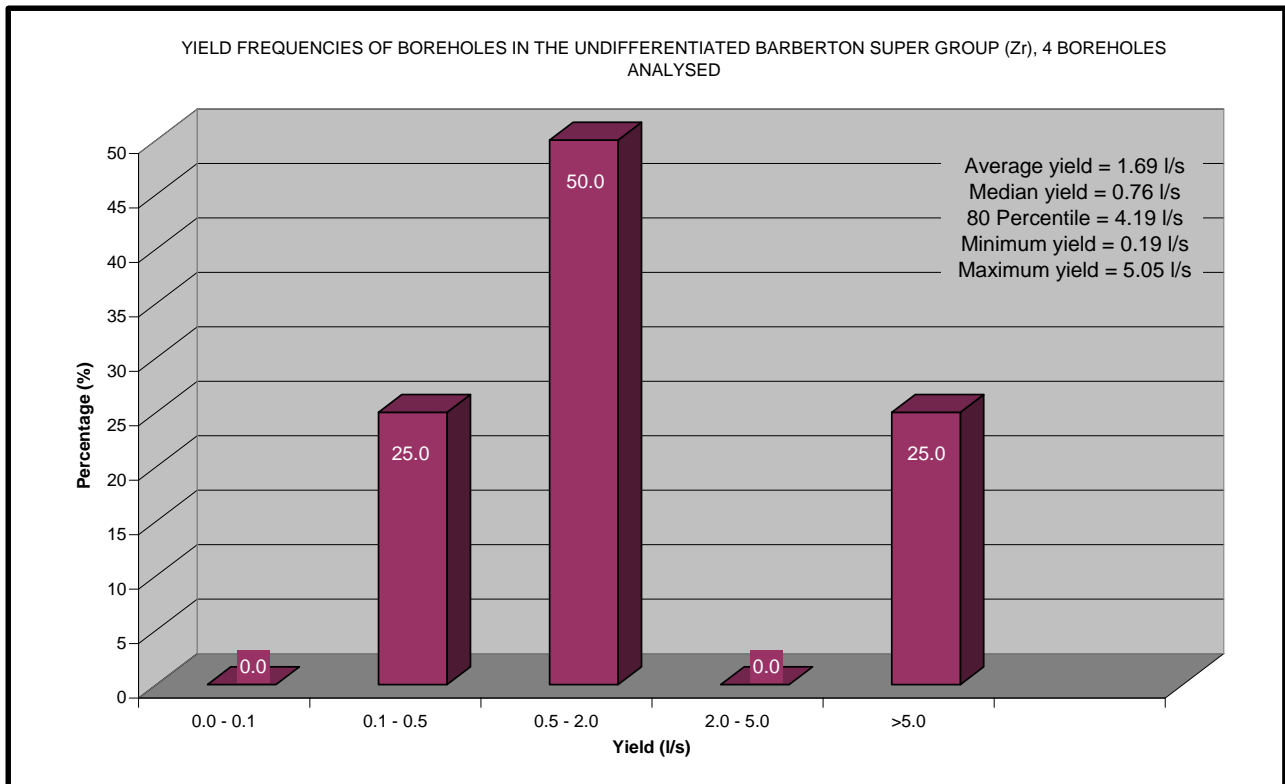


Figure 35: Yield frequency of boreholes in the undifferentiated Barberton Super Group (Zr).

3.3.4.2 Undifferentiated Tjakastad Subgroup (Zot-Zoo)

A prominent chert layer up to 9m thick known as the middle marker divides the Onverwacht Group into two subgroups. The lower formations grouped under the Tjakastad Subgroup are essentially an ultramafic and mafic, magnesium rich lower assemblage of lavas. Outcrop is predominantly as xenoliths within intrusive granitoid rocks or as contact-metamorphosed aureoles around individual granitoid masses.



Photo 7: The Consort Gold mine northeast of Barberton. Mineralization occurred along the folded and silica-rich contact between amphibole schist and interlayered leptite of the Onverwacht Group and hornfels and trachyte of the Fig Tree Group (photo W.H. Du Toit, 2006).

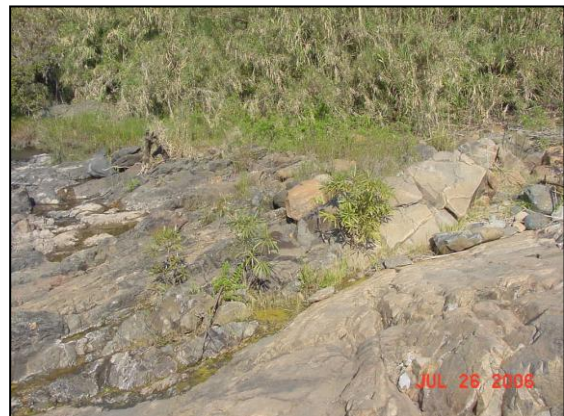


Photo 8: Contact between biotite-trondhjemite gneiss of the Stenton Pluton and green stones (mafic and ultramafic schist) of the Onverwacht Group (photo W.H. Du Toit, 2006).

Three formations are recognized under the Tjakastad Subgroup with the oldest; the Zandspruit Formation consisting of metabasaltic lava and tuff now altered to a variety of amphibole, chlorite

and talc-chlorite schist, serpentinised ultramafic rock and interlayered peridotitic komatiite lava. The Theespruit Formation consists of various mafic and ultramafic schist interlayered with banded ironstone and ferruginous, black, white, and grey chert: acid to intermediate volcanic rocks altered to quartz-sericitic schist and chert. The youngest is the Komati Formation consisting of basaltic and peridotitic komatiite, tholeiite and chemical sediment (Walraven, 1989). Based on the size of the unit (7.75% of the map area) and the available yields of boreholes within the unit (*Figure 37, p70*), it can be regarded as a significant aquifer.



Photo 9: Fractured schist of the Theespruit Formation in a road cutting between Kaapmuiden and Barberton (photo W.H. Du Toit, 2006).

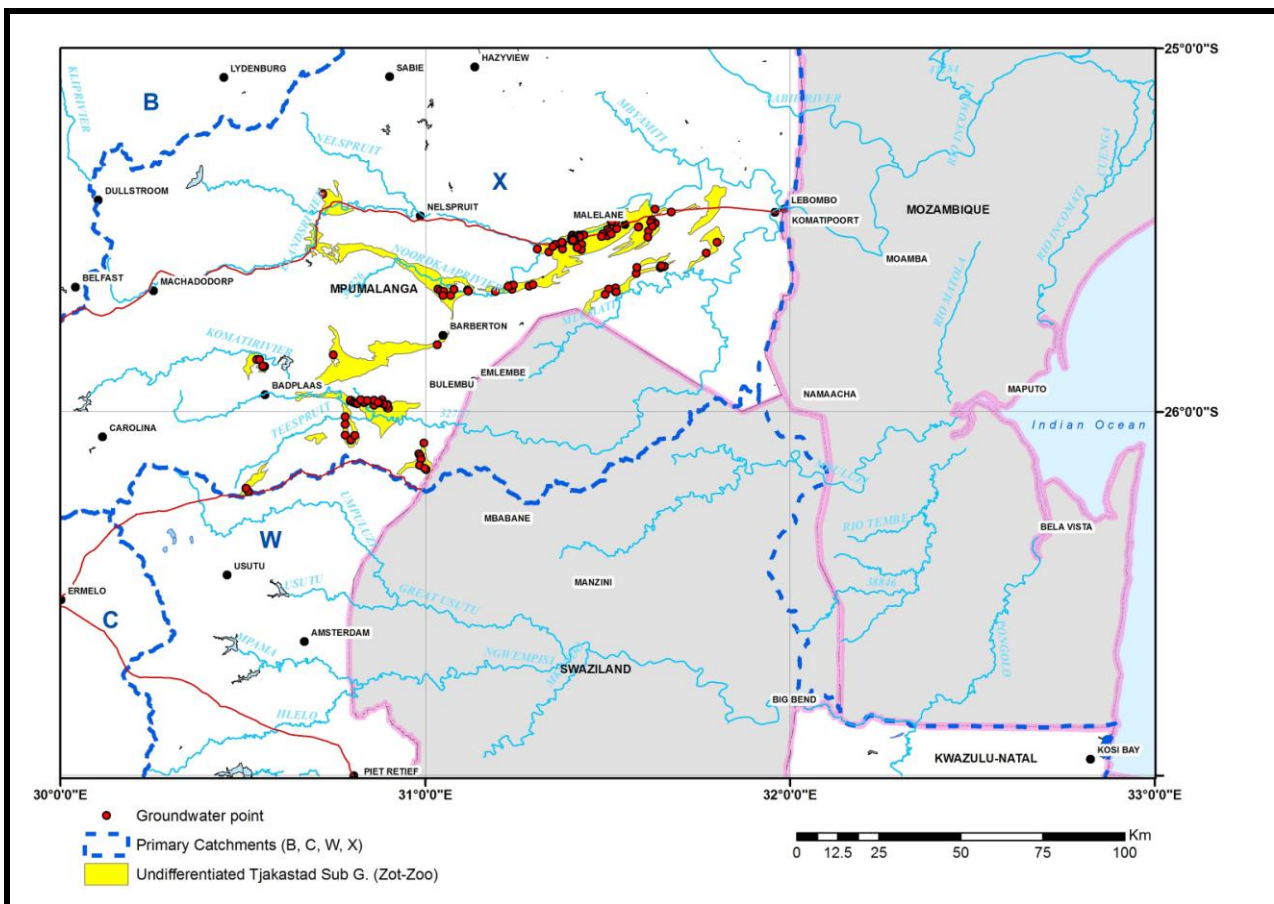


Figure 36: Geographical distribution of the undifferentiated Tjakastad Subgroup (Zot Zoo) and associated groundwater sampling points.

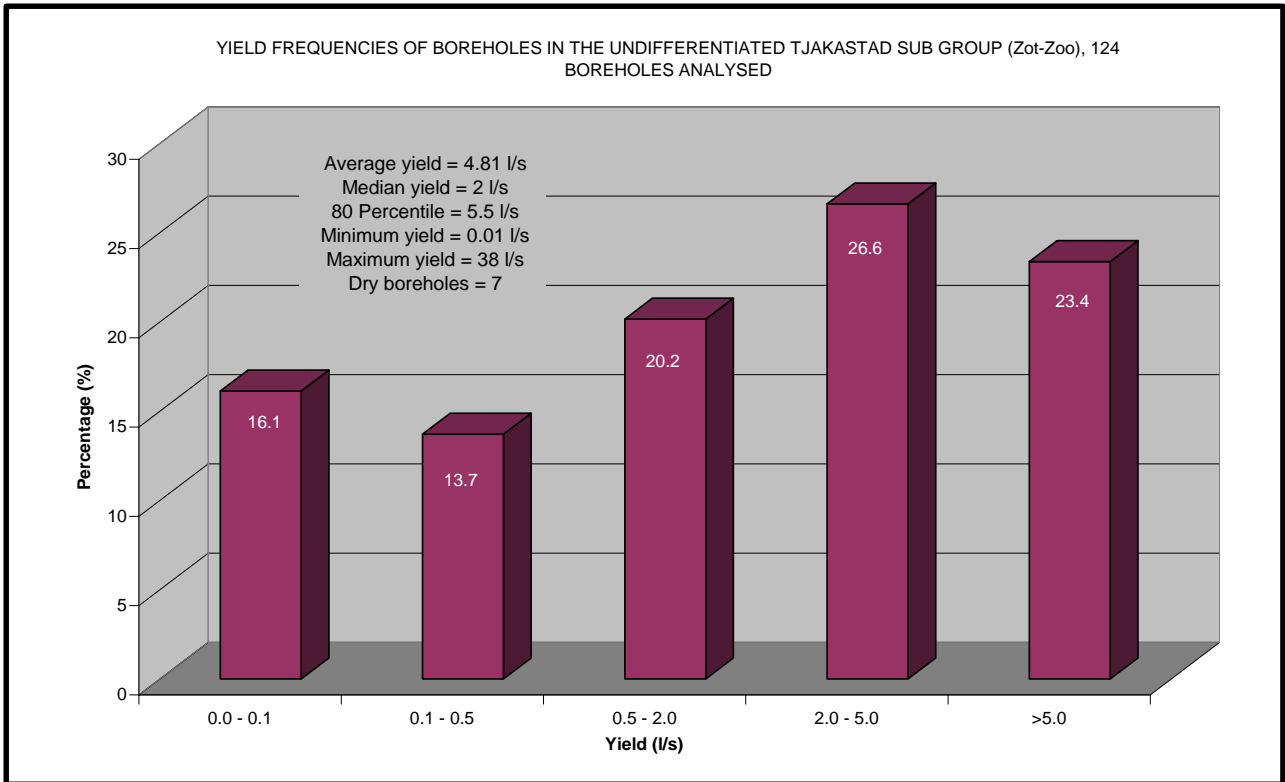


Figure 37: Yield frequency of boreholes in the undifferentiated Tjakastad Subgroup (Zot-Zoo).

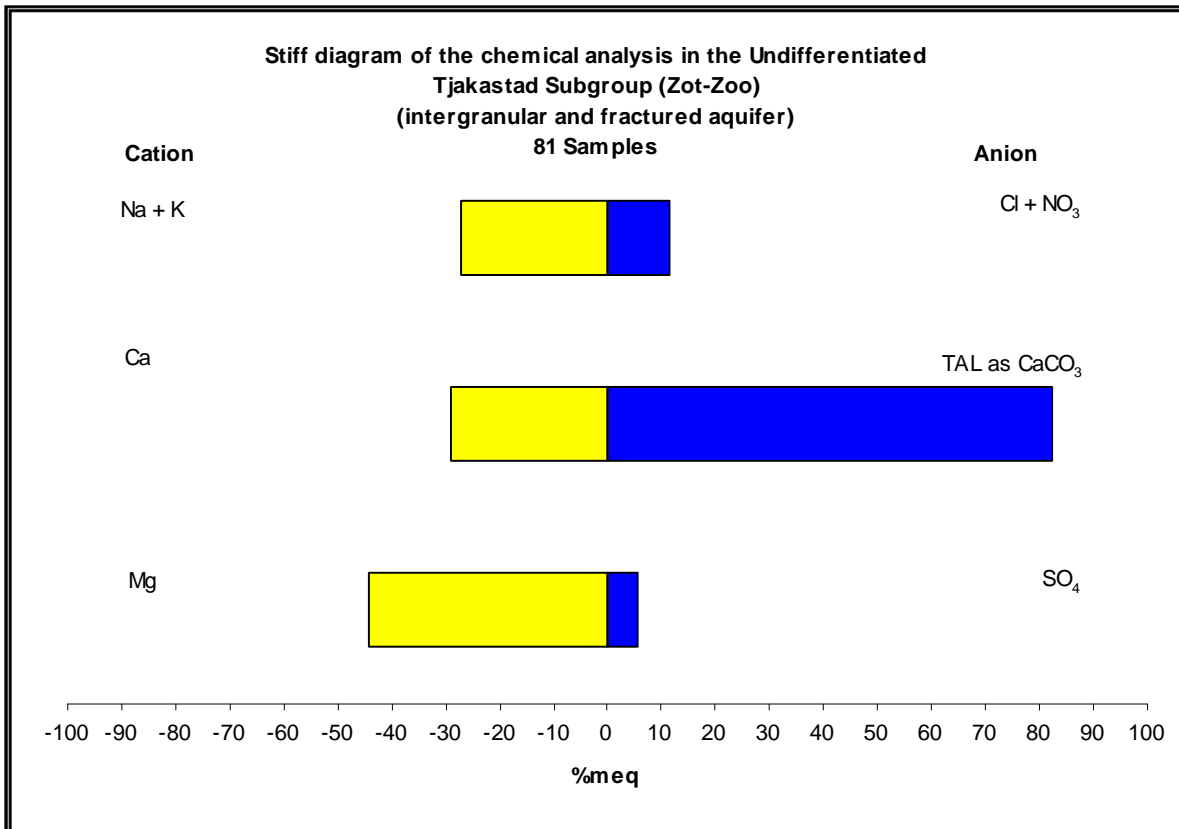


Figure 38: Stiff diagram representing chemistry for the undifferentiated Tjakastad Subgroup (Zot-Zoo).

The yield frequency diagram (Figure 37, p70) represents the maximum yield of 124 data points, 50% of the boreholes yield more than 2l/s, 33.9% yield between 0.5 and 2l/s and the remaining 16.1% are almost dry. Seven dry boreholes are recorded. Water strike data is available for

fourteen boreholes, ranging from 22-71m with 85% of the strikes between 20-50mbgl. Drilling depth data is available for 99 boreholes; ranging from 26-130m, averaging 61.84m. Static water levels are recorded at 74 boreholes; ranging from 0.98-44.86mbgl and are on average 11.67m deep.

Figure 38 shows the dominant anions and cations presented as a stiff diagram compiled from 81 available chemical records. The water displays a calcium-magnesium-bicarbonate character, with elevated sodium concentrations; HCO_3^- is the dominant anion. This type of water is often associated with dolomitic aquifers.

Generally the water quality of this unit is poor. A high number of major elements exceed the maximum allowable limit for domestic use as shown below: (refer to *Table 7 to Table 9*, p35 to p39)

- magnesium 13.6% ($\text{Mg} > 100\text{mg/l}$)
- nitrate 13.3% ($\text{N} > 20\text{mg/l}$)
- chloride 7.4% ($\text{Cl} > 600\text{mg/l}$)
- sodium 2.5% ($\text{Na} > 400\text{mg/l}$)
- fluoride 1.3% (1.5mg/l)

3.3.4.3 Undifferentiated Onverwacht Group, Fig Tree Group, Moodies Group (Zo-Zd)

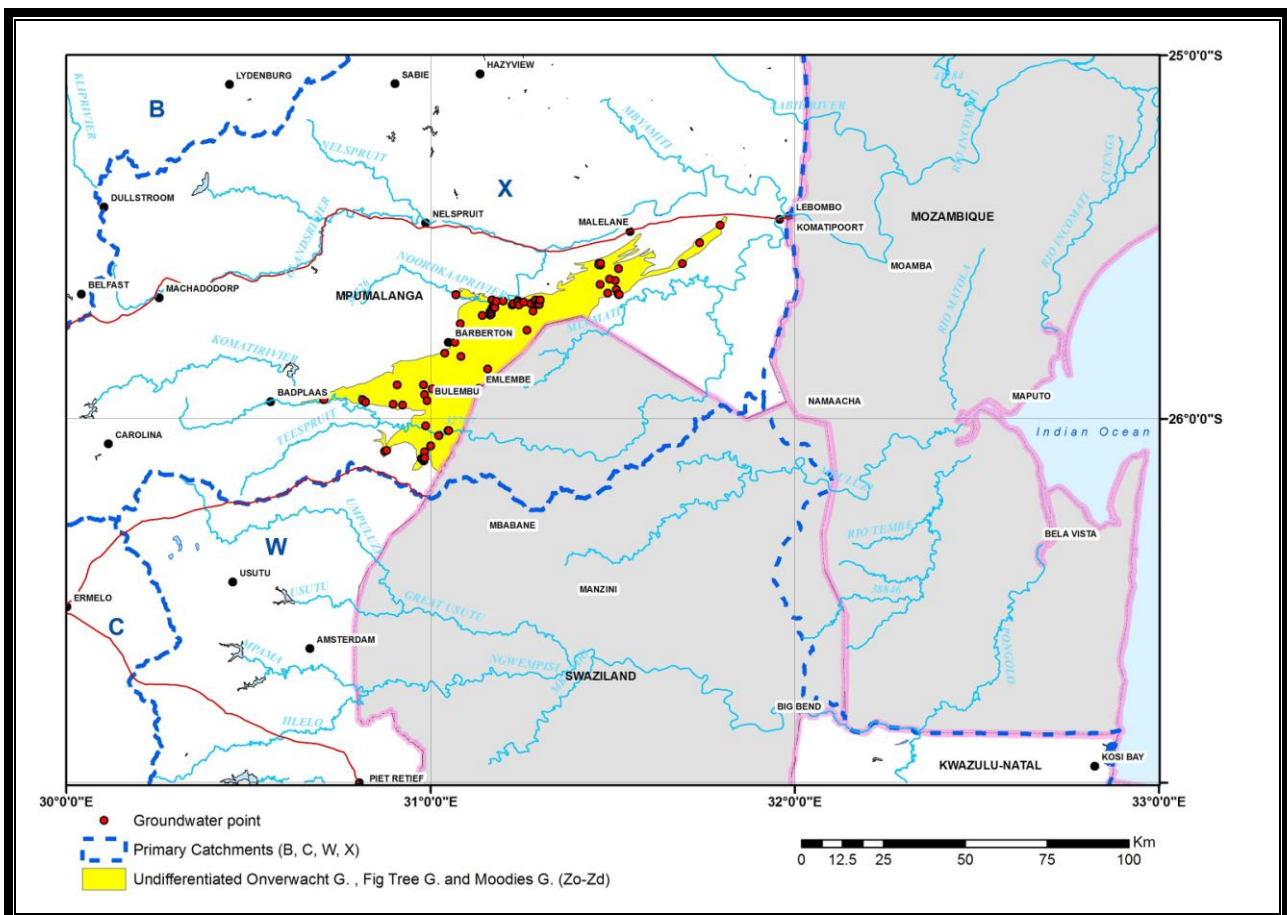


Figure 39: Geographical distribution of the undifferentiated Onverwacht, Fig Tree and Moodies Groups (Zo Zd) and associated groundwater sampling points.

Under this hydrogeological unit, the Onverwacht Group is mainly represented by the younger upper Geluk Subgroup although some rocks of the Tjakastad Subgroup are included. The latter relates to small outcrops within the Fig Tree and Moodies Group that are not separated due to

map scale. The Geluk Subgroup is an assemblage of mafic and intermediate to acid volcanic rocks, with a wider variety of pyroclastics (SACS, Handbook 8, p32). The Fig Tree and Moodies Groups predominantly consists of a sedimentary assemblage, the first largely argillaceous (particles < 4µm) and the latter arenaceous (sandy). The Fig Tree Group is represented in the map area by three formations. The oldest is the Sheba Formation consisting of greywacke overlain by the Belvue Road Formation which is predominantly shaly and characterized by banded ferruginous chert. The upper Schoongezigt Formation is mainly volcanic rock (Reimer, 1967; Anhaeusser, 1976b, pp. 256-258). The Moodies Group consists of repeated cycles of arenaceous and argillaceous rocks which accumulated in diverse alluvial and marginal marine and deltaic environments (Eriksson, 1978)

The hydrogeological unit underlies 4.9% of the map area. It forms a narrow north-eastern striking band within the granitoid and gneissic rocks from Badplaas to Komatipoort. This area is commonly referred to as the Barberton Mountain Land.

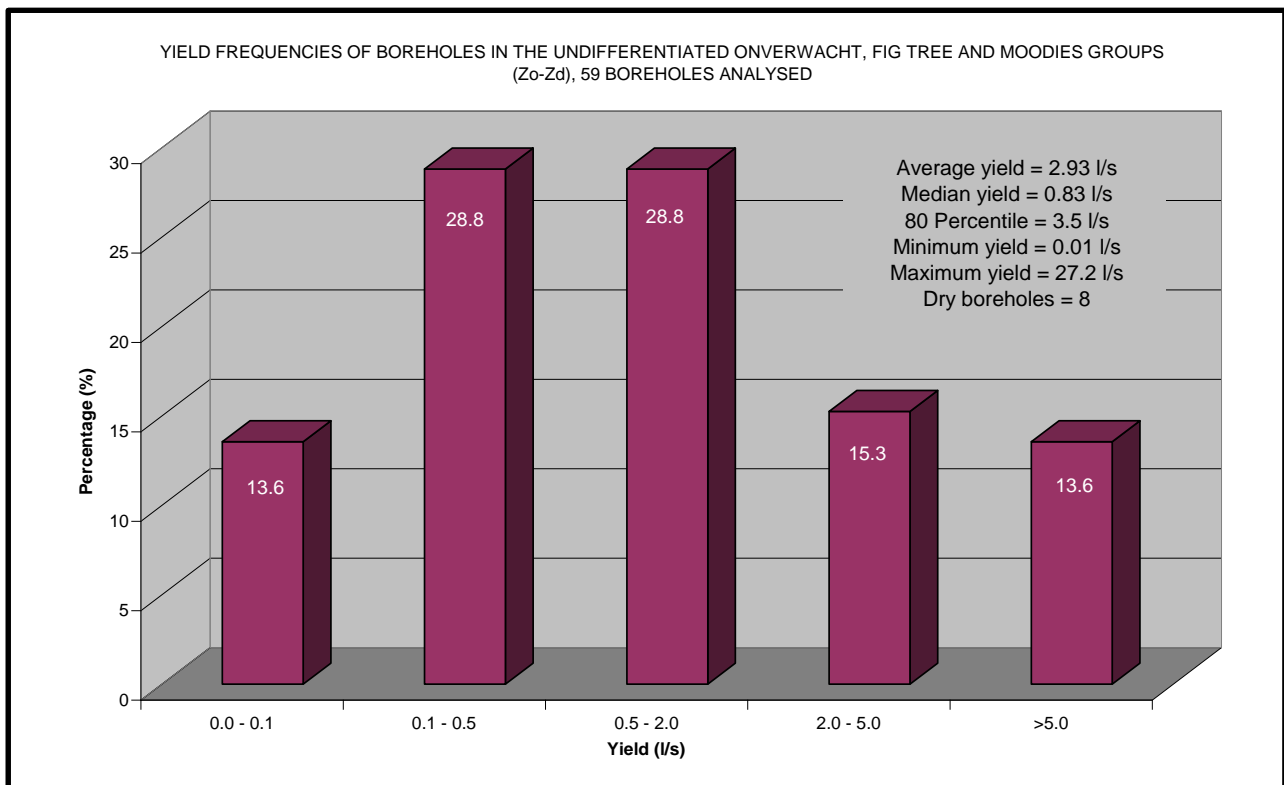


Figure 40: Yield frequency of boreholes in the undifferentiated Onverwacht, Fig Tree and Moodies Groups (Zo Zd).

Figure 40, p72 represents the maximum yield data of 59 data points: 57% of the boreholes have yields higher than 2l/s and an additional eight are reported to be drilled dry. Sixteen boreholes are reported with water strike depths which range between 15-61mbgl; 25% of the reported strike depths are between 10-30m, 31% between 30-40m and 38% between 40-70m. The data file with the recorded strike depths only reports the deepest strike with an accumulated maximum yield, therefore no correlation could be established between depth of strike and maximum yield. Static water levels were available for 36 sources, ranging from 2.22-44.77mbgl with a calculated average of 17.33mbgl.

Figure 41, p73 shows the dominant anions and cations presented as a stiff diagram compiled from 59 available chemical records. The water displays a calcium-magnesium-bicarbonate character, with elevated sodium levels; HCO_3^- is the dominant anion. The nitrate concentrations exceed the maximum allowable limits in 19.3% ($\text{N} > 20\text{mg/l}$) of the samples and the sodium and chloride concentrations in 4.8% of the samples ($\text{Na} > 400\text{mg/l}$, $\text{Cl} > 600\text{mg/l}$).

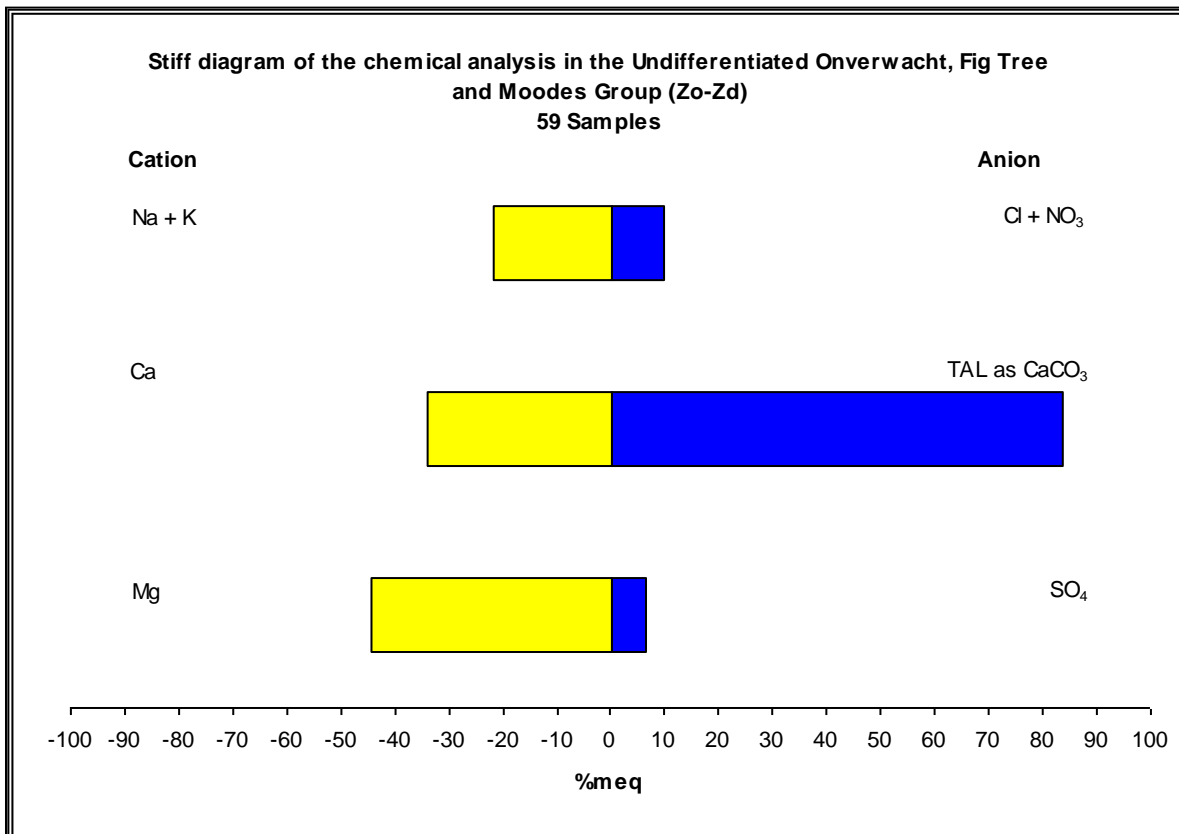


Figure 41: Stiff diagram representing chemistry for the undifferentiated Onverwacht, Fig Tree and Moodies Groups (Zo-Zd).

3.3.4.4 Unnamed Swazian Rocks (Zz)

Within the map area, various gneisses and granitoids of Swazian age occur predominantly in an area bordered by the rocks of the Transvaal and Karoo Supergroup and the Barberton Mountain Land. The unit consists of a suite of biotite-bearing trondhjemitic gneiss bodies mostly elongated in shape and bordered or surrounded by greenstones of the Barberton Sequence (Walraven, 1986). In the southern portion of the map bordering Swaziland an intrusive body consisting of mesocratic granite-gneiss represents the unit.

Maximum yield data is available for 142 boreholes (Figure 43, p74) and 23 boreholes are known to be dry. From the yield diagram 55.7% of the yields are less than 0.5l/s, 33.1% are between 0.5-2l/s and 11.3% yield more than 2l/s. Thirty five boreholes are reported with water strikes ranging between 11-90.6mbgl. The highest yielding strike depths are less than 30m. The main target in the search for groundwater will thus be deep weathered and fractured zones within recharged areas followed by contact zones along intrusive dykes. The static water levels are available for 90 sources, ranging from 1.1-36.8mbgl with the average as 11.58mbgl.

Although the unit is the seventh biggest unit occupying 4.6% of the map area it is rated a poor aquifer due to the low maximum yields.

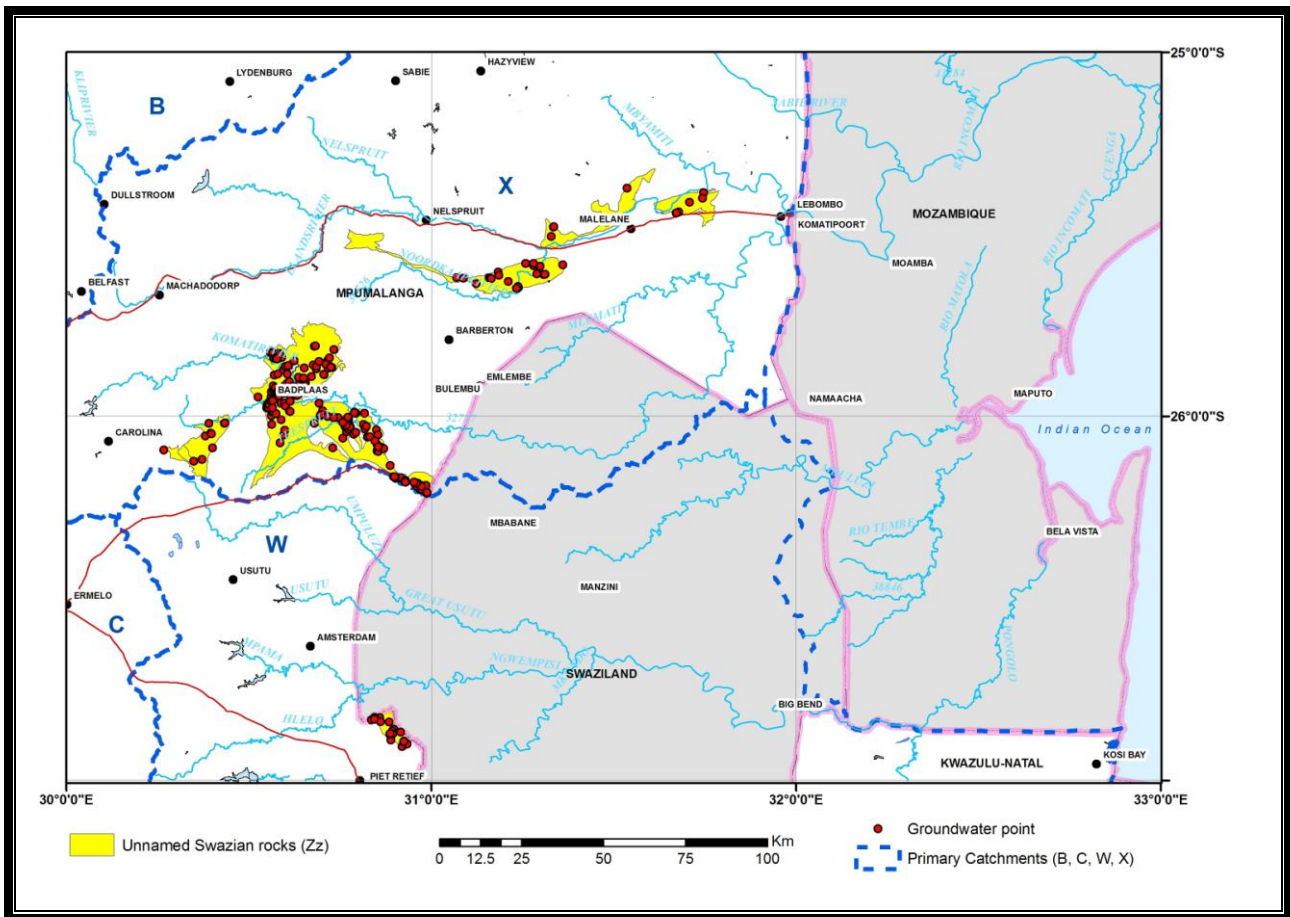


Figure 42: Geographical distribution of the unnamed Swazian rocks (Zz) and associated groundwater sampling points.

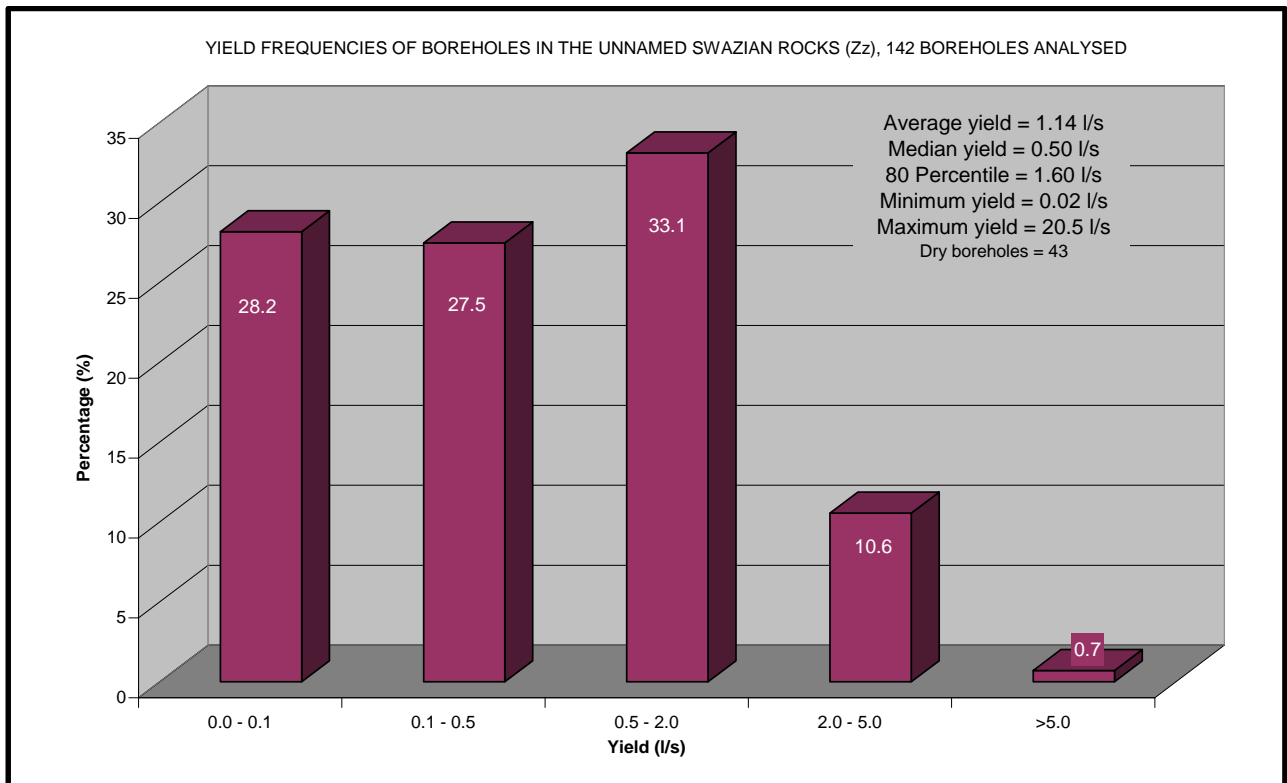


Figure 43: Yield frequency of boreholes in the unnamed Swazian rocks (Zz).

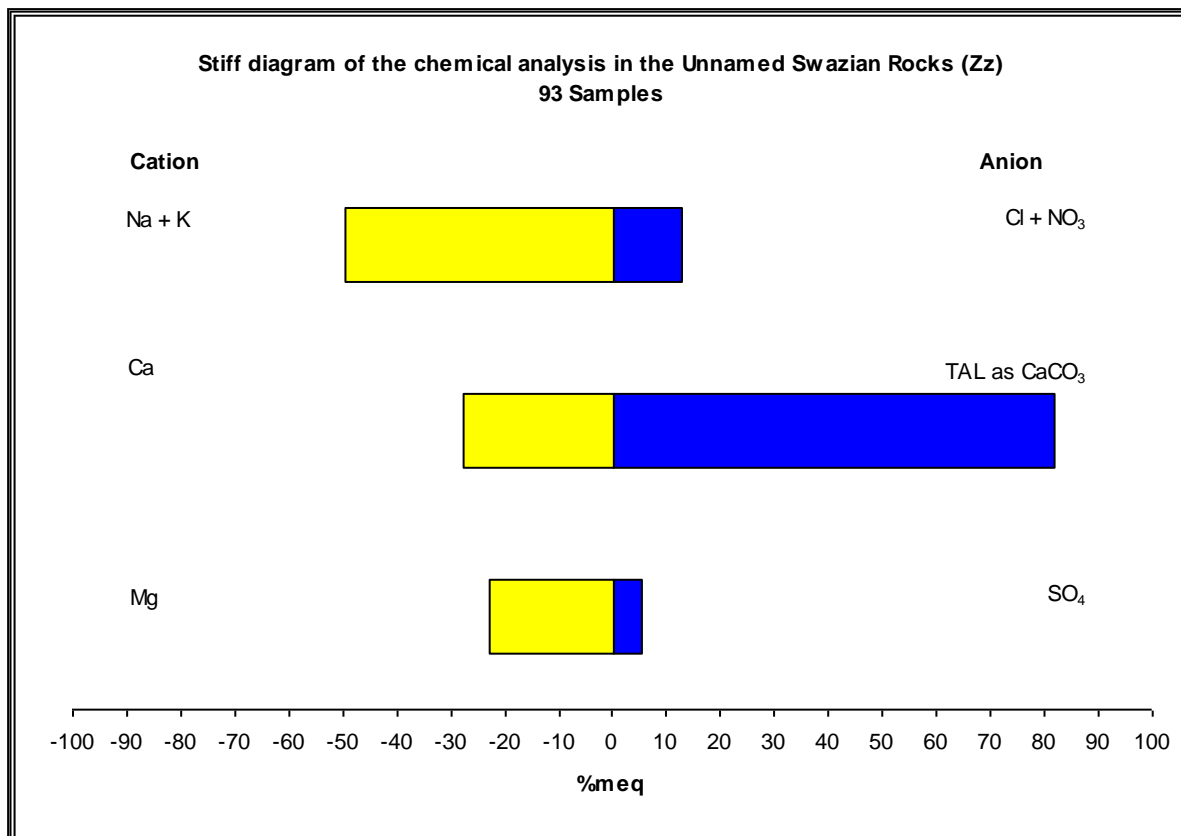


Figure 44: Stiff diagram representing chemistry for the unnamed Swazian rocks (Zz).

The water of the Unnamed Swazian rocks (Zz), displays a sodium-calcium-magnesium-bicarbonate water type (Figure 44, p75). The dominant anion is HCO_3^- . The fluoride concentrations exceed the maximum allowable limit in 19.9% ($\text{F} > 1.5\text{mg/l}$) and nitrate in 8.6% ($\text{N} > 20\text{mg/l}$) of the total samples.

3.3.4.5 Nelspruit Suite (Ze)

The unit dominates the northern part of the map sheet in the area between rocks of the Transvaal Supergroup (Drakensberg escarpment) in the west and the border with Mozambique in the east. The unit consists of granite, porphyritic granite and migmatite. Ruff topography with prominent hills and zones of coarse-grained pegmatite zones is characteristic of areas underlain by the unit. Deep chemical weathering occurs in higher rainfall zones as along the Drakensberg escarpment while the hilly area around Nelspruit is more un-weathered with prominent outcrop. The granite is grey to white, medium-to-coarse-grained. The porphyritic granite is similar with abundant large phenocrysts (up to 5cm). Migmatite and gneissic variants is most prominent along the contact zone with the rocks of the Barberton Sequence and along the Crocodile River (Walraven, 1986).

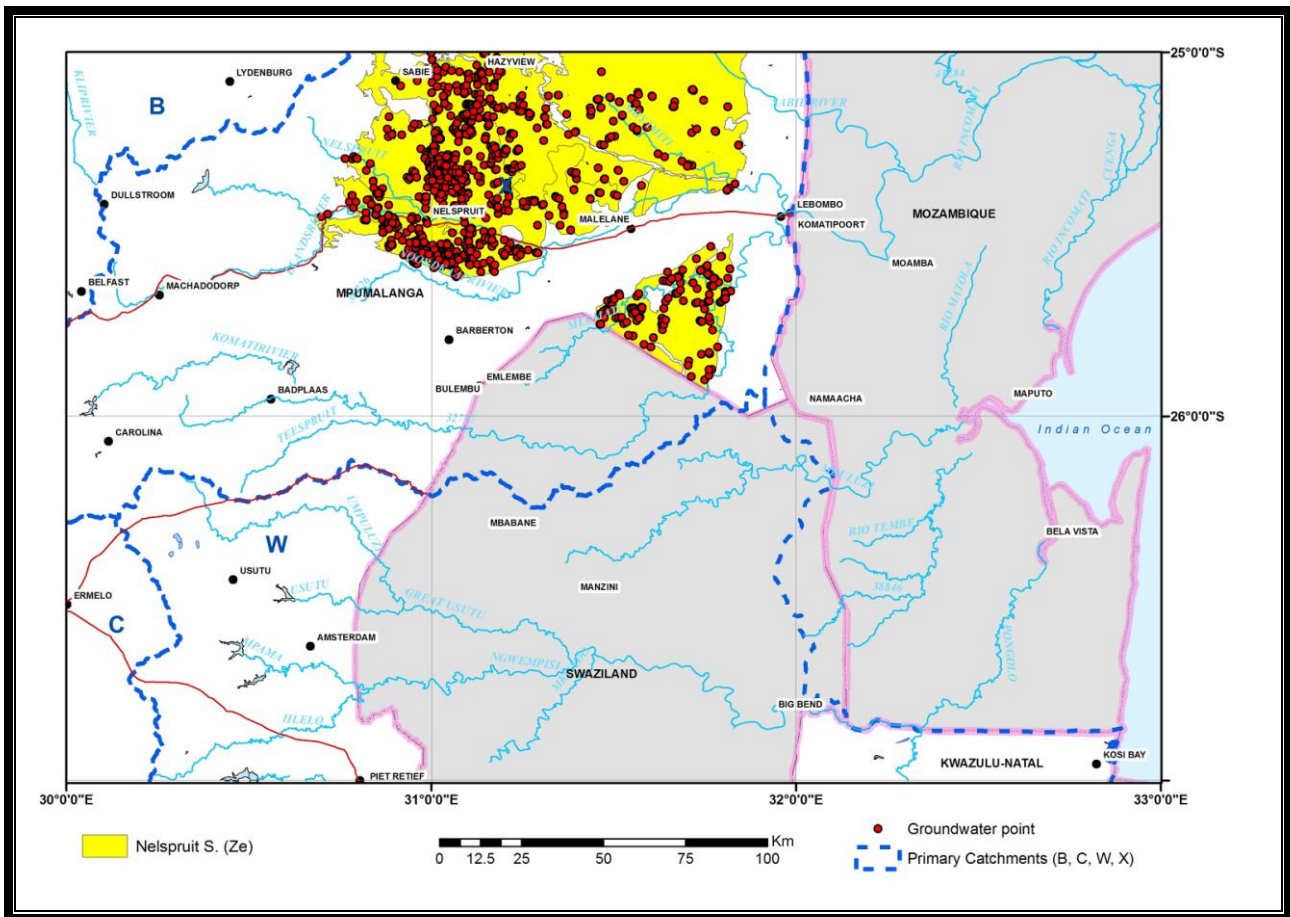


Figure 45: Geographical distribution of the Nelspruit Suite (Ze) and associated groundwater sampling points.

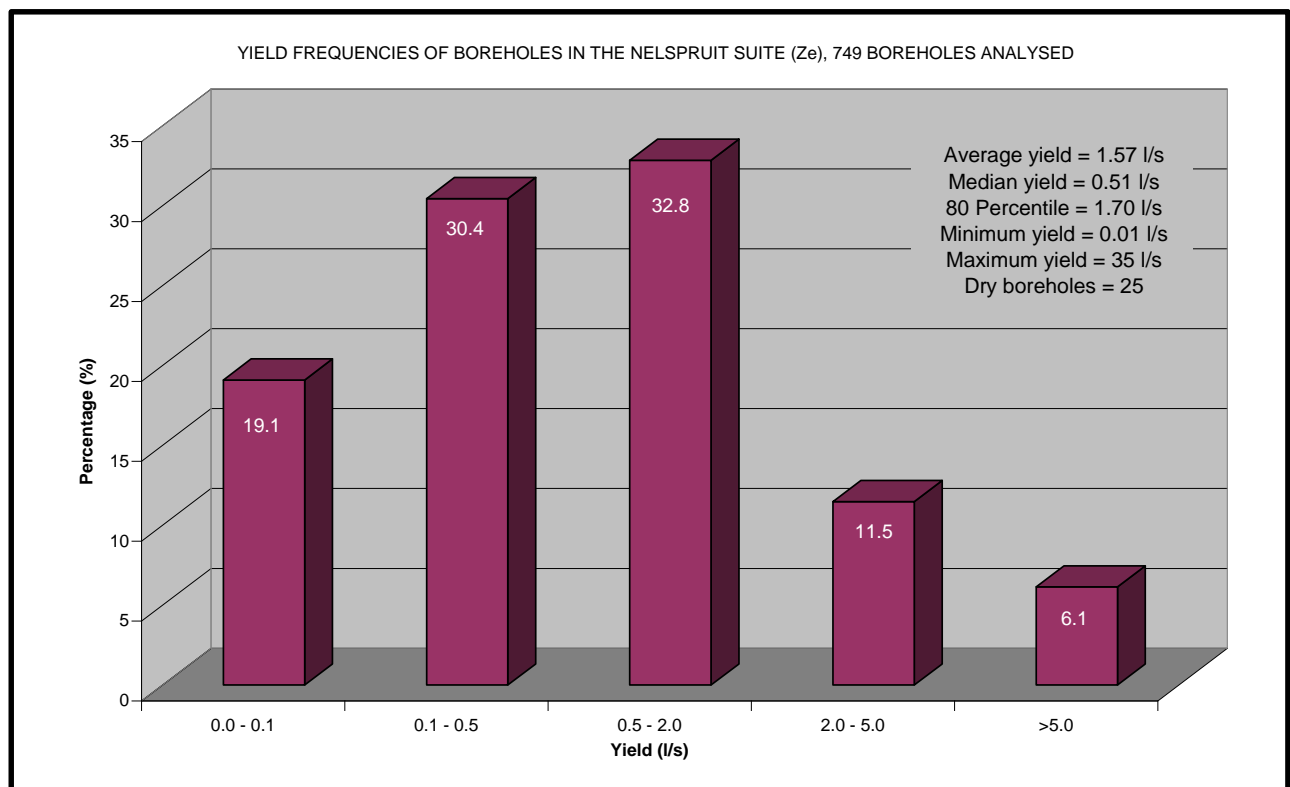


Figure 46: Yield frequency of boreholes in the Nelspruit Suite (Ze).

The yield diagram, (Figure 46, p76) represents the maximum yields of 749 sources; 6.1% yield more than 5l/s, 11.5% are between 2-5l/s, 82.3% yield less than 2l/s and 25 boreholes are dry. Water strike depths are available for 44 or 5.8% of these boreholes. In 44.7% of the cases the deepest water strike is more than 40m with the deepest recorded strike at 73m, which also represents the highest maximum yield (30l/s). The average calculated strike depth is 41.5m. It should be noted that the strike depth available on the data sheets used represent the deepest strike and an accumulated yield. From the 44 boreholes with water strike depths, 7 or 15.9% have yields exceeding 5l/s; 6 sources, or 85%, have recorded strike depths exceeding 34m. The minimum recommended depth to drill exploration boreholes within the unit is 80m. The calculated average static water level is 13.83mbgl.



Photo 10: In the Kruger National Park, granite-gneiss of the Nelspruit Suite is well exposed in numerous bare exfoliation domes, formed by the splitting-off of rock slabs by a process of mechanical weathering. This often results in spectacular patterns of stacked boulders appearing almost as if there was human interference (photo W.H. Du Toit, 2006).

Photo 11: Fractures in the gneiss of the Nelspruit Suite was initially formed by a process of mechanical weathering. Over an extended period of time chemical weathering caused by penetrating rainwater enlarged the fractures (photo W.H. Du Toit, 2006).

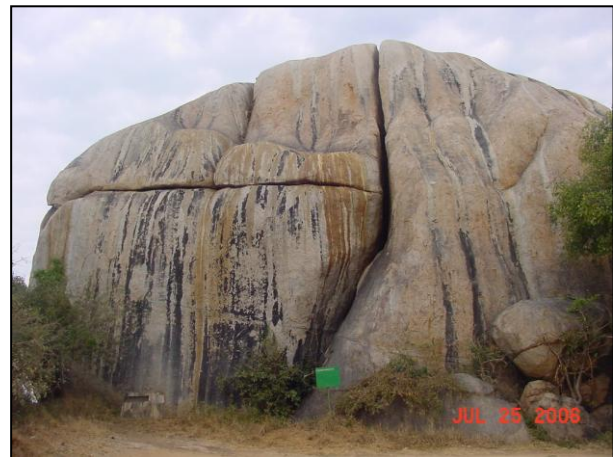


Figure 47, p78 shows the dominant anions and cations presented as a stiff diagram compiled from 472 available chemical records. The water displays a sodium-bicarbonate character with elevated calcium and magnesium concentrations. This type of water is generally related to the movement of groundwater from intensive recharge areas and normally indicates a cation exchange process. It is dominated by the cation Na^+ and the anion HCO_3^- .

The percentage samples with concentrations exceeding the maximum allowable limit for domestic use for the following elements are as follows; (refer to Table 7 to Table 9, p35 to p39)

- fluoride 33.3% (F->1.5mg/l)
- nitrate 11.09% (N->20mg/l)
- sodium 4.5% (Na->400)mg/l)
- magnesium 1.3% (Mg->100mg/l).

Agricultural practices may contribute to the high number of elevated nitrate concentrations.

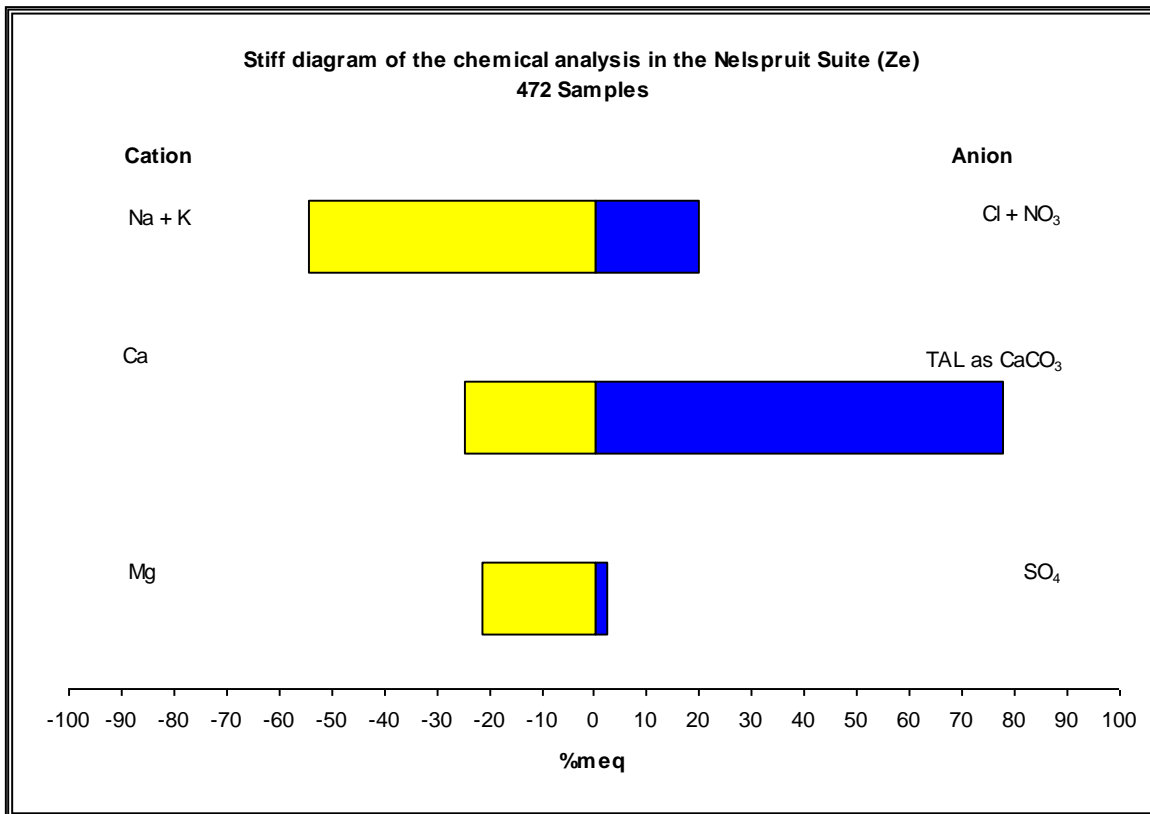


Figure 47: Stiff diagram representing chemistry for the Nelspruit Suite (Ze).

3.3.4.6 Nsuzi Group (Zn)

The Nsuzi Group represents the oldest group of the Pongola Sequence. It is divided into two formations. The lower Mantonga Formation consists of quartzite alternating with ferruginous quartzite and basaltic lavas with an estimated thickness of 300m. The overlying Bivane Formation has an estimated thickness of 2000m and consists of basalt and andesite with interlayered amygdaloidal zones (Hammerbeck, 1982). The unit occurs as various narrow zones in the southern part of the map sheet, extending from Amsterdam south-easterly up to the end of the map sheet at the border with Swaziland.

The yield frequency diagram (Figure 49, p79) represents the maximum yield of 13 data points. Most of the boreholes within the unit have recorded yields ranging between 0.5-2l/s. Two water strike depths are available - both are between 41-42m with recorded yields of 0.8 and 1l/s. Seventeen boreholes have recorded static water levels that ranges between 4-20.5mbgl. The average static water level for the unit is 10.17mbgl.

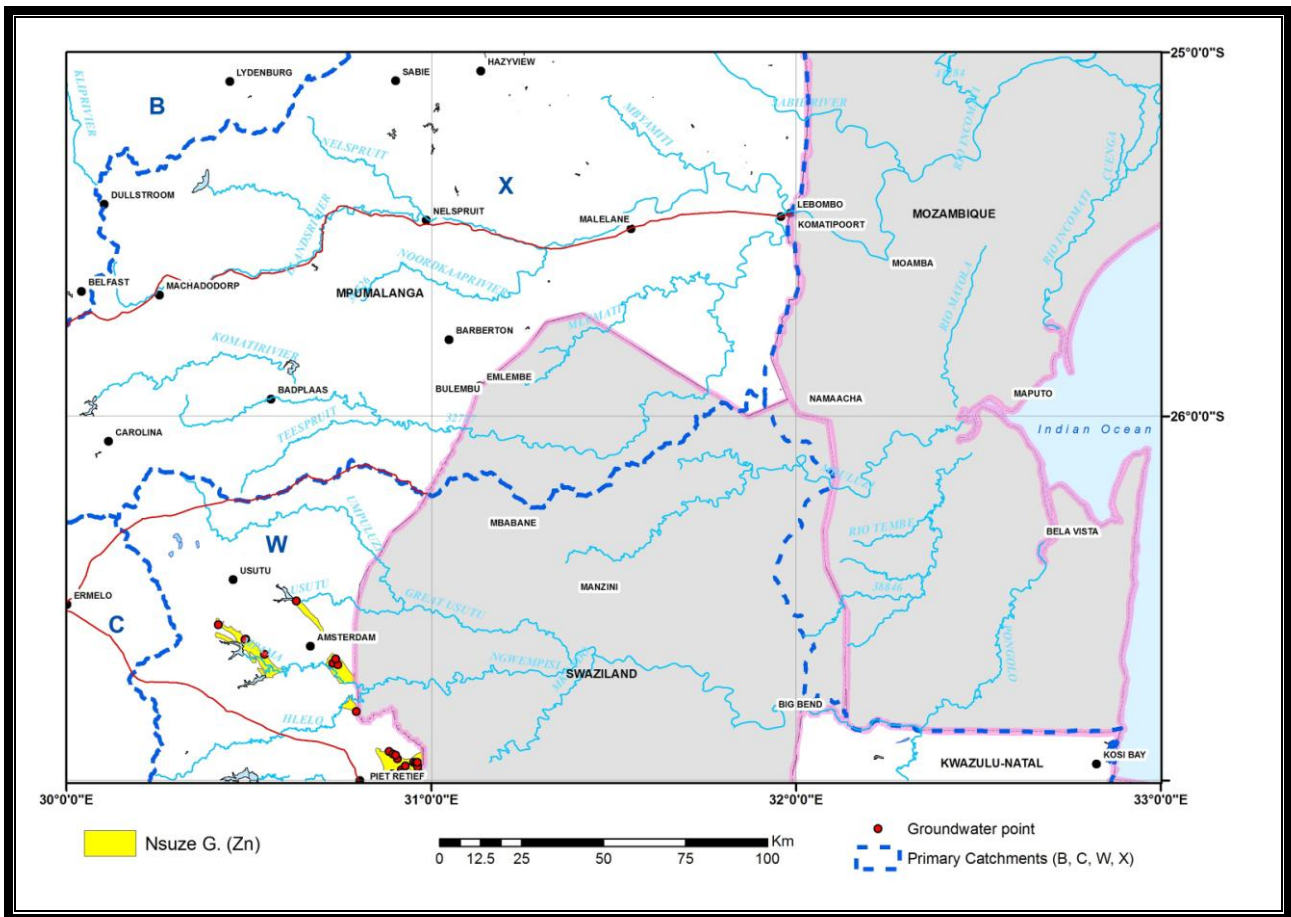


Figure 48: Geographical distribution of the Nsuzi Group (Zn) and associated groundwater sampling points.

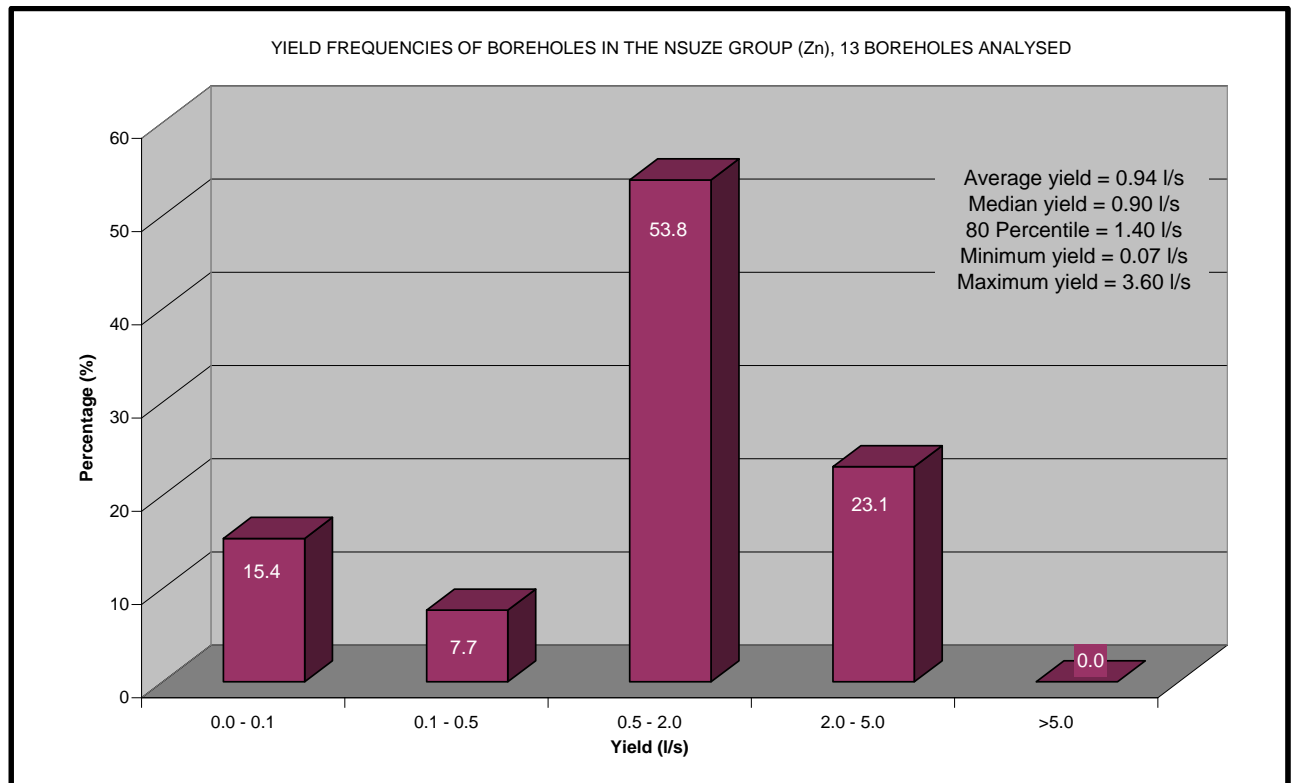


Figure 49: Yield frequency of boreholes in the Nsuzi Group (Zn).

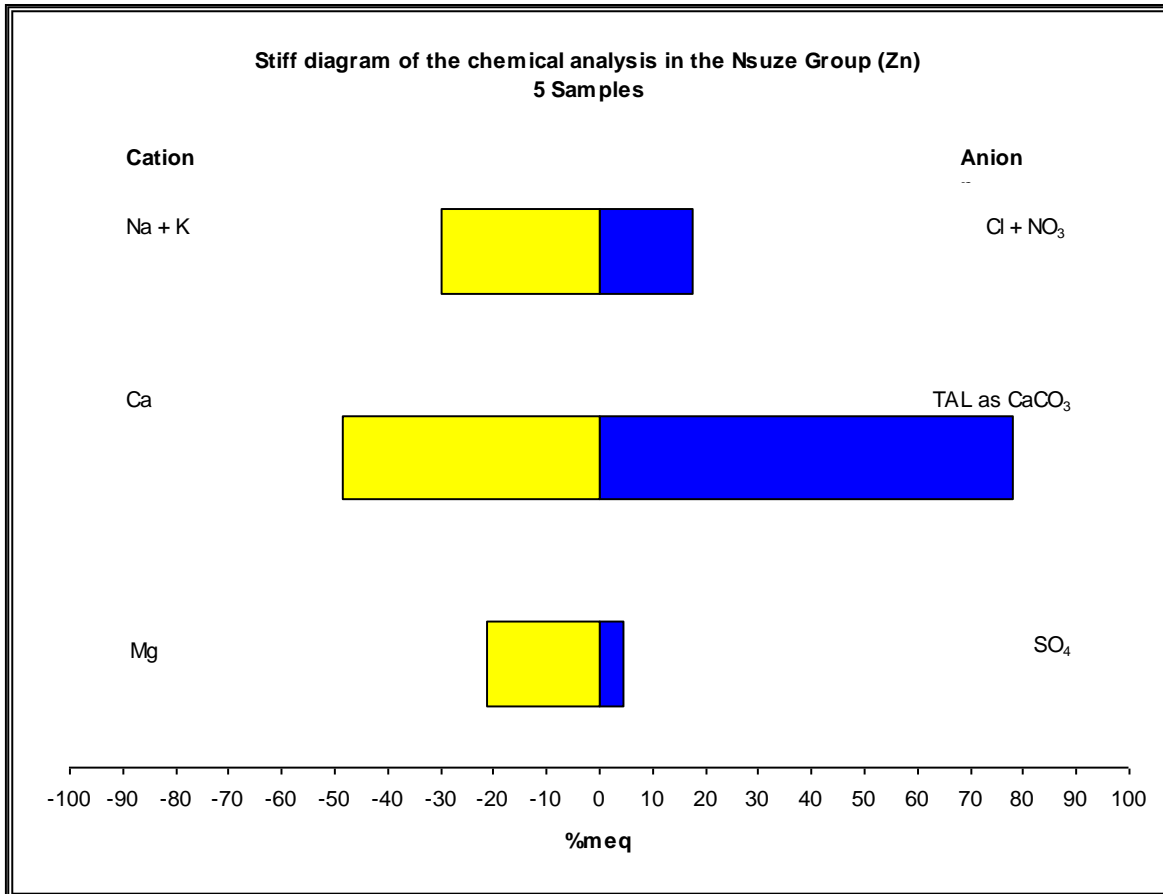


Figure 50: Stiff diagram representing chemistry for the Nsuzze Group (Zn).

Only 5 chemical analyses were available for characterization of the unit of which only two passed data quality checks. From these two data sets the water is classified as a calcium-sodium-magnesium-bicarbonate type.

3.3.4.7 Kaap Valley Granite (Zka)

A single occurrence south-west of the Barberton Mountain Land represents the unit. The unit is considered one of the oldest granitoid intrusives that intruded and partly deformed the Barberton Sequence. The central zone is massive but the outer zone exhibits strong foliation parallel to the contact. The rock is hornblende tonalitic gneiss with hornblende notably more abundant than in similar related intrusive bodies of the area. Basic dykes trending predominantly south-easterly tend to stand out due to the more resistive nature thereof (Walraven, 1986).



Photo 12: Proterozoic dyke in the Kaap Valley Granite between Badplaas and Barberton. Dykes are important targets for successful groundwater development in the map area (photo W.H. Du Toit, 2006).

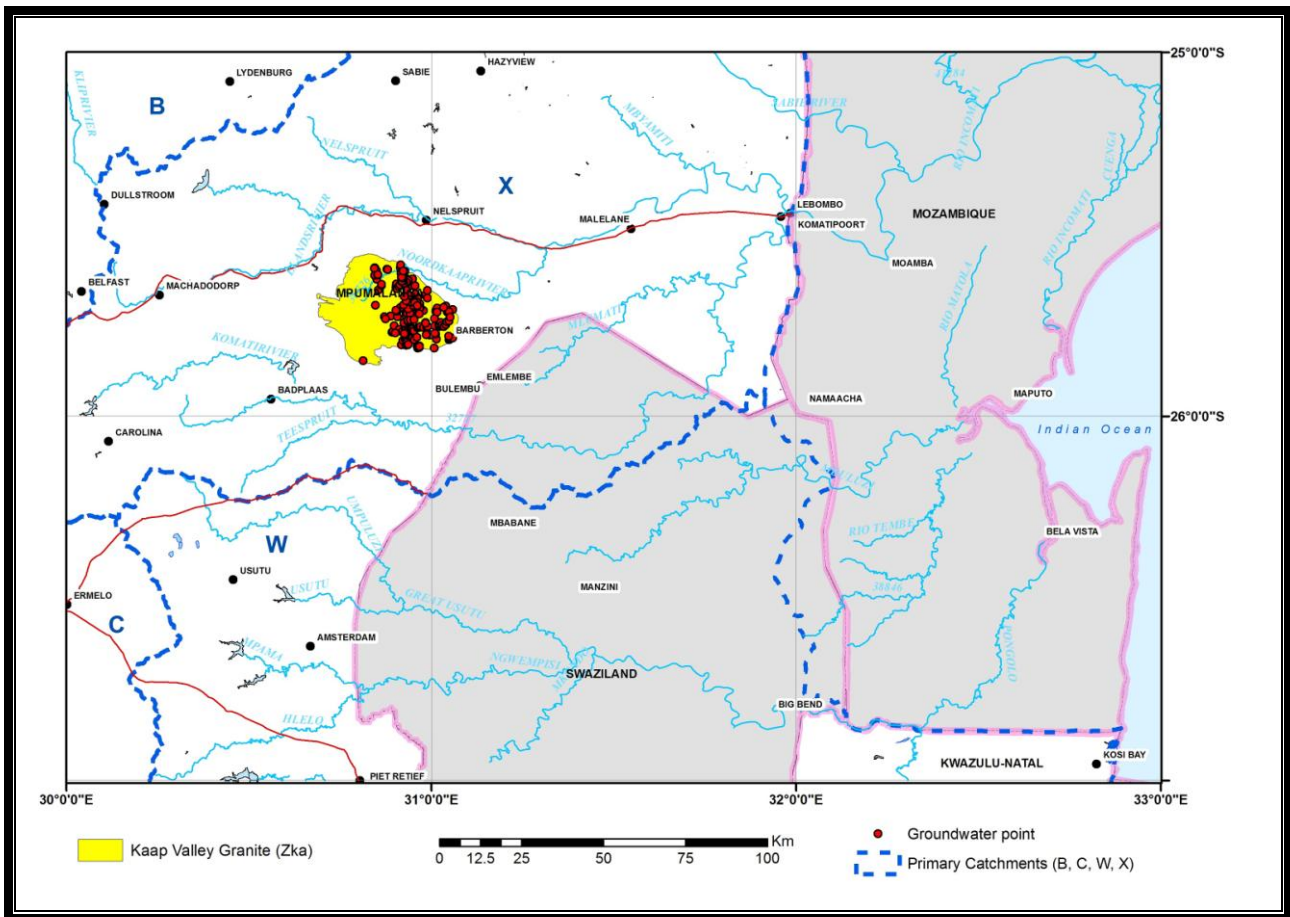


Figure 51: Geographical distribution of the Kaap Valley Granite (Zka) and associated groundwater sampling points.

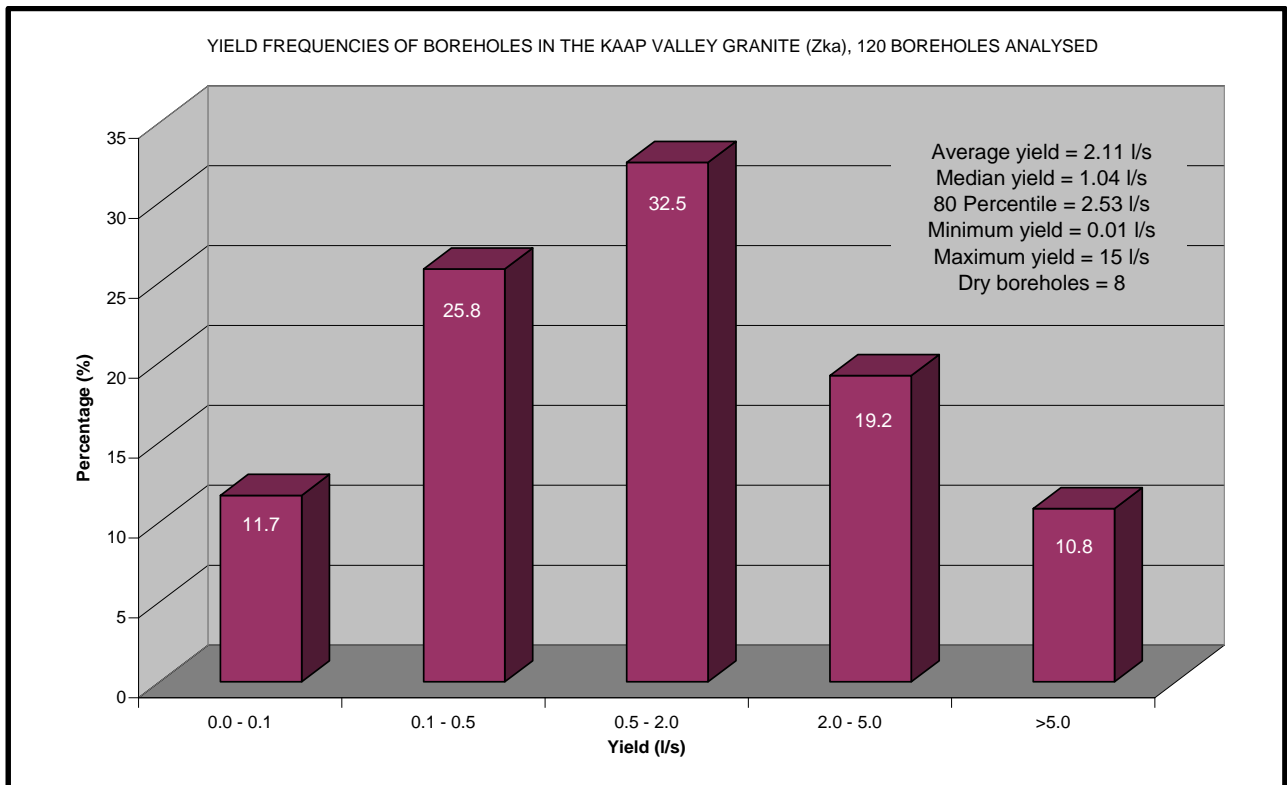


Figure 52: Yield frequency of boreholes in the Kaap Valley Granite (Zka).

The yield frequency diagram (Figure 52, p81) represents the maximum yield of 120 boreholes. Most of the boreholes yield between 0.5-2l/s (32.5%), 37.5% are less than 0.5l/s and 30% are yielding more than 2l/s. Twenty six boreholes with data on water strike depths are available ranging from 16-52m with a calculated average depth of 29.5m. From these 3 or 2.76% have yields exceeding 5l/s. The strike depths of the strongest holes exceed 37m. Seventy nine boreholes have recorded drilling depths ranging from 16-100m - the average is 52.7m. Sixty three boreholes with data on the static water level are available. The static water level ranges between 2.81-37mbgl - the average is 16.22mbgl. It is advisable to plan exploration boreholes within the unit to be drilled to at least 66m.

Photo 13: Fractured Kaap Valley granite in a road cutting between Badplaas and Barberton (photo W.H. Du Toit, 2006).

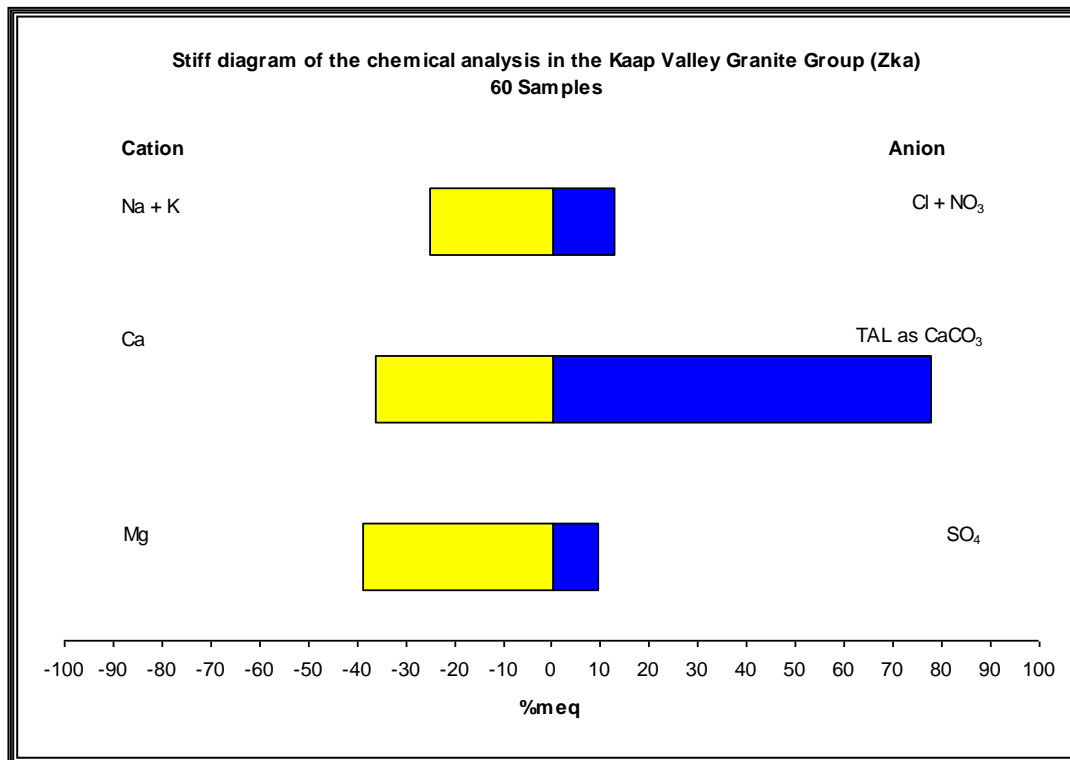


Figure 53: Stiff diagram representing chemistry for the Kaap Valley Granite (Zka).

Figure 53, p82 shows the dominant anions and cations presented as a stiff diagram compiled from 60 available chemical records. The water displays a calcium-magnesium-bicarbonate character, with elevated sodium levels. The dominant anion is HCO₃⁻. Although 45% of the samples failed the electro neutrality quality check (EN ± 10%), the data were still used as it did not influenced the results of the stiff diagram. The nitrate concentrations exceeded the maximum allowable limit for domestic use in 35% (N > 20mg/l) of the samples. The measured EC values in 90% of the samples are less than 70mS/m. This could relate to the high percentage of

analyses failing the acceptable electro neutrality range as one element not analysed can influence the ion balance in good quality water.

3.3.4.8 Various intrusive rocks of the Mozaan Group and Nsuzze Group (Z-Rg)

The unit represents leucocratic biotite granite occurring along the southern flank of the Pongola Sequence in the southern part of the map sheet.

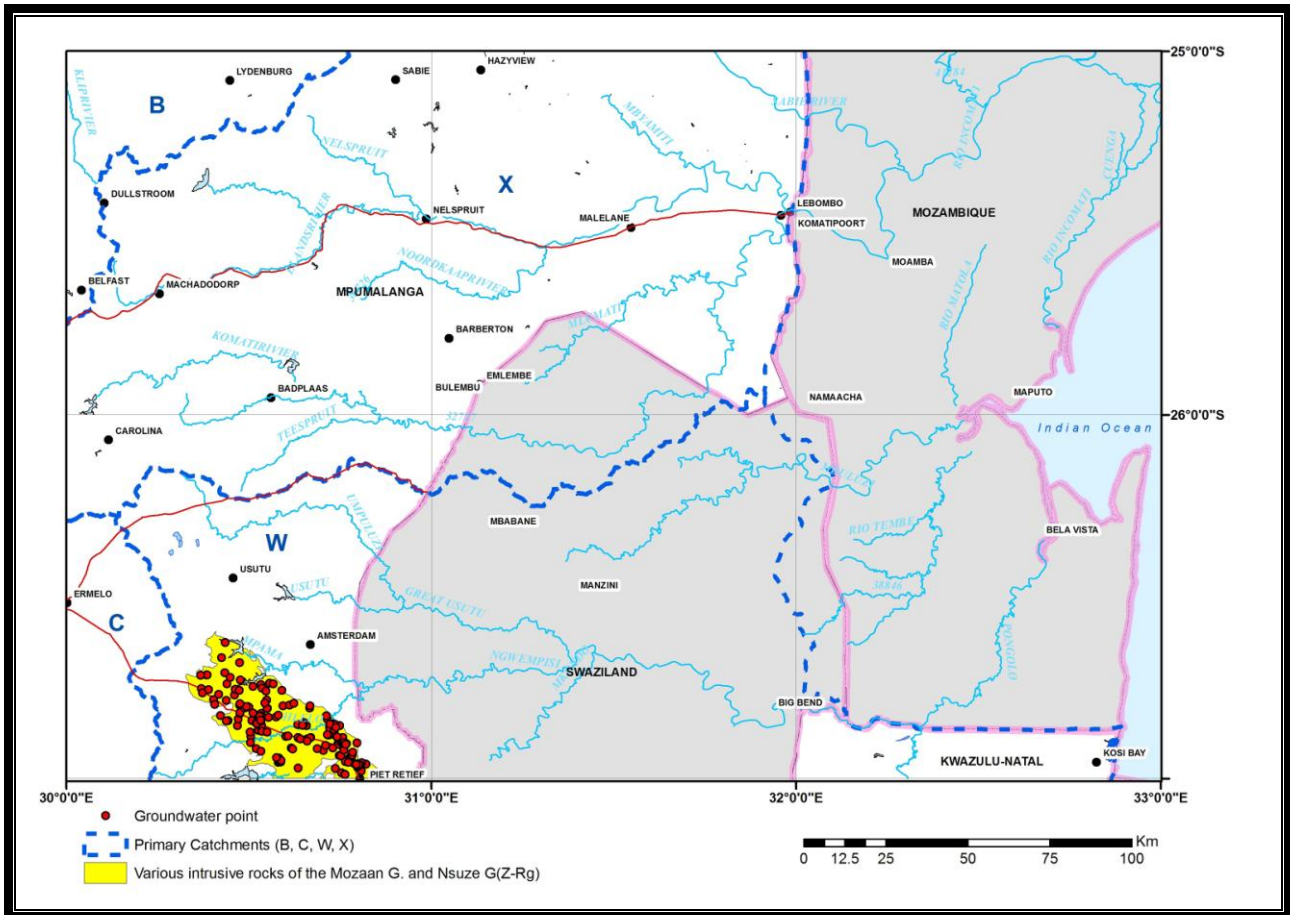


Figure 54: Geographical distribution of the various intrusive rocks of the Mozaan and Nsuzze Groups (Z-Rg) and associated groundwater sampling points.

The yield frequency diagram (Figure 55, p84) represents the maximum yield of 21 data points. Of these 42.9% fall within the range 0.5-2l/s, 33.3% yield less than 0.5l/s and 23.8% yield more than 2l/s. Twenty two boreholes have recorded depth and static water level data, the depth of boreholes ranges between 19-140m; the average is 54.05m. The static water level ranges between 3-26mbgl with an average of 10.59mbgl.

Figure 56, p84 represents the Stiff diagram compiled from 10 available records. Five of these records did not pass the quality checks but still used as it did not influence the results of the stiff diagram. The water is of two types either a Calcium-Magnesium-Bicarbonate or Sodium-Bicarbonate water type. The EC values and important macro elements falls within the ideal domestic water quality range.

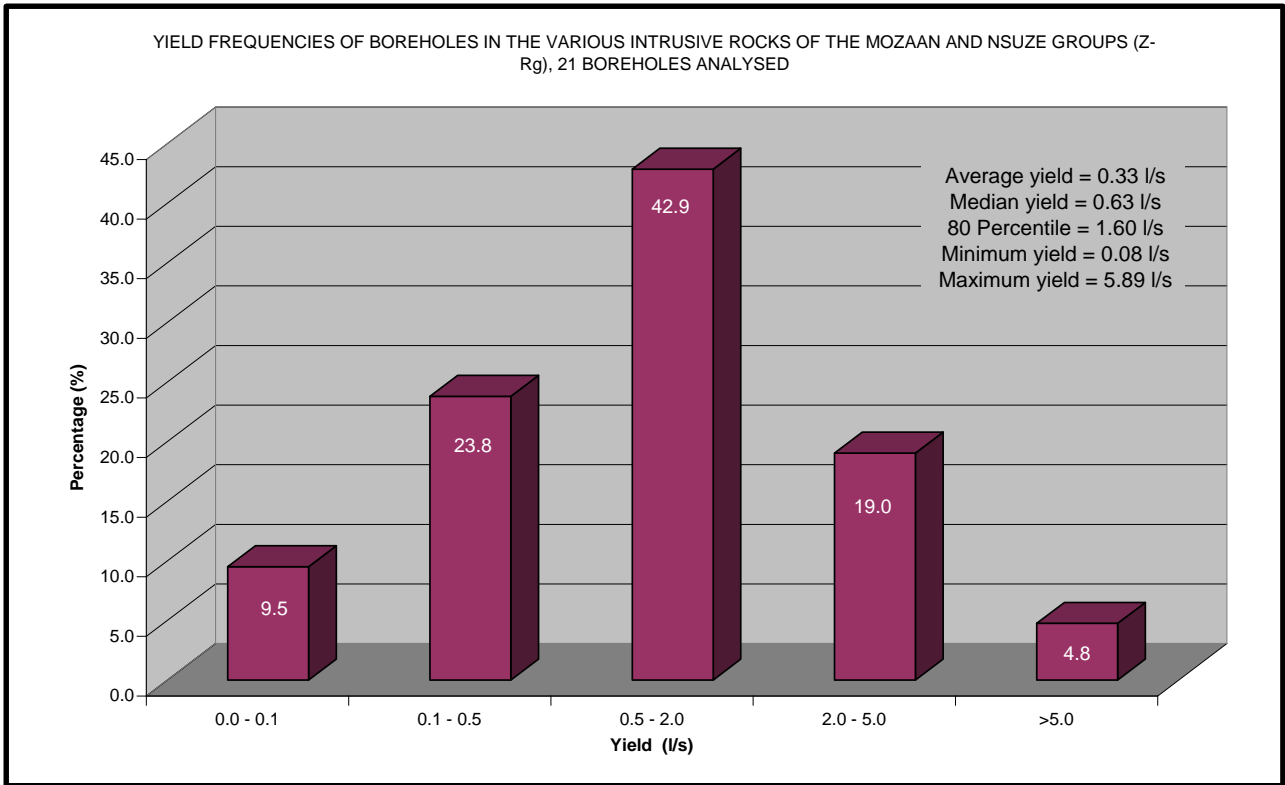


Figure 55: Yield frequency of boreholes in the various intrusive rocks of the Mozaan and Nsuze Groups (Z-Rg).

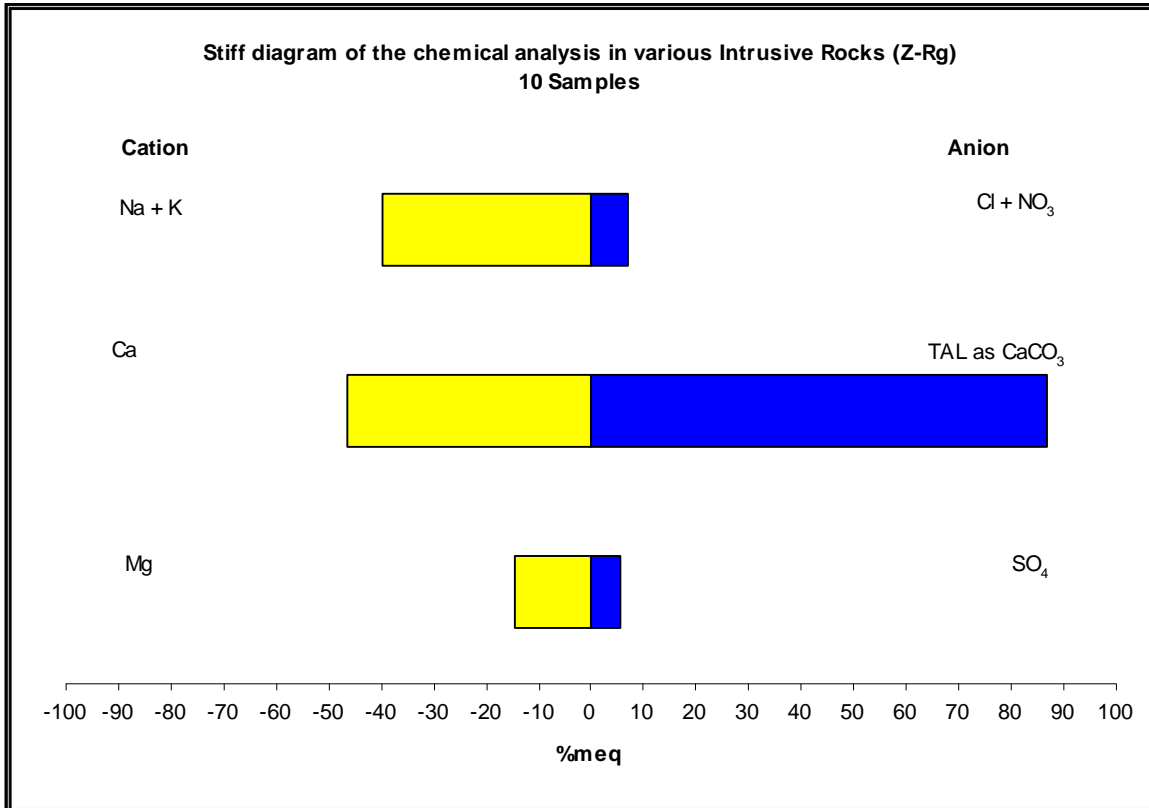


Figure 56: Stiff diagram representing chemistry for the various intrusive rocks of the Mozaan and Nsuze Groups (Z-Rg).

3.3.4.9 Dalmein Granite (Zda)

The unit occurs as a single oval shaped granitoid pluton south-south-west of the Barberton Mountain Land and near the border with Swaziland. The pluton was emplaced discordantly during the final intrusive phase into the Barberton Sequence. It is homogenous, coarse-grained, commonly porphyritic, K-rich ranging from adamellite to Syenite in composition (Anhaeusser and Robb, 1980).

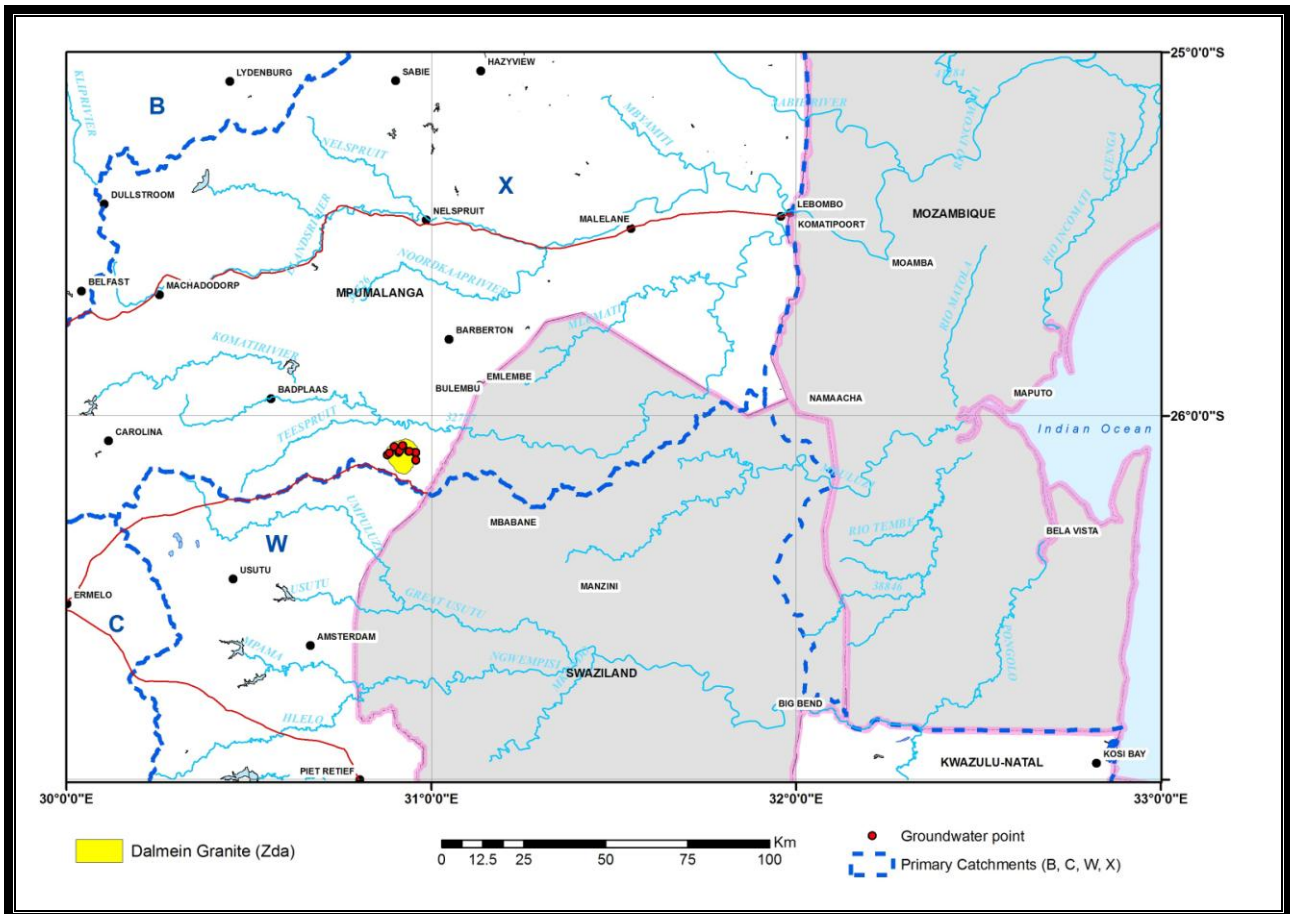


Figure 57: Geographical distribution of the Dalmein Granite (Zda) and associated groundwater sampling points.

The yield frequency diagram, (Figure 58, p86) represents the maximum yield of 9 sources. The unit is an insignificant aquifer due to the low reported yields and the small occurrence of the unit on the map sheet (0.21% of map area). Five static water level data points were used for analysis, ranging from 3.5-37.4mbgl - the average is 14.94mbgl. The drilling depths of 6 boreholes were available ranging from 49-102m - the average is 73m. Water strike depths were available for 3 sources ranging between 32-44m.

Figure 59, p86 represents the chemical analysis of 10 sources. The water displays a calcium-magnesium-bicarbonate character, with elevated sodium levels and HCO_3^- as the dominant anion. Fluoride concentrations exceeding the maximum allowable limit for domestic water ($F > 1.5\text{mg/l}$) were found in 30% of the samples.

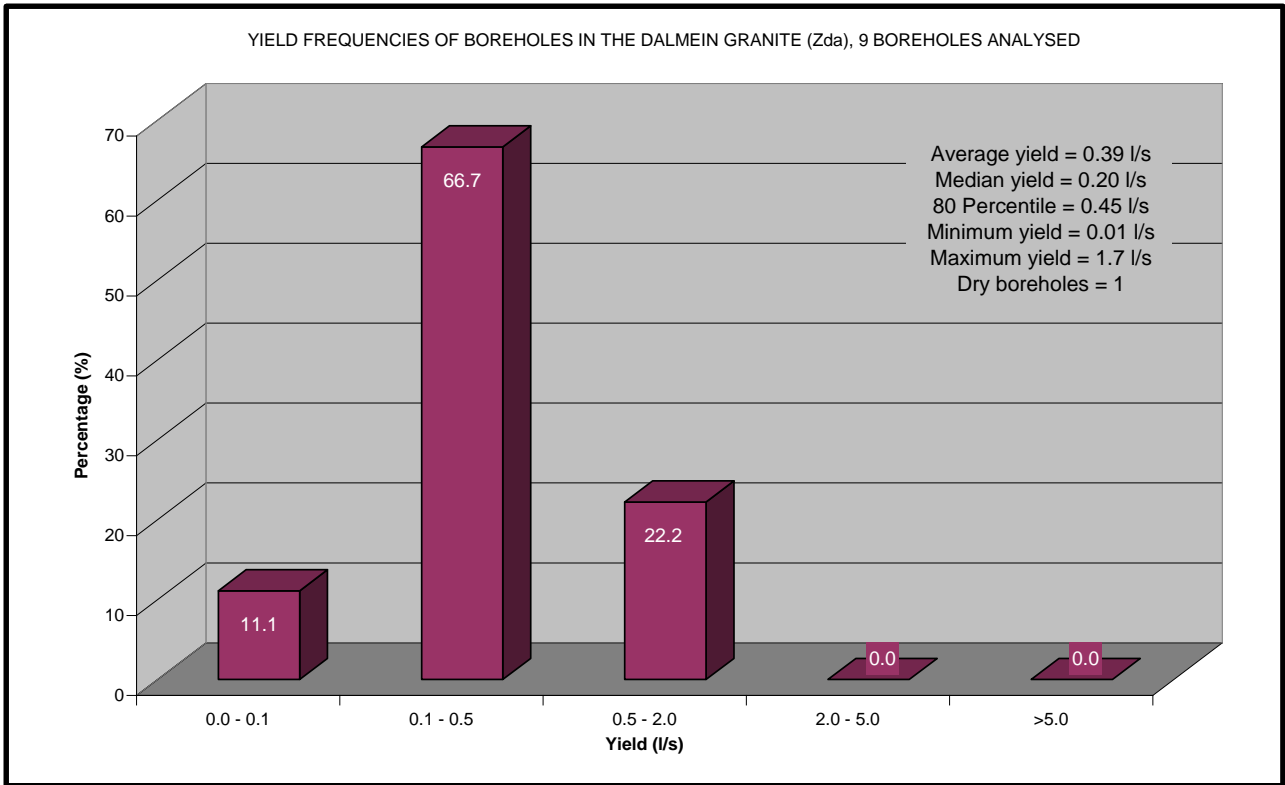


Figure 58: Yield frequency of boreholes in the Dalmein Granite (Zda).

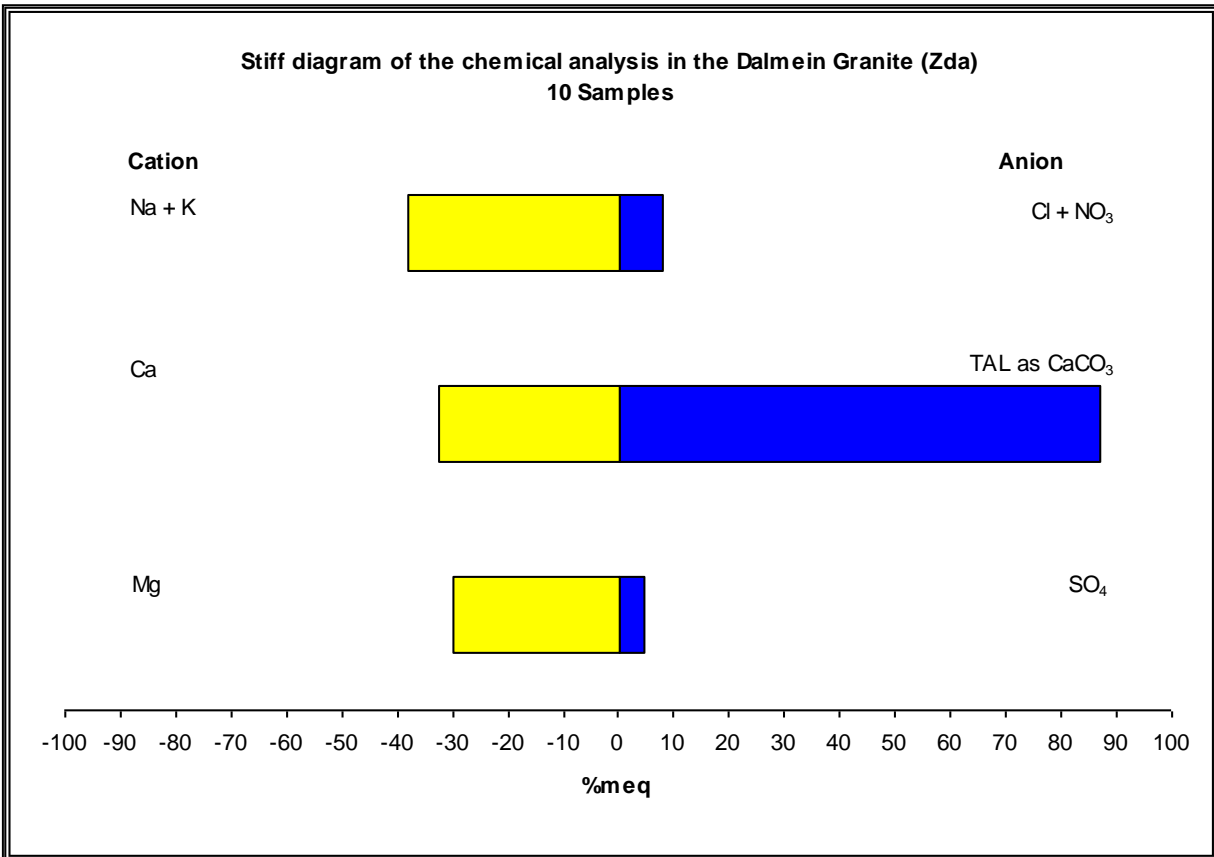


Figure 59: Stiff diagram representing chemistry for the Dalmein Granite (Zda).

3.3.4.10 Hebron Granodiorite (Zhe)

Intrusive into the Nelspruit Suite, the unit occurs as a single isolated pluton approximately 28km north-north-west of Nelspruit and occupying 0.21% of the map area. It is massive, medium-grained and blue-grey in colour. Two other small narrow occurrences in the same area are described (Visser and Verwoerd, 1960) but are not shown on the map. Thin dykes and veins consisting of medium-to-fine grained biotite granite occur abundantly and widely within the Nelspruit Suite. It is considered to be part of the Hebron Granodiorite (Robb, 1977).

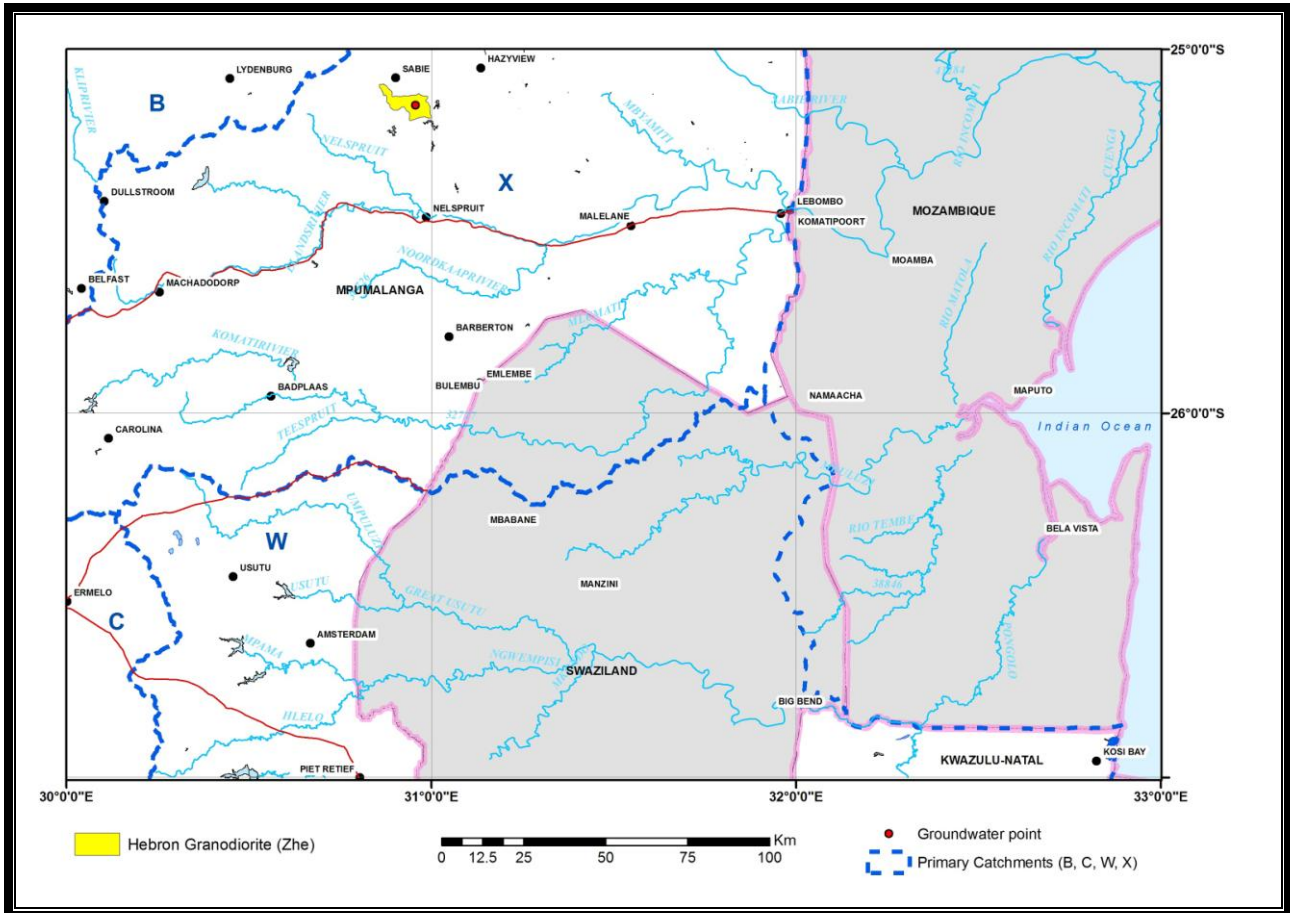


Figure 60: Geographical distribution of the Hebron Granodiorite (Zhe) and associated groundwater sampling points.

No chemical or yield data was available for the characterization of the unit.

3.3.4.11 Undifferentiated rocks of the Thole and Piet Retief Suite (Rth-Rup)

The ultramafic to mafic rocks of the Thole Suite intruded as sheets and sills predominantly into the strata of the Mozaan Group of the Pongola Sequence (Hammerbeck, 1982). As most of these occur as small outcrops they were not shown on the map sheet. A single outcrop represents the unit on the map sheet that occur north-north-east of Amsterdam. It intruded into the granitoid rocks of the Mpuluzi Batholith. Rocks of the Piet Retief Suite consist of pyroxenite, quartz gabbro, magnetite gabbro, gabbro and hyperite, occurring as isolated massifs intruded into the basement rocks (Walraven, 1986). Insufficient data records for the maximum yield and groundwater chemistry prevented the proper hydrological characterization of the unit.

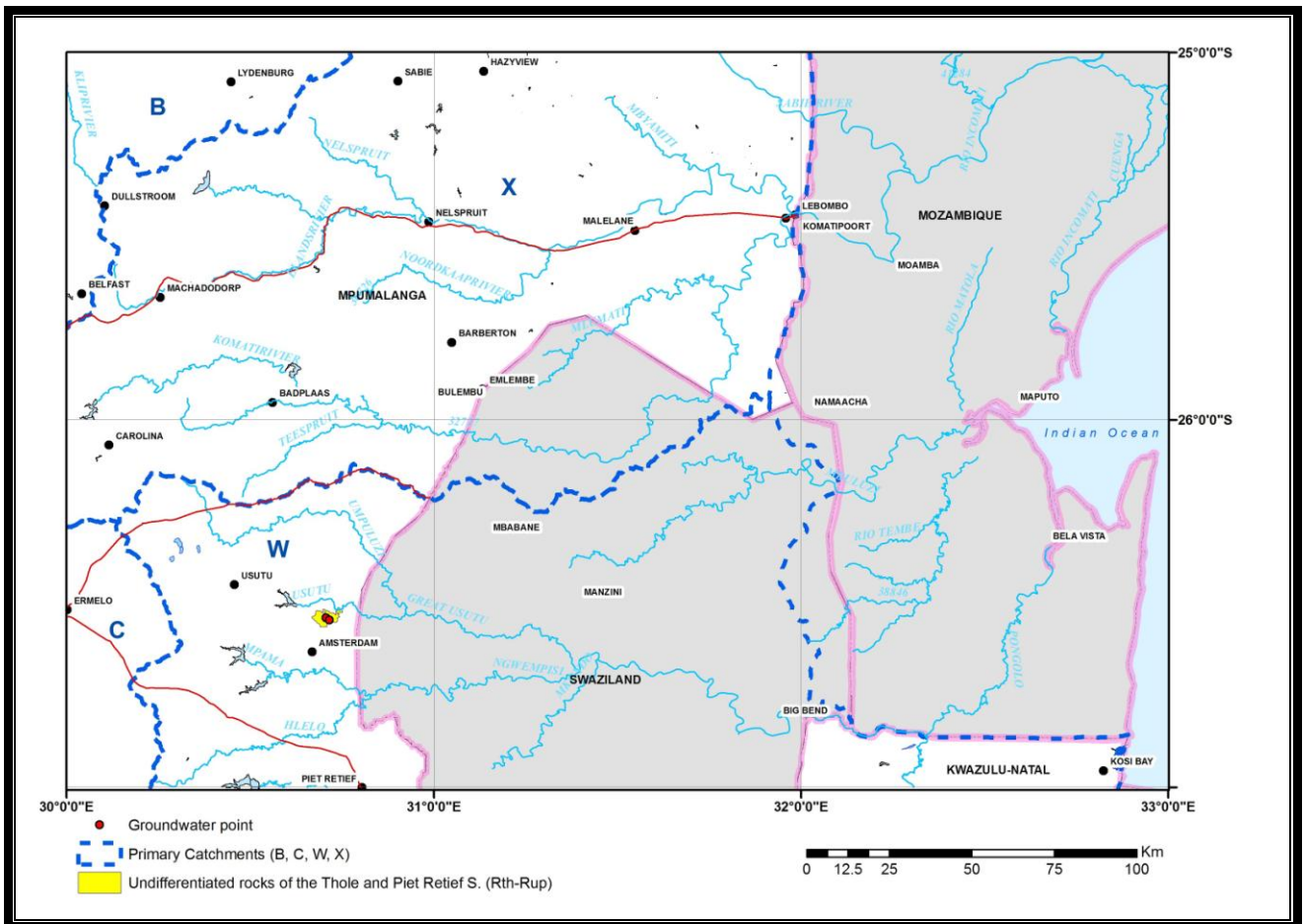


Figure 61: Geographical distribution of the undifferentiated rocks of the Thole and Piet Retief Suite (Rth-Rup) and associated groundwater sampling points.

3.3.4.12 Undifferentiated rocks of the Mozaan Group, Amsterdam Formation, and Usushwana Complex (Rm-Ru)

The Mozaan Group, Amsterdam Formation and Usushwana Complex are grouped under a single hydrogeological unit. The unit occurs on the map sheet in a south-easterly trending zone from an area north of Amsterdam towards the border of Swaziland. The Mozaan Group represents the younger upper part of the Pongola Sequence and is estimated to be 2300m thick. It is of sedimentary origin and consists of quartzite, ferruginous quartzite and ferruginous shale. The Amsterdam Formation represents an extrusive phase and consists primarily of intermediate to acid volcanic rocks. The Usushwana Complex consists of intrusive igneous rock and is divided into the Piet Retief Suite representing the basic rocks and the Hlelo Suite representing the acid rocks (Walraven, 1986).

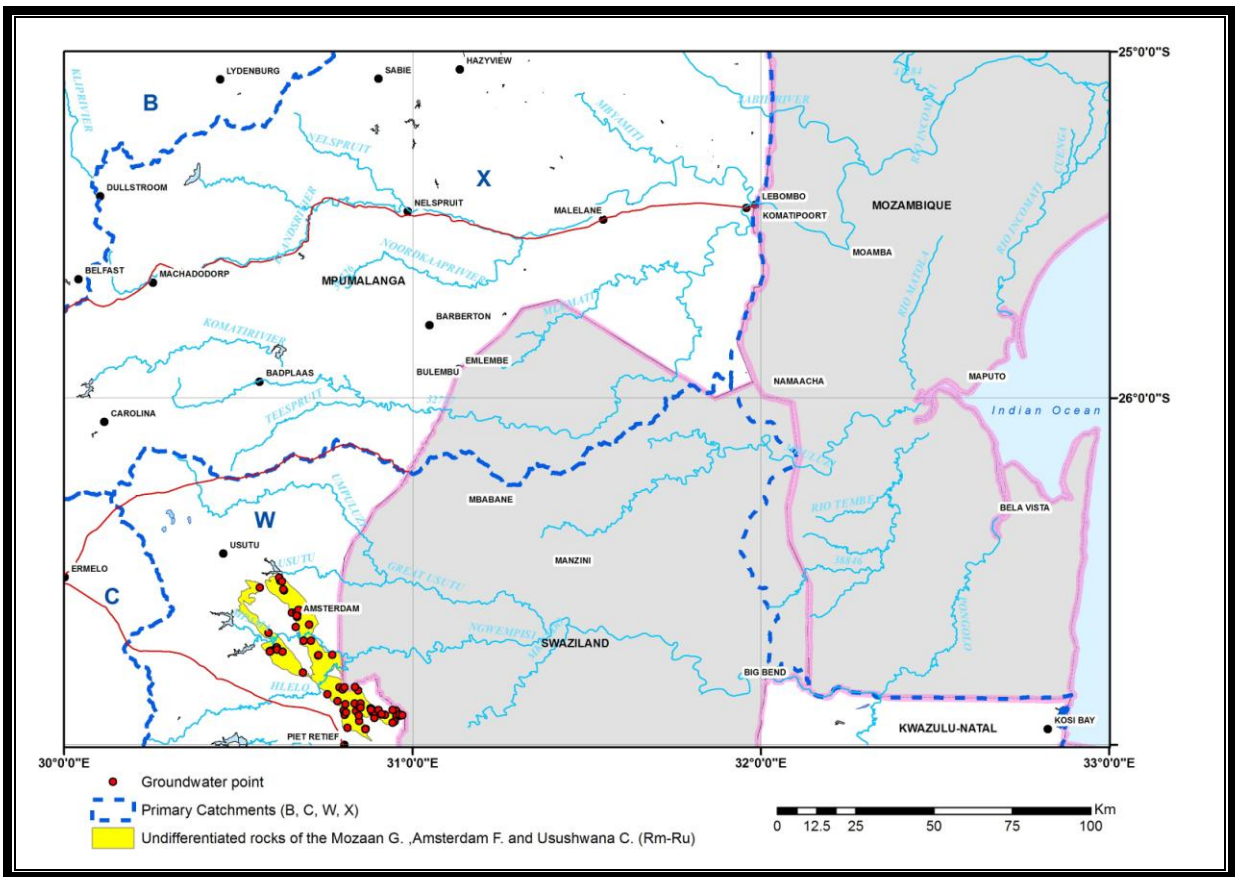


Figure 62: Geographical distribution of the undifferentiated rocks of the Mozaan Group, Amsterdam Formation and Usushwana Complex (Rm-Ru) and associated groundwater sampling points.

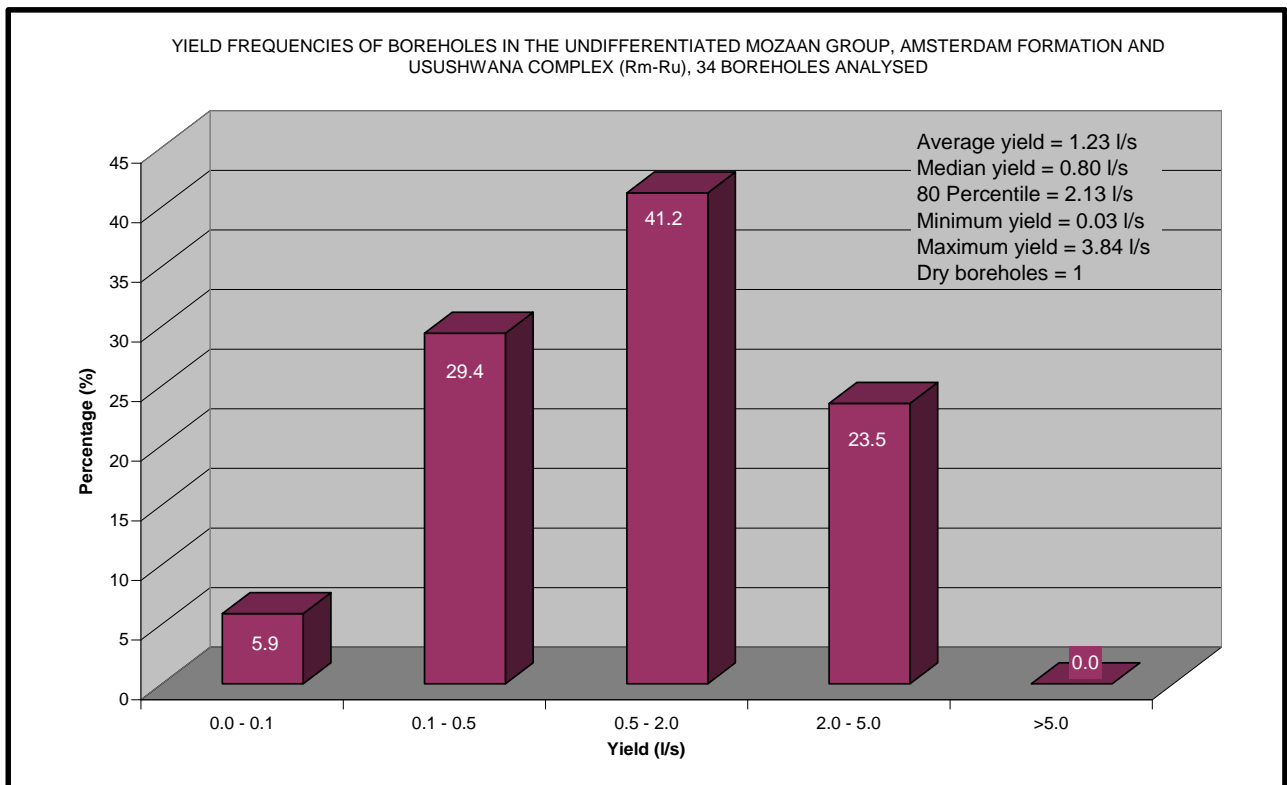


Figure 63: Yield frequency of boreholes in the Undifferentiated Mozaan Group, Amsterdam Formation and Usushwana Complex (Rm-Ru).

Thirty-four boreholes had maximum yield data available for analysis. The yield diagram (Figure 63, p89) shows that 41.2% of the boreholes yield between 0.5-2l/s, 35.3% are less than 0.5l/s and the remaining 23.5% are between 2-5l/s. Drilling depth data was available for 10 boreholes ranging from 37-100m and averaging 62.24m. Nine boreholes have data on the static water level averaging 14.97mbgl. Water strike data was available at one borehole i.e. 52m with a yield of 0.8l/s.

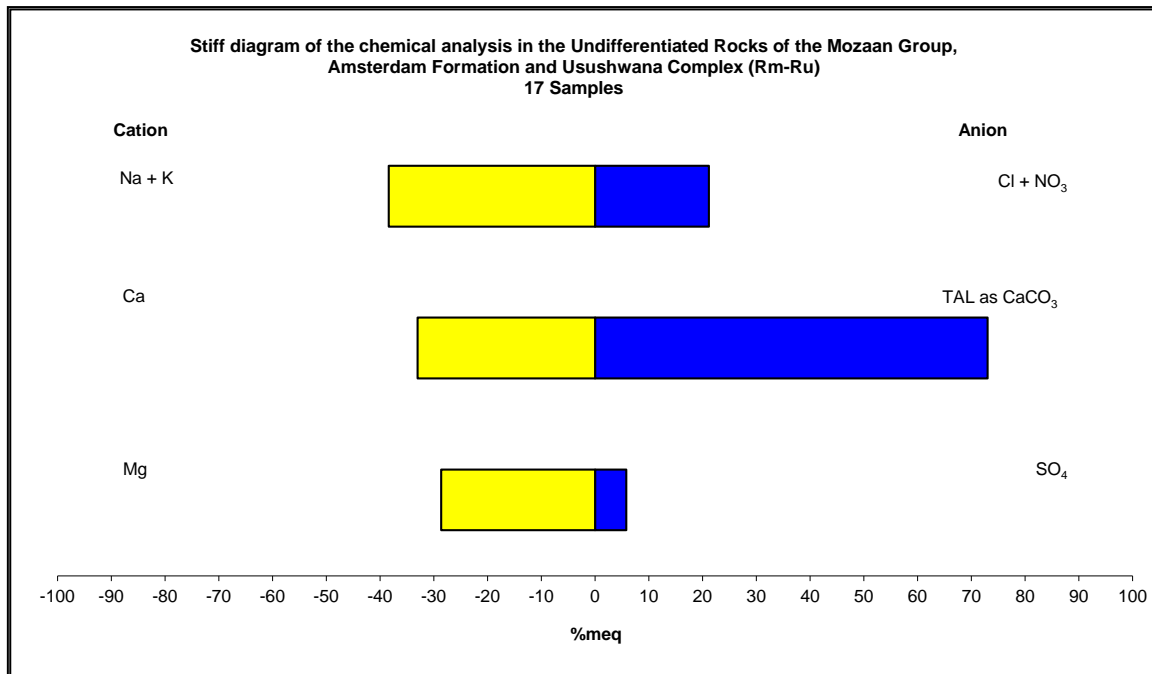


Figure 64: Stiff diagram representing chemistry for the Undifferentiated Mozaan Group, Amsterdam Formation and Usushwana Complex (Rm-Ru).

Figure 64, p90 shows the dominant anions and cations presented as a Stiff diagram compiled from 17 available chemical records. The water displays a calcium-magnesium-bicarbonate character, with elevated sodium levels. The dominant anion is HCO₃⁻. Ninety five percent of the EC values are within the ideal domestic water limit (EC < 70mS/m) whereas the remaining 5.9% is within the maximum allowable range (150-370mS/m). 12.5% of the samples have fluoride concentrations exceeding maximum allowable limits (F > 1.5mg/l).

3.3.4.13 Unnamed Randian Rocks (Rz)

The unit underlay the area on the map between the rocks of the Transvaal and Karoo Supergroups in the east, the Swaziland border in the west, the Barberton Mountain Land in the north and the rocks of the Pongola Sequence in the south. Granitoid rocks of the intrusive Mpuluzi and Heerenveen batholiths represent the unit. Both consist of porphyritic granite, characterized by microcline megacrysts, which shows strong local variations. Dyke like linear bodies of homogenous, medium-grained, pinkish-grey adamellite cuts across the porphyritic granite (Walraven, 1986).

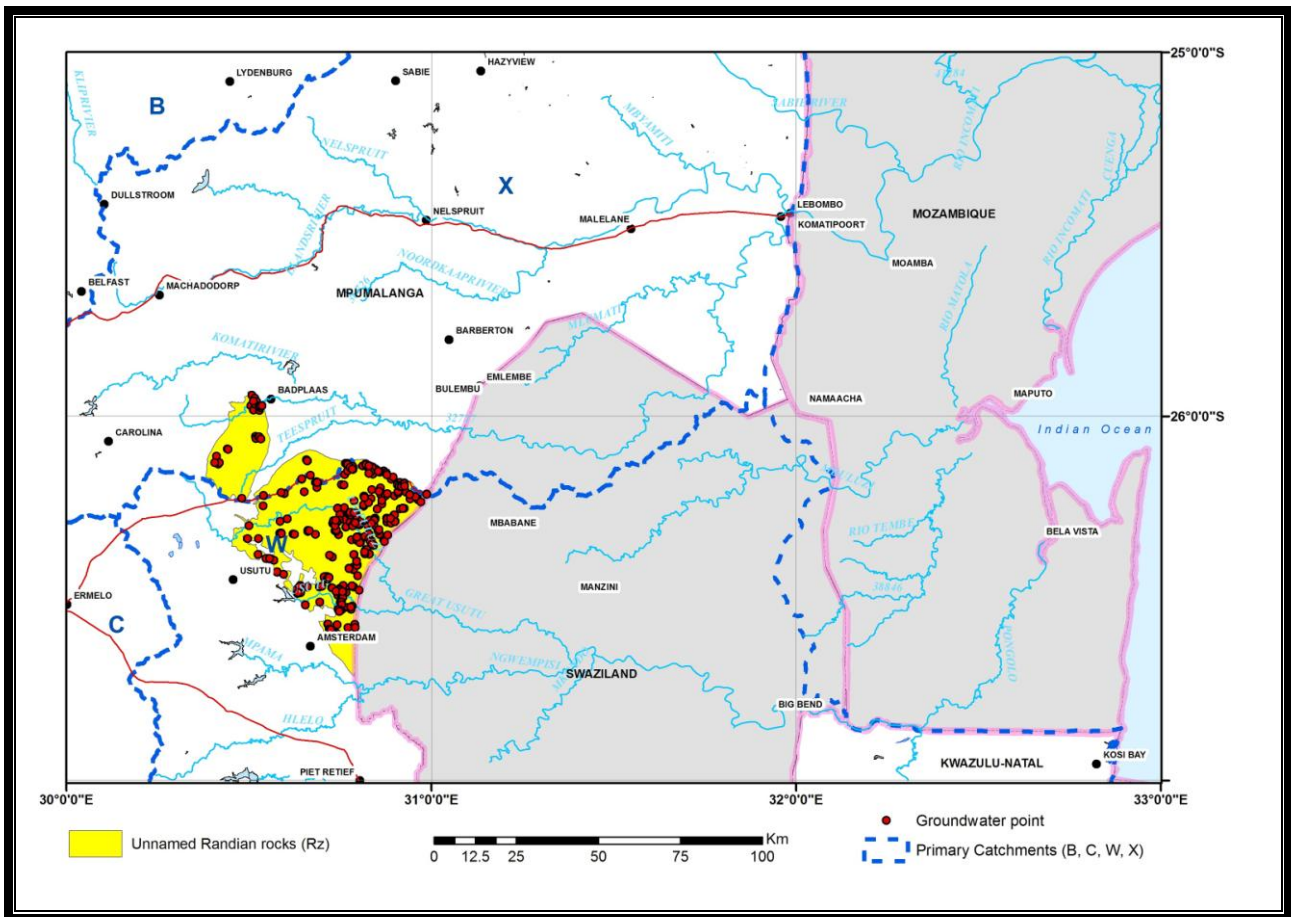


Figure 65: Geographical distribution of the Unnamed Radian rocks (Rz) and associated groundwater sampling points.

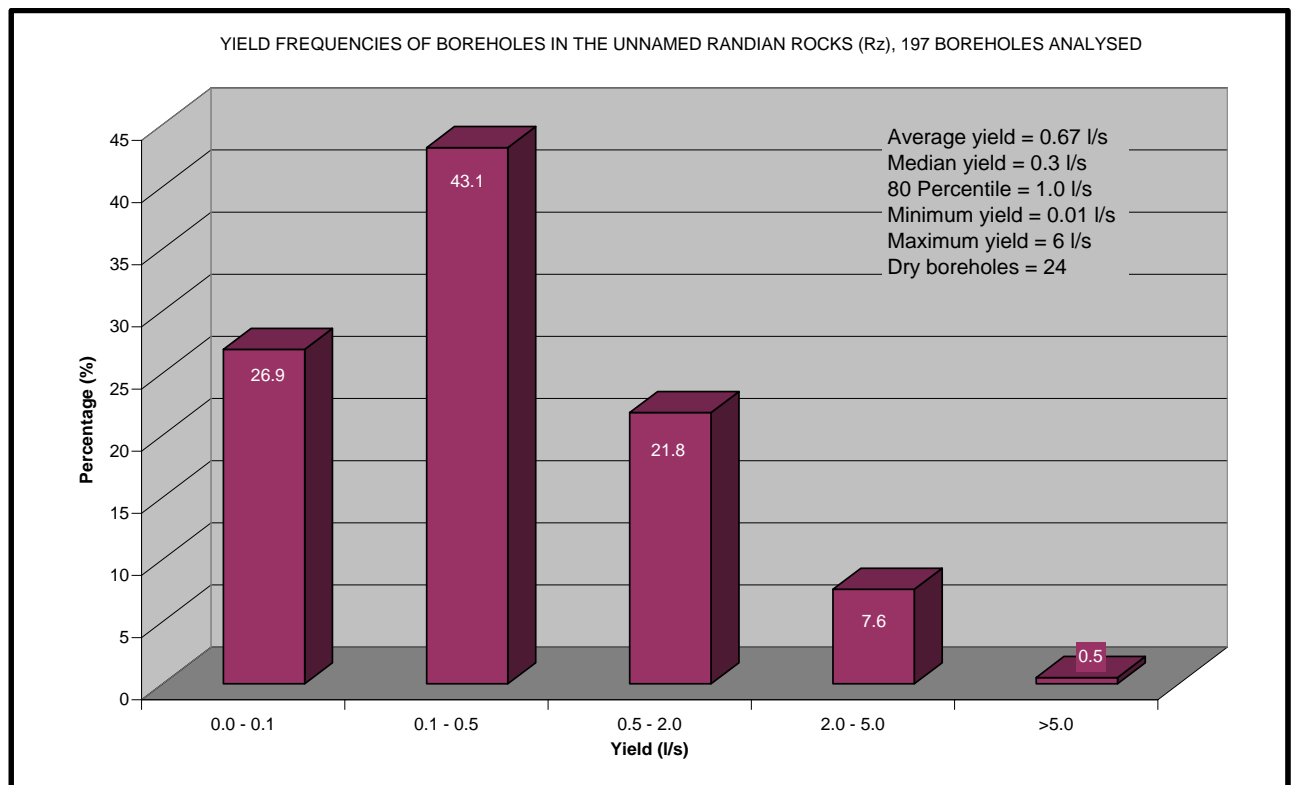


Figure 66: Yield frequency of boreholes in the Unnamed Radian rocks (Rz).

The yield frequency diagram in Figure 66, p91 represents 197 sources with maximum yield data. The same number of boreholes has recorded static water levels ranging from 1-39mbgl; the average was calculated as 12.96mbgl. The aquifer is not high yielding as 70% of the boreholes have yields less than 0.5l/s, 21.8% are between 0.5-2l/s and 8.1% are yielding more than 2l/s. Water strike depths were available for 93 boreholes. Water strike depths range between 8-80m with an average strike depth of 32.42m. Water strike depths are predominantly between 10-20m (32.3%) and 20-50m (50.54%) with 15% exceeding a depth of 50m. Except for the highest yielding borehole (6l/s) that have a recorded water strike at 12m and two others with strikes depths at 18 and 65m, all the boreholes yielding more than 2l/s have strikes depths that is between 23-43m. From this data it is concluded that deep weathered and fracture zones in recharged areas will be the main target in the search for groundwater.

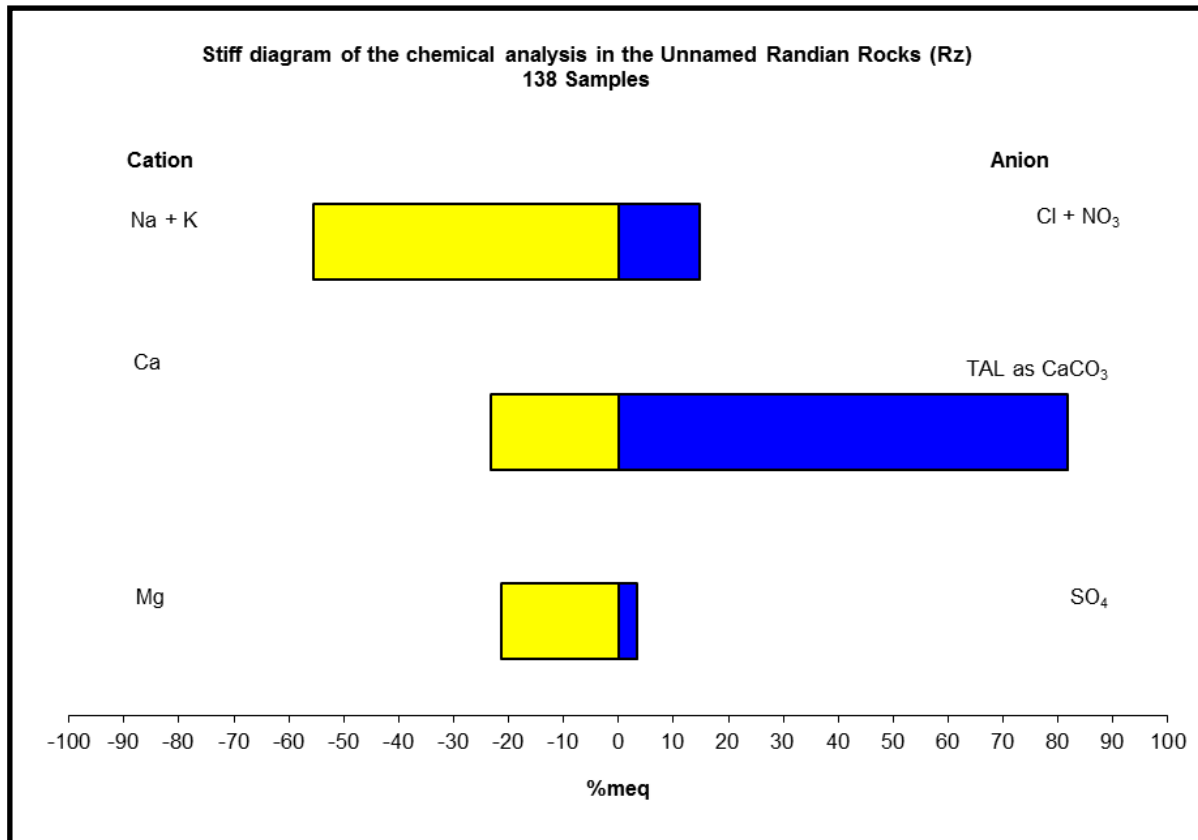


Figure 67: Stiff diagram representing chemistry for the Unnamed Radian rocks (Rz).

Chemical analysis of 138 sample points is presented as a Stiff diagram (Figure 67, p92). The water exhibits a sodium-bicarbonate water type. 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 the cation Na^+ and the anion HCO_3^- . The water is predominantly of an ideal water quality although 7% of the samples have unacceptable nitrate concentrations ($\text{N} > 20\text{mg/l}$).

3.3.4.14 Boesmanskop Syenite (Rbs)

The unit is located south-west of the Barberton Mountain Land and north of the Mpuluzi Batholith. The name on the South African 1:250 000 map sheet, 2630 Mbabane for this intrusion is Bosmanskop Syenite. The unit is intrusive to the gneisses and granites in the area as well as to the greenstones of the Barberton Sequence. It consists of coarse-grained syenite and quartz-syenite.

The available data is inadequate for a proper characterization of the unit.

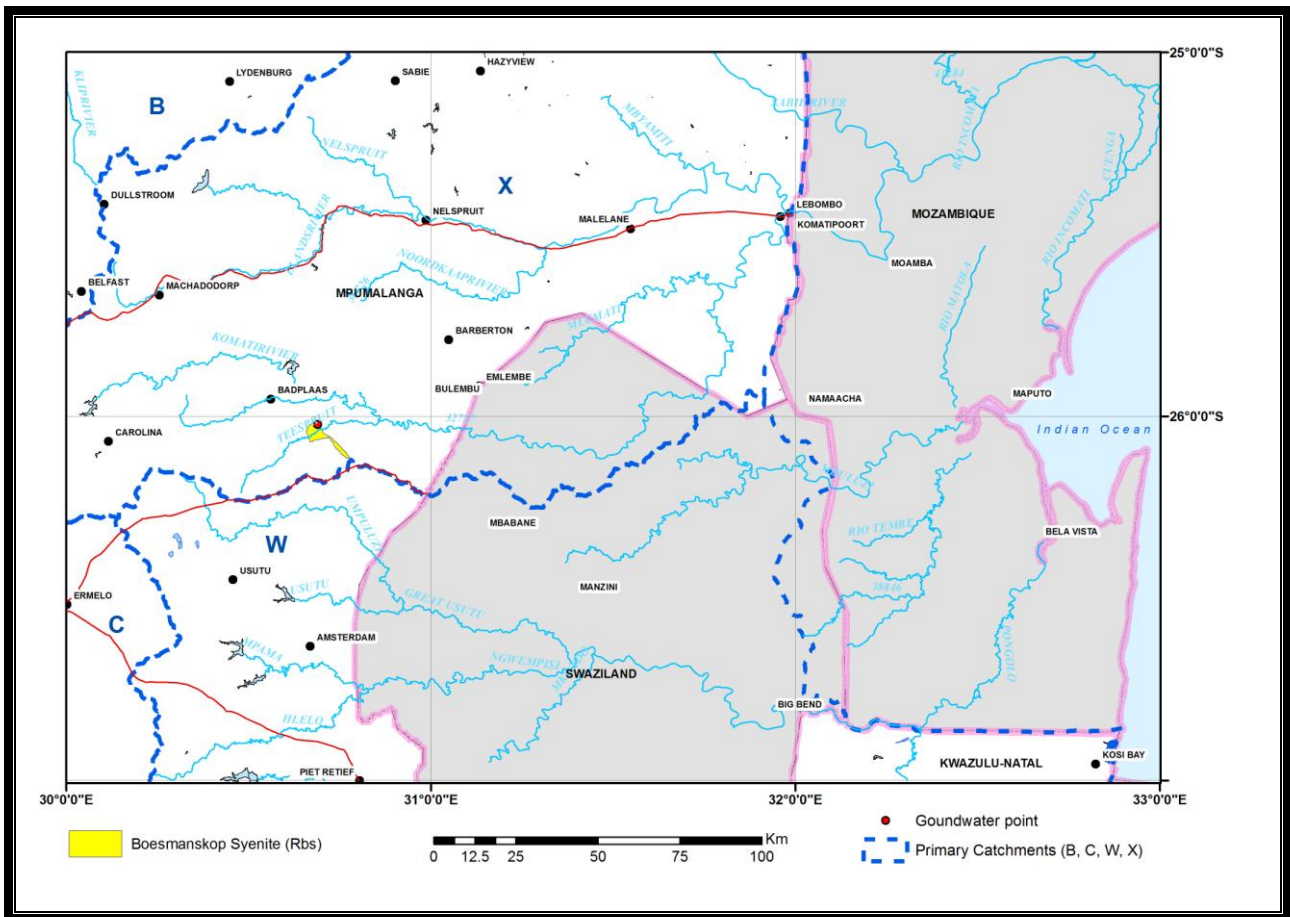


Figure 68: Geographical distribution of the Boesmanskop Syenite (Rbs) and associated groundwater sampling points.

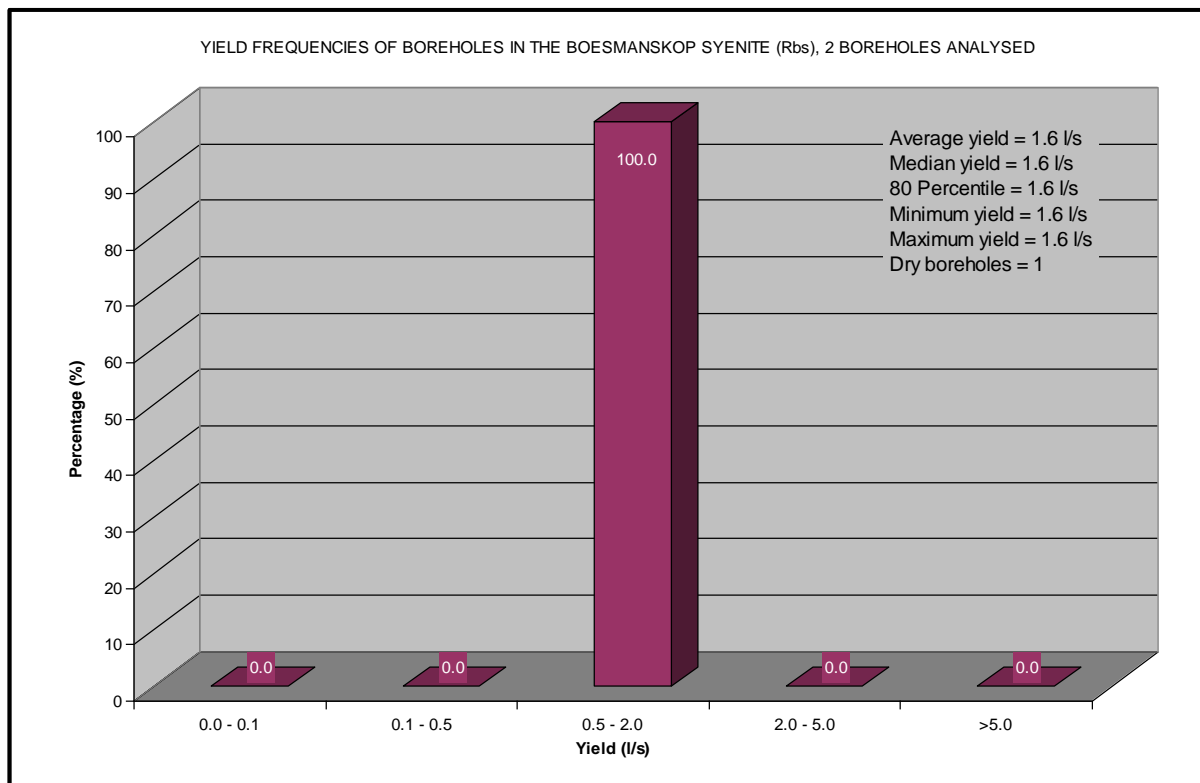


Figure 69: Yield frequency of boreholes in the Boesmanskop Syenite (Rbs).

3.3.4.15 Salisbury Kop Granodiorite (Rsk)

The intrusive pluton is located south of Hectorspruit in the north-eastern part of the Barberton Sequence. It underlies 0.42% of the map area.

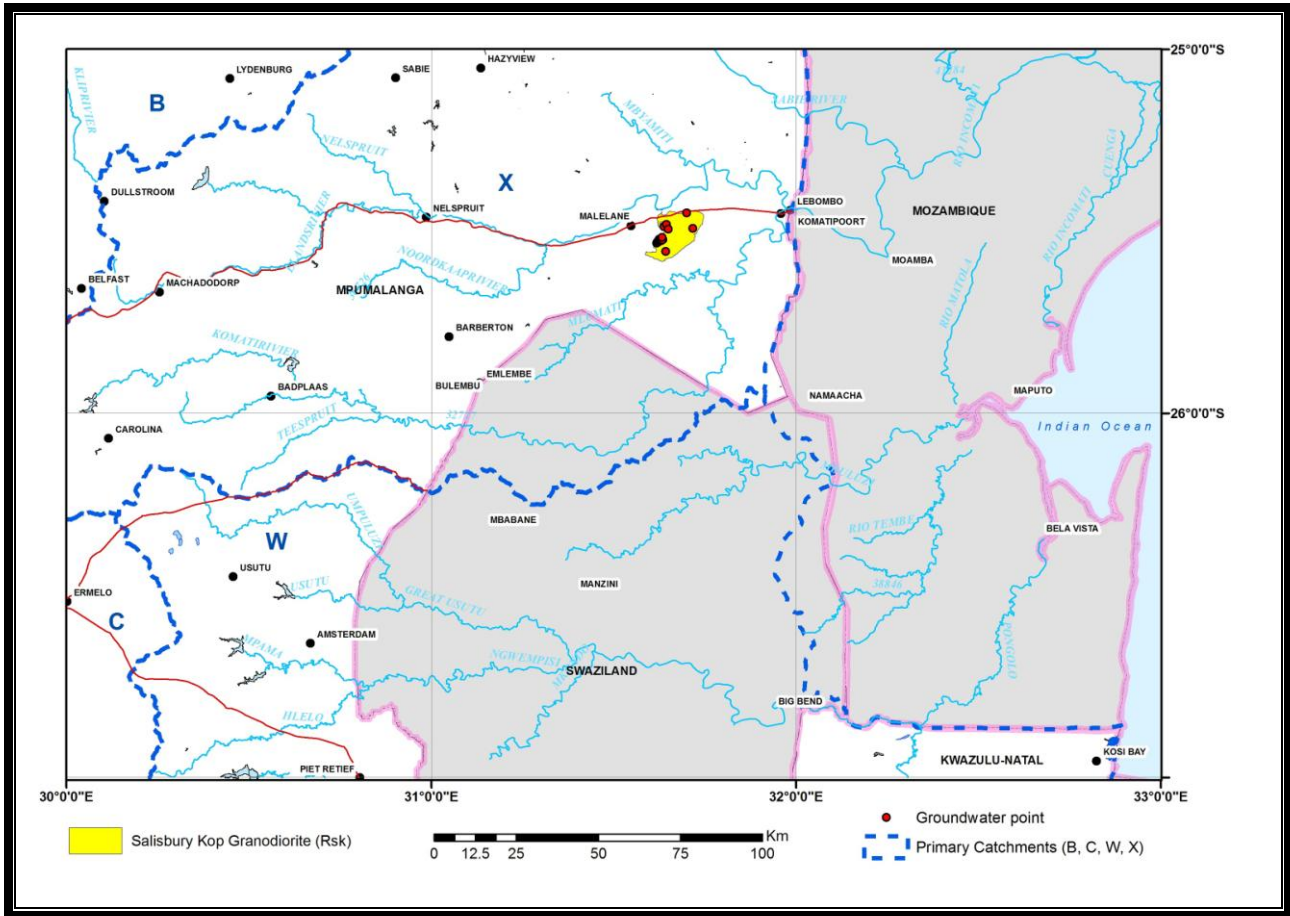


Figure 70: Geographical distribution of the Salisbury Kop Granodiorite (Rsk) and associated groundwater sampling points.

The frequency yield diagram represents maximum yield data for 12 boreholes. Fifty percent of the boreholes have maximum yields exceeding 0.5l/s and 41.7% are between 0.1-0.5l/s. A high number (16.7%) of the boreholes have maximum yields exceeding 5l/s. Static water level data are available at 22 sources ranging between 2.5-15.68mbgl and averaging 9.12mbgl. Inadequate data records on water quality, water strike, and borehole depths prevented the proper hydrological characterization of the unit.

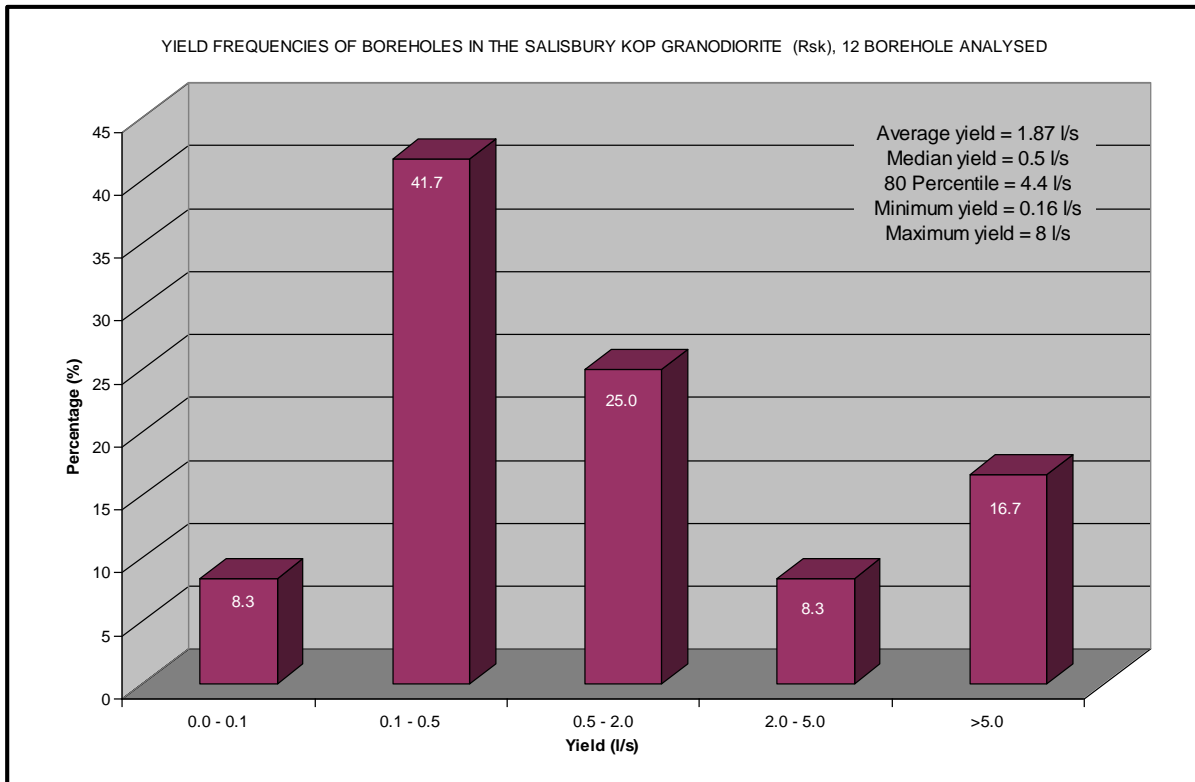


Figure 71: Yield frequency of boreholes in the Salisbury Kop Granodiorite (Rsk).

3.3.4.16 Mpangeni Granite (Rmp)

The unit is represented on the map sheet as a single intrusive granite pluton east of Nelspruit and along the northern bank of the Crocodile River. Field recognition is relatively easy due to the prominent hills that characterize the topography and the grain size that is coarser than the surrounding granitoid rocks of the Nelspruit Suite. The rock is reddish, massif and weathered into big blocks (Walraven, 1989).

Data records were inadequate for the proper analysis of the quality and quantity of groundwater occurring within the unit. The unit underlies a very small area of the map area (0.08%).

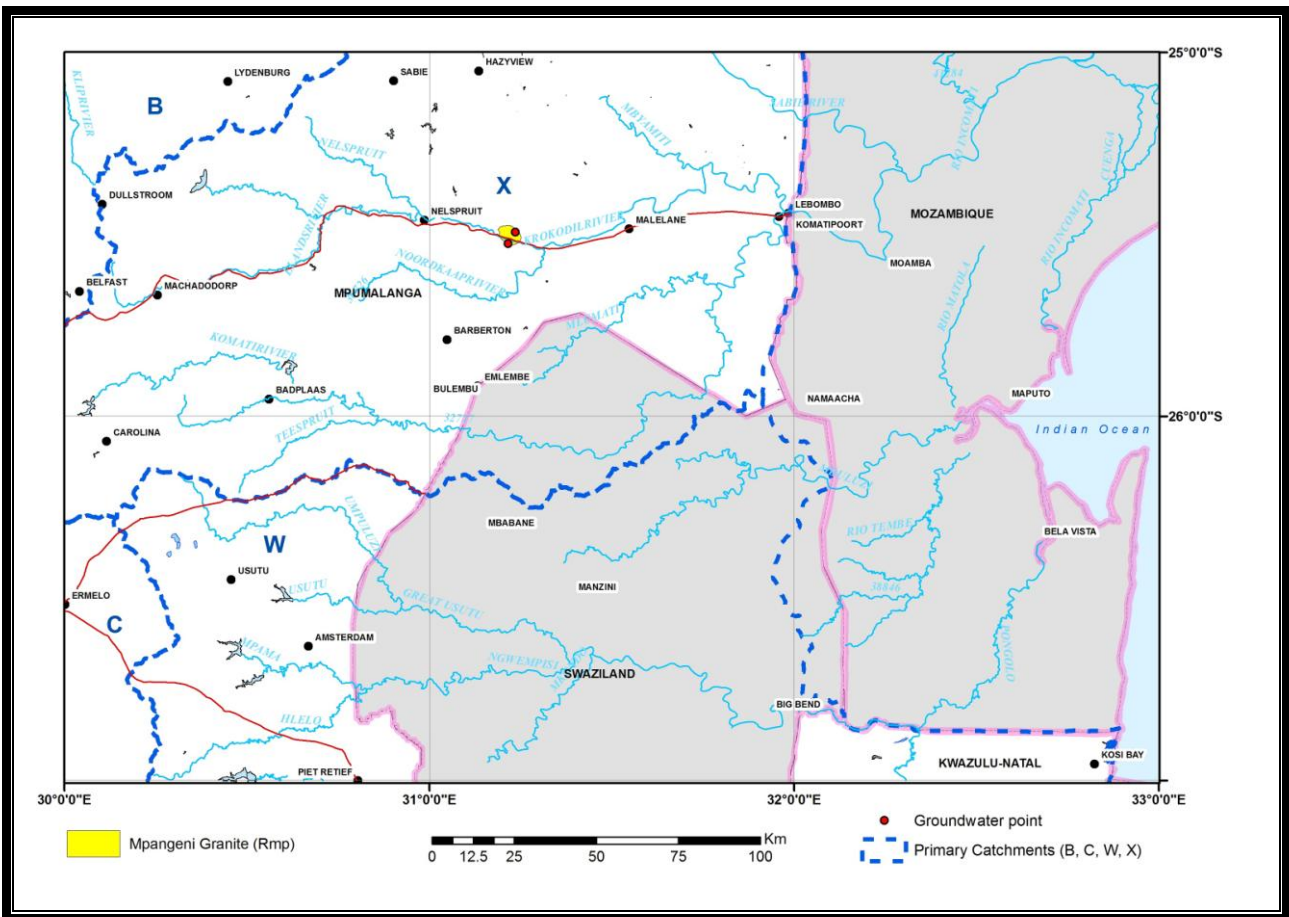


Figure 72: Geographical distribution of the Mpangeni Granite (Rmp) and associated groundwater sampling points.

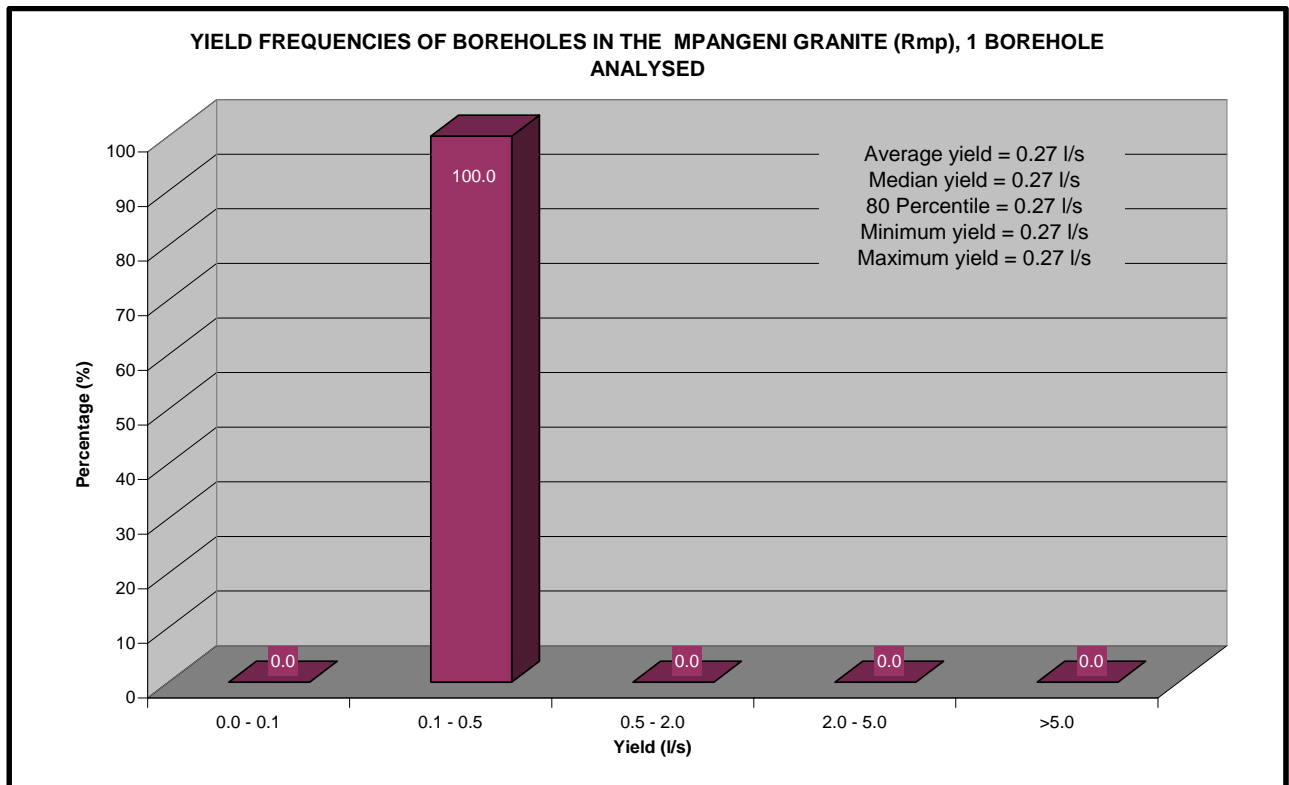


Figure 73: Yield frequency of boreholes in the Mpangeni Granite (Rmp).

3.3.4.17 Mozaan Group (Rm)

In section 3.3.4.12, p88 the Mozaan Group was listed as a hydrogeological unit together with other undifferentiated rocks of the Amsterdam Formation and the Usushwana Complex. In this hydrogeological unit the Mozaan Group refers to a small occurrence depicted on the hydrogeological map sheet underlying an area on the south-eastern part of the Pongola Sequence near the Swaziland border. The unit is flanked by two south-to-north trending faults. The unit consists of ferruginous shale and banded iron formation of the Redcliff Formation overlying quartzite with interlayered shale of the Skurwerant Formation.

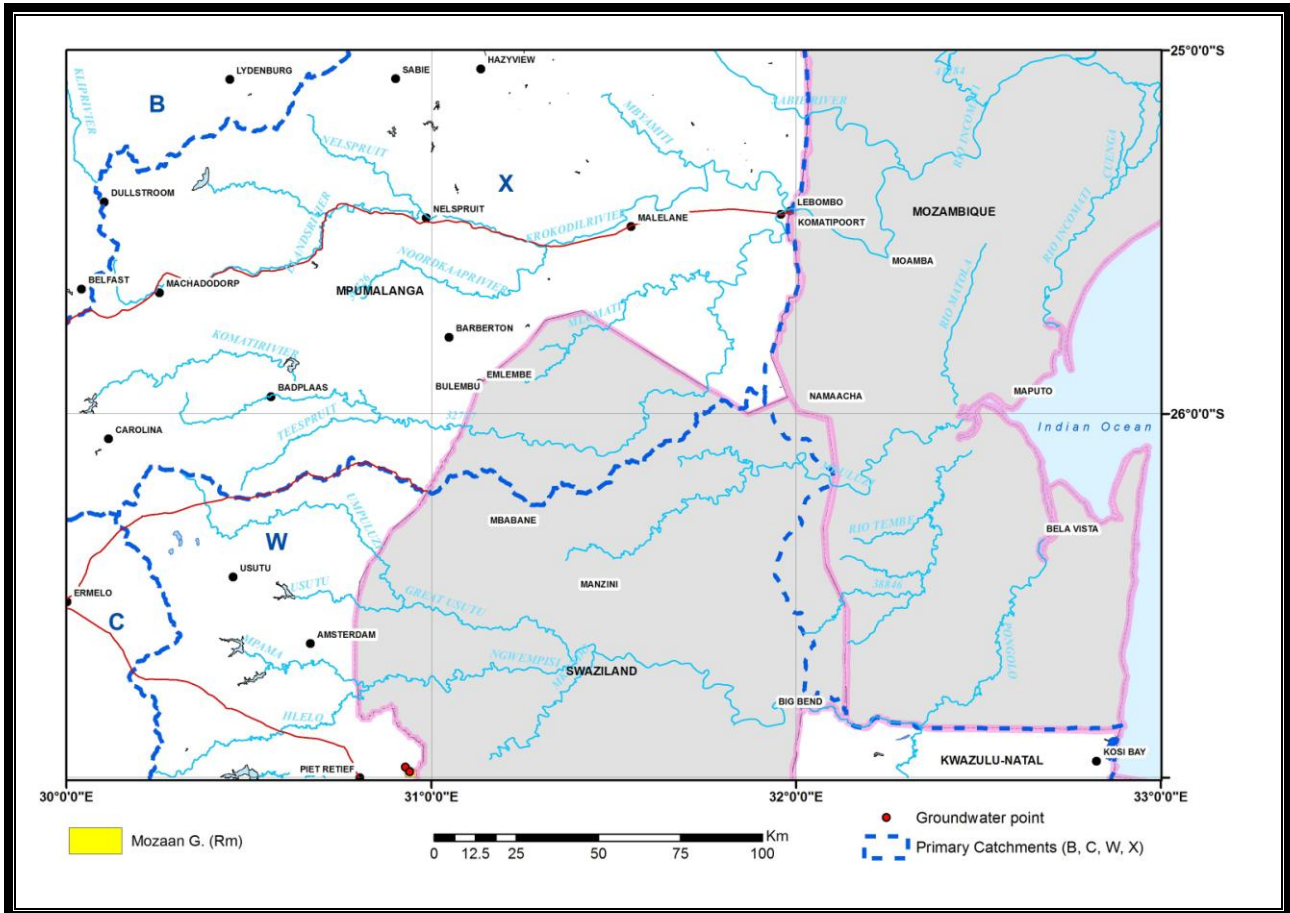


Figure 74: Geographical distribution of the Mozaan Group (Rm) and associated groundwater sampling points.

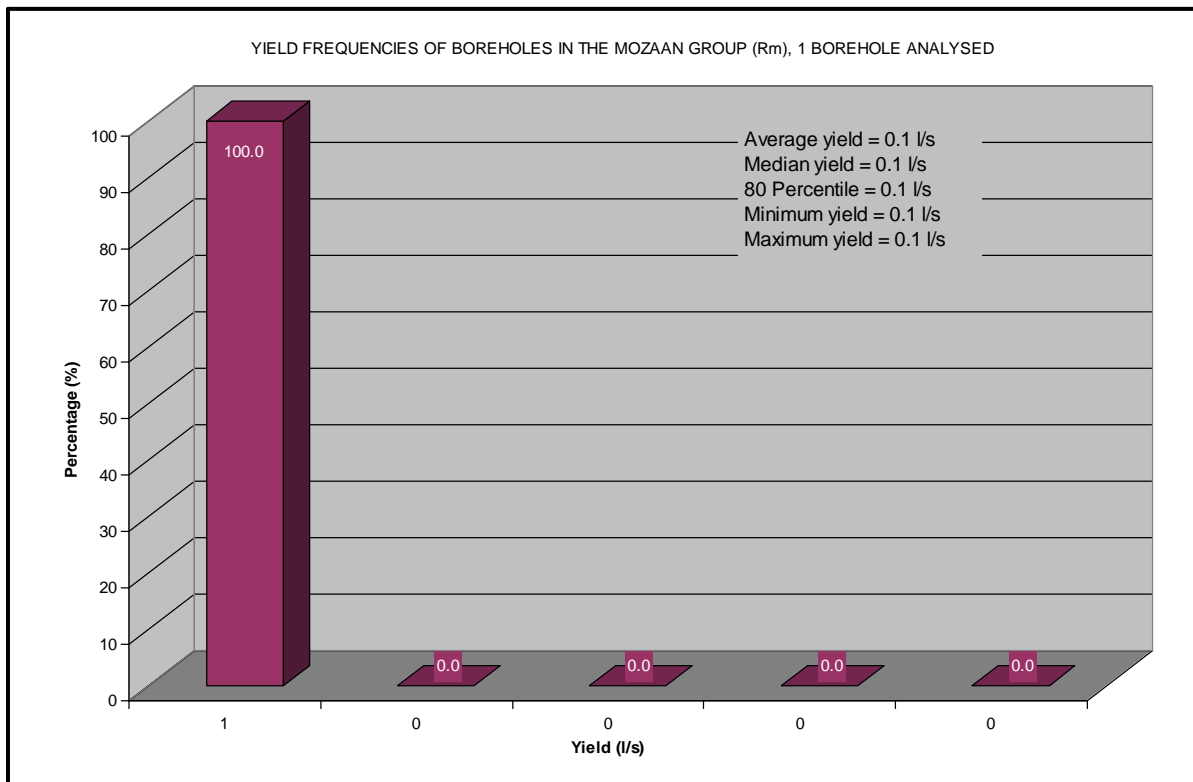


Figure 75: Yield frequency of boreholes in the Mozaan Group (Rm).

Insufficient data was available for the proper characterization of the unit.

3.3.4.18 Wolkberg Group (Vw)

This unit represents the Godwan Formation which is the oldest formation of the Transvaal Supergroup on the map sheet. It occurs in two small basins within the granitoid basement rock and consists of intermediate volcanic rocks that include massive and amygdaloidal lava (the volcanic member), agglomerate, and tuff with arkose, shale, and conglomerate (the sedimentary member), (Visser en Verwoerd, 1960).

The yield frequency diagram (*Figure 77*, p99) represents the maximum yield data of 6 sources. Insufficient chemical and yield data is available for the characterization of the unit. Due to the small (0.01% of map) extent on the map sheet it is an insignificant aquifer.

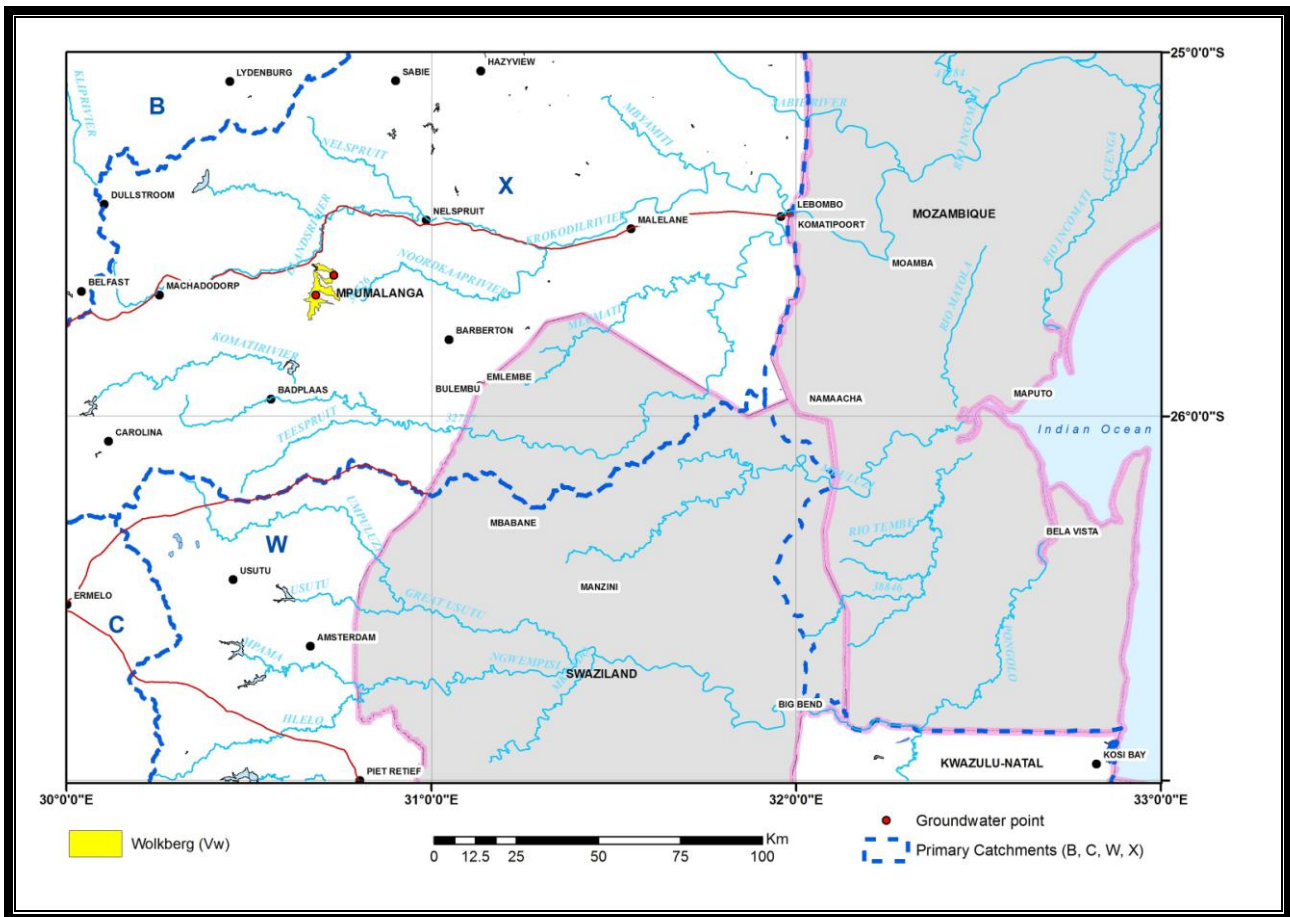


Figure 76: Geographical distribution of the Wolkberg Group (Vw) and associated groundwater sampling points.

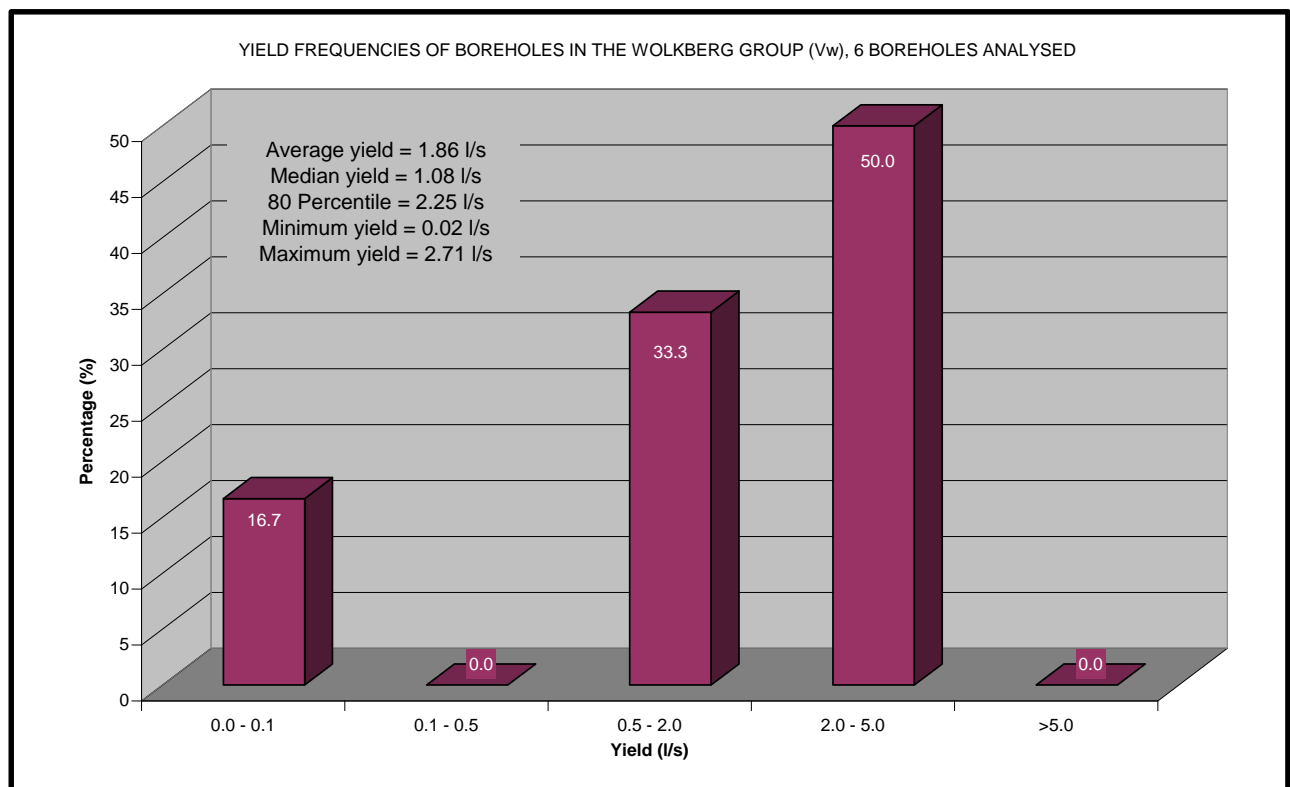


Figure 77: Yield frequency of boreholes in the Wolkberg Group (Vw).

3.3.4.19 Pretoria Group (Vp), intergranular and fractured

The unit dominates the north-western part of the map sheet covering an area that is more or less defined by Carolina in the south upwards along the western side of the Drakensberg Escarpment up to the end of the map sheet in the north. Due to similar hydrogeological characteristics and cartographic reasons, the majority of the different formations of the Pretoria Group are grouped under this unit except the Steenkampsberg Formation, which is a fractured aquifer.

The Pretoria Group consists predominantly of quartzite and shale with a prominent volcanic unit, the Hekpoort Andesite Formation and minor conglomerate, chemical and volcanic members (SACS, Handbook 8, p192). Pure quartzites such as those found in the Daspoort, Magaliesberg and Lakenvallei Formations are examples of tidal flat deposits (Tankard *et al.*, 1982). The thick shale deposits of the group points to a deep-water depository environment (Button, 1973). On the map sheet the Pretoria Group in particular was intruded on a large scale by diabase in the form of sills and dykes especially the Silverton Formation.

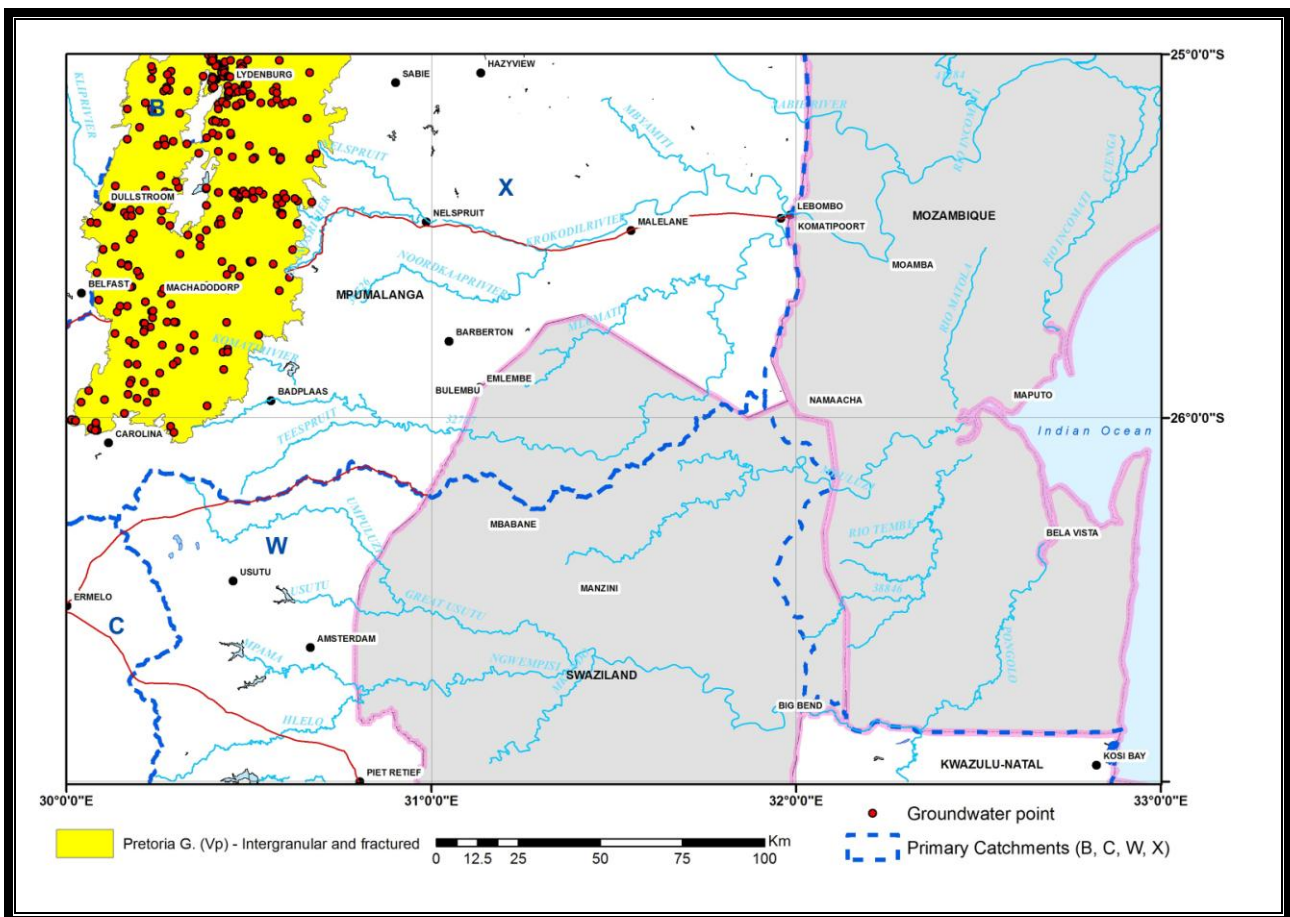


Figure 78: Geographical distribution of the fractured and intergranular aquifers of the Pretoria Group (Vp) and associated groundwater sampling points.



Photo 14: The remains of a volcanic breccia pipe just west of Lydenburg. The pipe, which is about 30m in diameter, is known as the Motlolo Volcano and occurs in shale of the Silverton Formation. The breccia includes fragments of rocks from many of the formations in the lower part of the Pretoria Group (photo W.H. Du Toit, 2006).

The diabase intrusions play a significant role in the occurrence of groundwater in the Pretoria Group. In general, the shaly groups and intrusive diabase sills tend to occupy the lower ground while the quartzites stand out as ridges. The water-bearing properties of the quartzite and shale are dependent on fracturing. The shale is in general far more favourable than the quartzites although the quartzites constitute good aquifers when fractured. Shale and sandstone exposed to contact metamorphism with the intrusion of the Bushveld Complex re-crystallized to hornfels and quartzite. The hornfels is a poor aquifer even when deeply weathered.

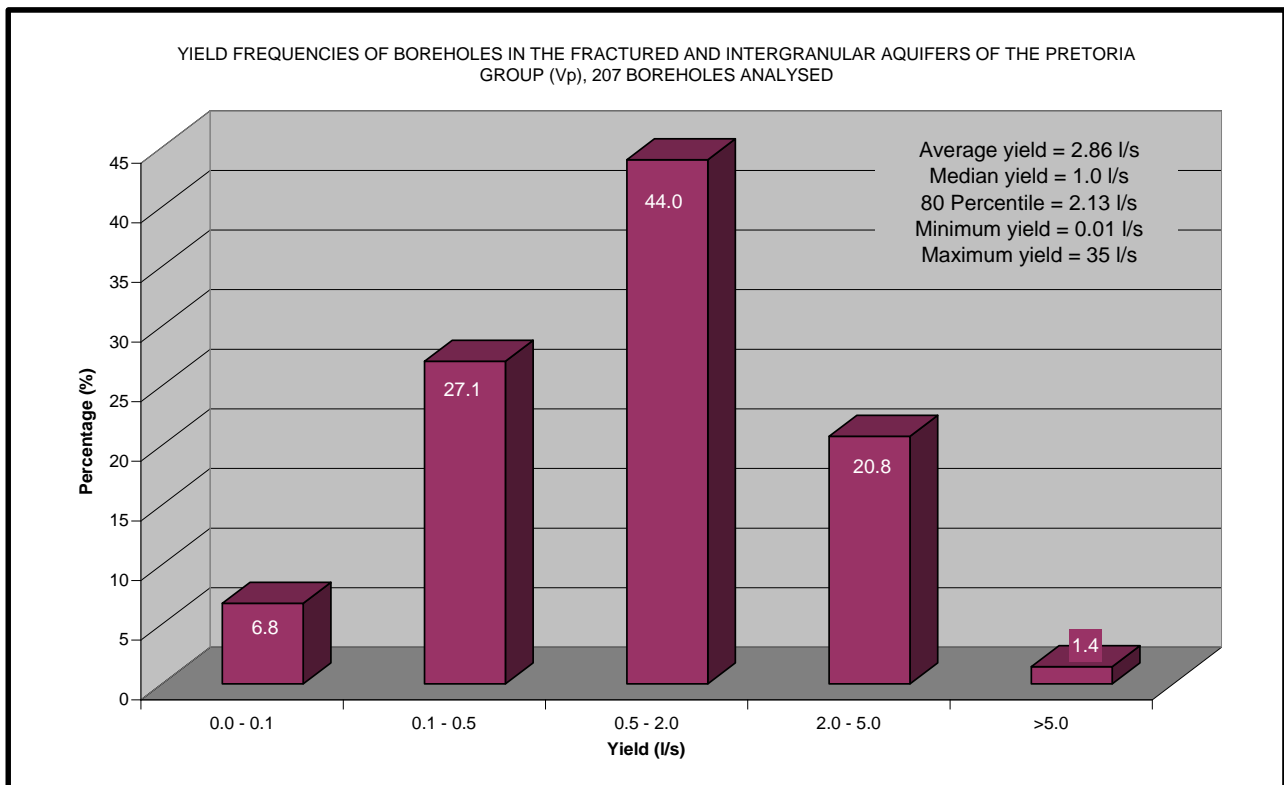


Figure 79: Yield frequency of boreholes in the fractured and intergranular aquifers of the Pretoria Group (Vp).

The yield frequency diagram (Figure 79, p101) represents the maximum yield data of 207 sources. In 33.9% of the samples the maximum yield is less than 0.5l/s, 44% are between 0.5-2l/s, and the remaining 22.1% yield more than 2l/s. Four boreholes have recorded water strike depths ranging from 8-38m with the calculated average as 22.5m. Due to limited data no correlation could be determined between yield and strike depth although the deepest strike has the highest recorded yield (6l/s). Static water levels were available at 79 sources ranging between 0.1-49.14mbgl and averaging 7.66mbgl. Although the unit underlies the largest area on the map sheet (17.54%) it is not a high yielding aquifer as only 1.4% of the boreholes have maximum yields exceeding 5l/s.

Groundwater is intercepted in basins of weathering, at the fractured contact between the weathered and unweathered zone, at the contacts with dykes and sills, and in fractures caused by offloading or tectonic stresses.

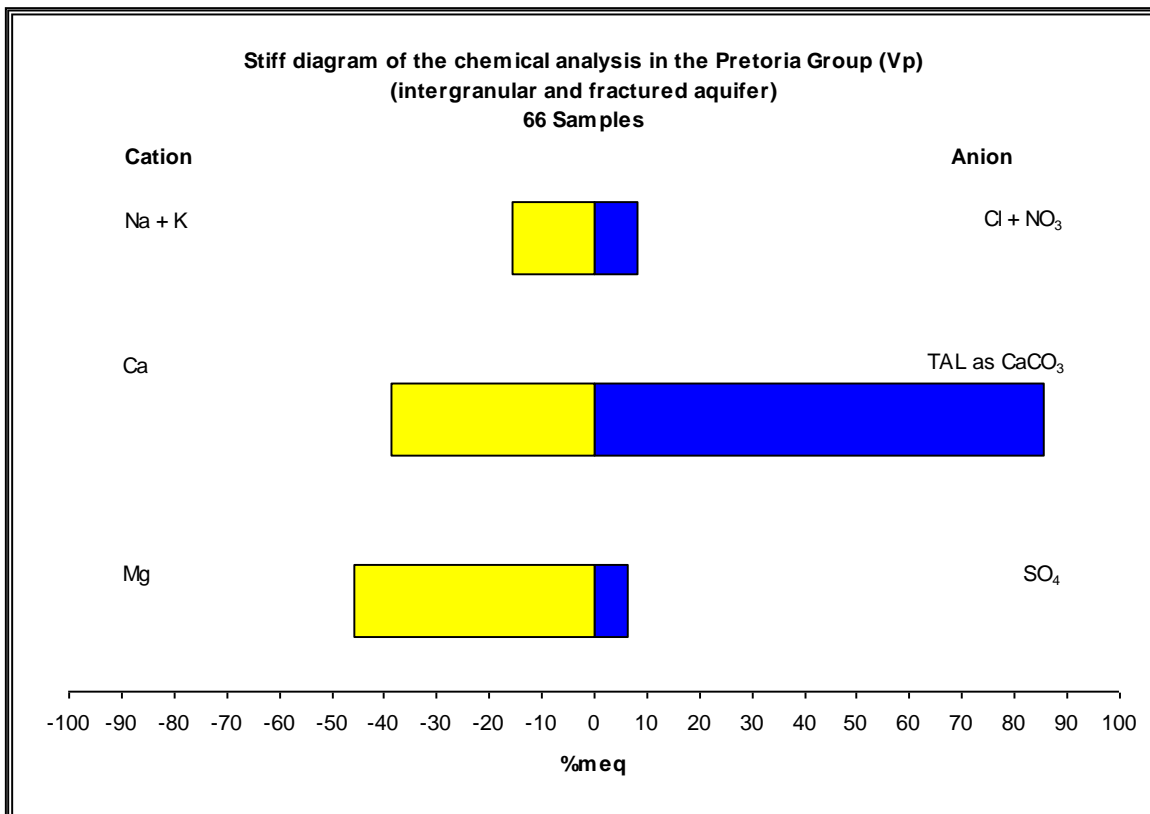


Figure 80: Stiff diagram representing chemistry for the fractured and intergranular aquifers of the Pretoria Group (Vp).

Figure 80, p102 represents the Stiff diagram compiled from the major cations and anions of 66 samples. The water is a calcium-magnesium-bicarbonate type. The dominant cations are Ca⁺² and Mg⁺² with the dominant anion HCO₃⁻. In 98.5% of the samples the EC values falls within the ideal domestic water class. In 3% of the samples the water quality exceeds the maximum allowable standard for drinking water due to elevated fluoride concentrations (F > 1.5mg/l).

3.3.4.20 Diabase Intrusions (N-Zd)

Intrusive diabase dykes and sills occur throughout the map area in the Swazian granites and gneisses and at various levels of the Pretoria Group. Red clayey soil and loose boulders indicates the presence of sills within the granitoid rocks. Sills is abundant in the rocks of the Pretoria Group with thicknesses up to 150m reported in the shales of the Time Ball Hill Formation. Due to cartographic reasons dykes and the smaller sills not all are shown in the map. Most of the hydrogeological importance of the diabase intrusions is discussed in the other units where reference is made to geological lineaments that could be targeted in the search for groundwater.

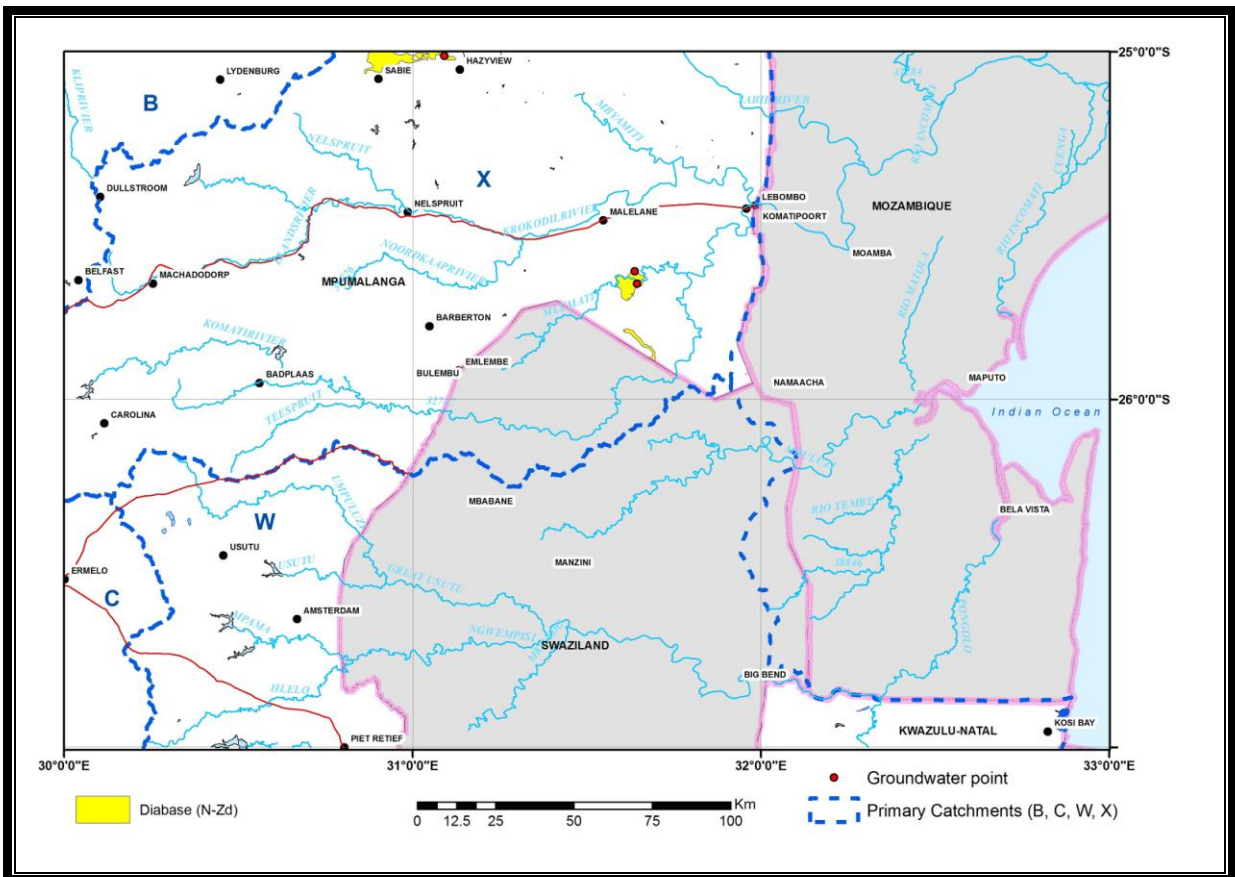


Figure 81: Geographical distribution of the Diabase intrusions (N-Zd) and associated groundwater sampling points.

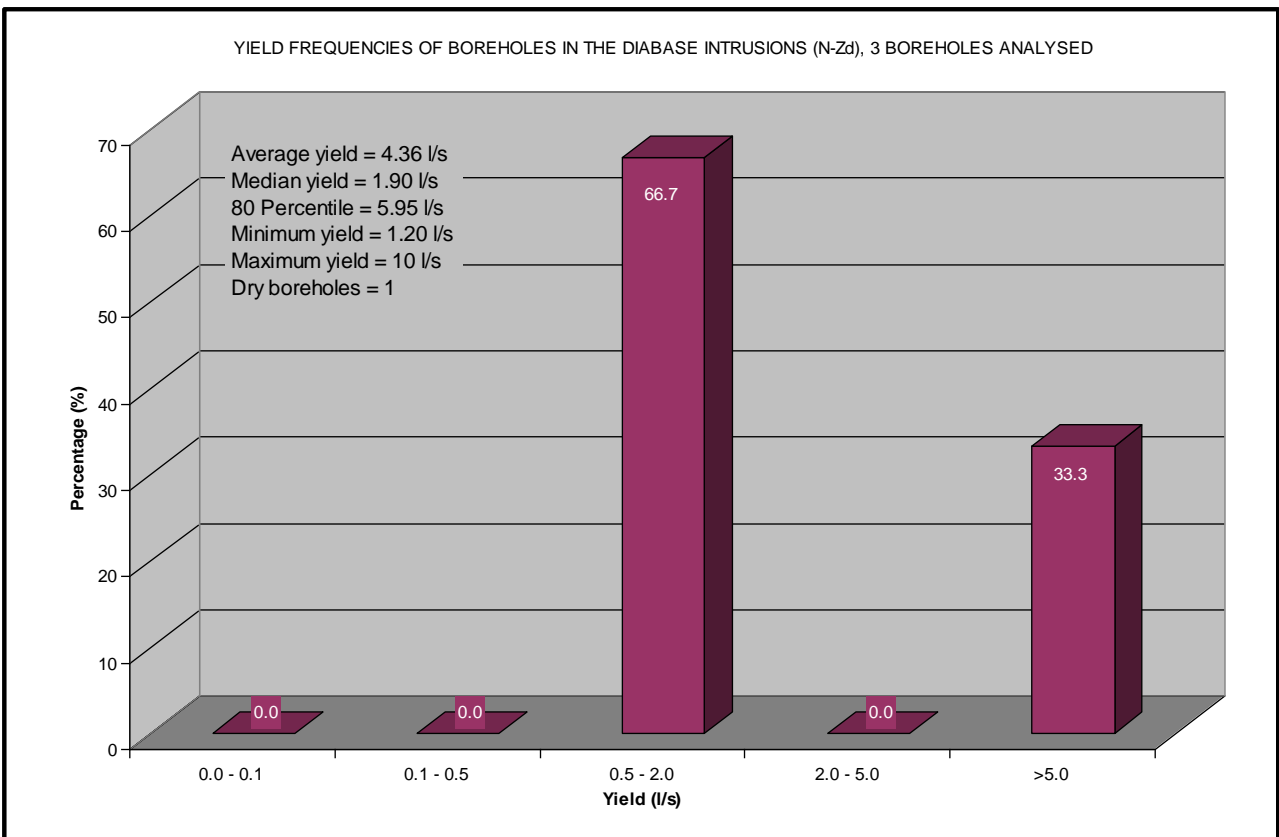


Figure 82: Yield frequency of boreholes in the Diabase intrusions (N-Zd).

Figure 82, p103 is a poor reflection of the maximum yield distribution of the unit due to inadequate sample representation. The samples grouped under this unit only reflect data from three sills within the Nelspruit Suite (Ze) as the scale and the GIS method of choosing holes to represent the unit cannot distinguish if boreholes were drilled along dykes. Three borehole depths are available that range between 40.8-71m.

Important aspects to consider when choosing a drilling site in the vicinity of a dyke intrusion are width, geological setting, strike, dip and the lateral extent 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.

The lack of chemical data prevented characterization of the water quality for the unit.

3.3.4.21 Rustenburg Suite (Vr)

The unit is confined to the north-western part of the map sheet and west of the Pretoria Group. Rocks belonging to this Suite are characterised by well-developed igneous layering. The Suite consists mainly of mafic rocks including norite, gabbro, magnetite gabbro, anorthosite and pyroxenite.

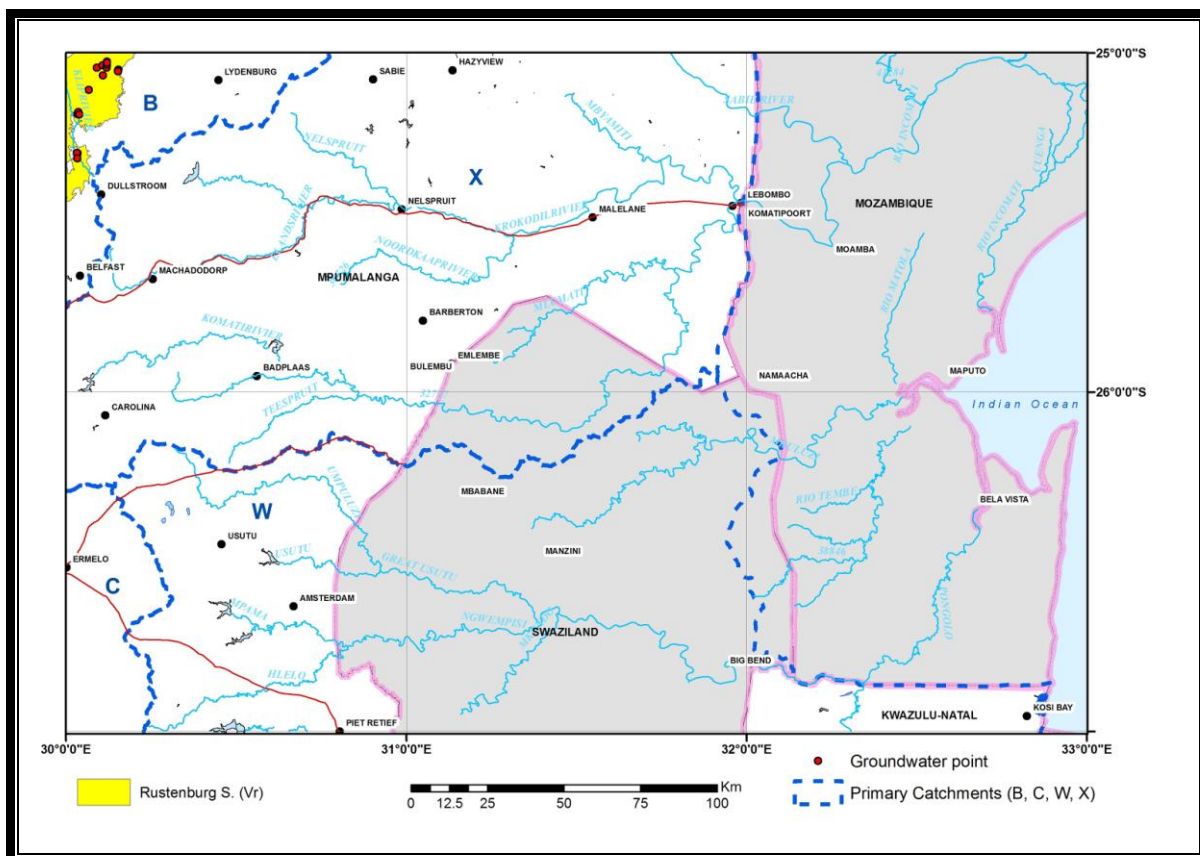


Figure 83: Geographical distribution of the Rustenburg Suite (Vr) and associated groundwater sampling points.

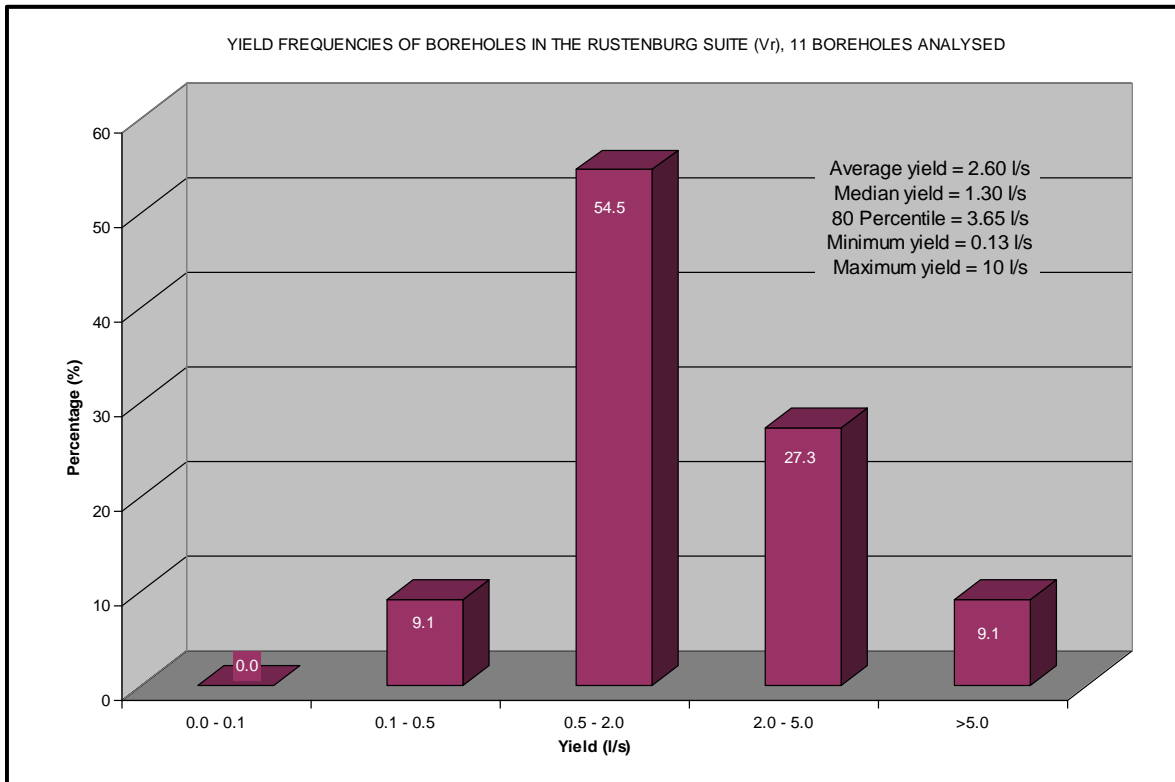


Figure 84: Yield frequency of boreholes in the Rustenburg Suite (Vr).

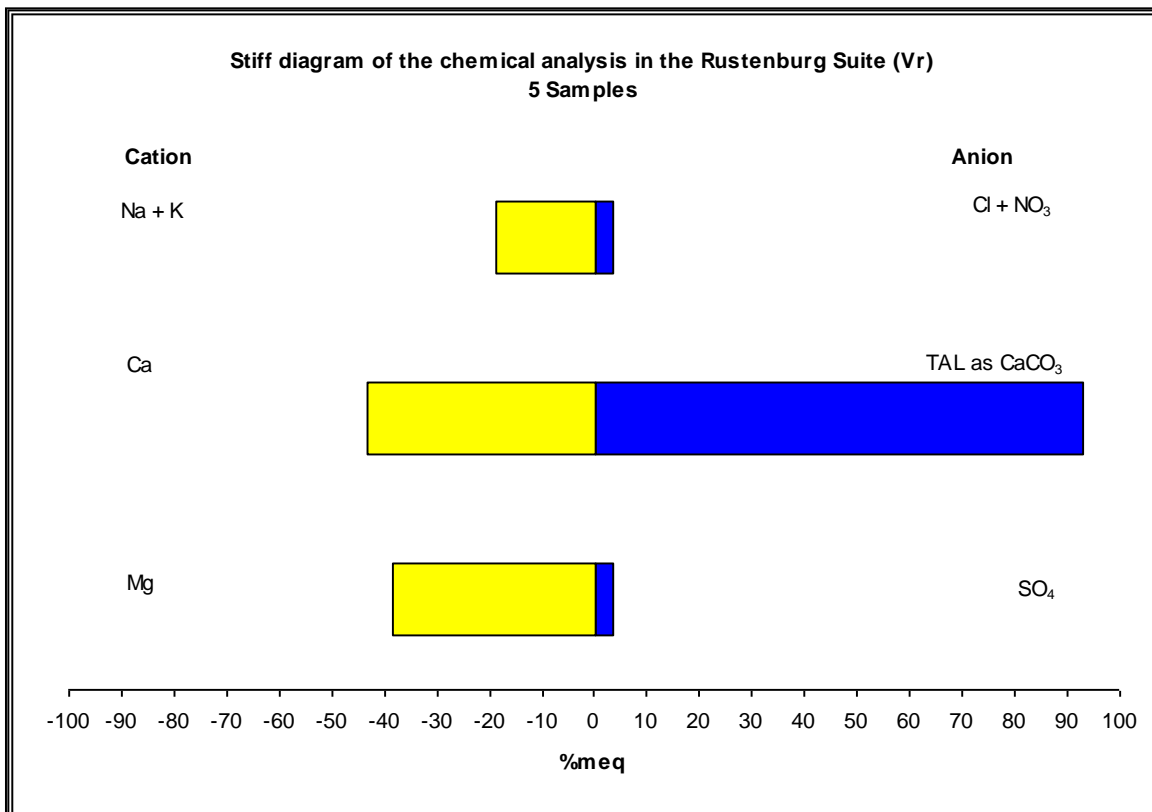


Figure 85: Stiff diagram representing chemistry for the Rustenburg Suite (Vr).

The yield frequency diagram (Figure 84, p105) represents the maximum yield of 11 sources. Most (54.5%) of the yields fall within the range 0.5-2l/s and 36.4% yield more than 2l/s. Insufficient data is available on water strike and drilling depths but data from the adjacent hydrogeological map (sheet 2330 Phalaborwa) shows that groundwater occurs mainly in deeply weathered and fractured mafic rocks. Due to the relative high permeability of the weathered

and fractured rock, deep weathered basins can be extremely good aquifers. Water is also obtained in fault and associated shear or fracture zones, contact zones, and dyke contacts. Equally spaced highly fractured dolerite dykes or 'Blokies klip' and highly weathered pyroxenite (texture looks like brown sugar) are very good targets to explore in the search for groundwater.

Figure 85, p105 represents the dominant anions and cations presented as a Stiff diagram compiled from five chemical records. The water displays a calcium-magnesium-bicarbonate character. EC values are a good indication of water quality with 80% of the samples falling within the ideal domestic water quality (EC < 70mS/m) and 20% within the acceptable (EC 70 to 150mS/m) domestic water quality range.

3.3.4.22 Lebowa Suite (Mle)

The unit consists of pink to red, coarse-grained hornblende-biotite granite. The Steelpoort Park Granite represents the unit and occurs within a single area in the north-western corner of the map sheet.

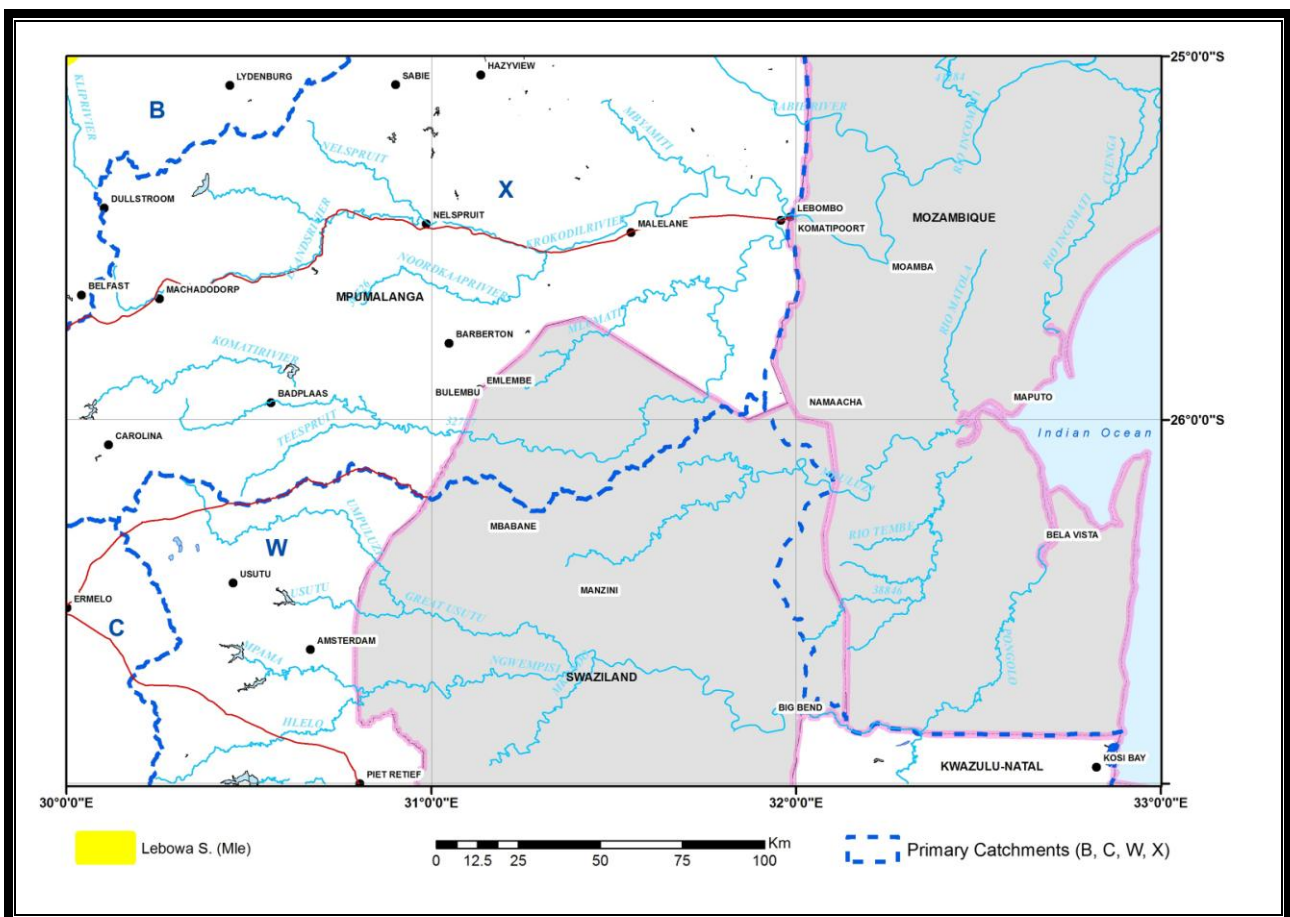


Figure 86: Geographical distribution of the Lebowa Suite (Mle) and associated groundwater sampling points.

Insufficient information is available on the quality and quantity of groundwater sources within the unit for analysis.

3.3.4.23 Timbavati Gabbro (Nti)

In the north-eastern sector of the map area the Timbavati Gabbro intruded the older granites and gneisses of the Basement Complex as irregular sill-like bodies dipping between 20° and

30° to the east (Schutte, 1986 and Venter, 1990). The unit consists of olivine gabbro, gabbro and quartz gabbro. The average thickness is approximately 100m with estimated maximum thicknesses up to 480m (Clubley-Armstrong, 1979).

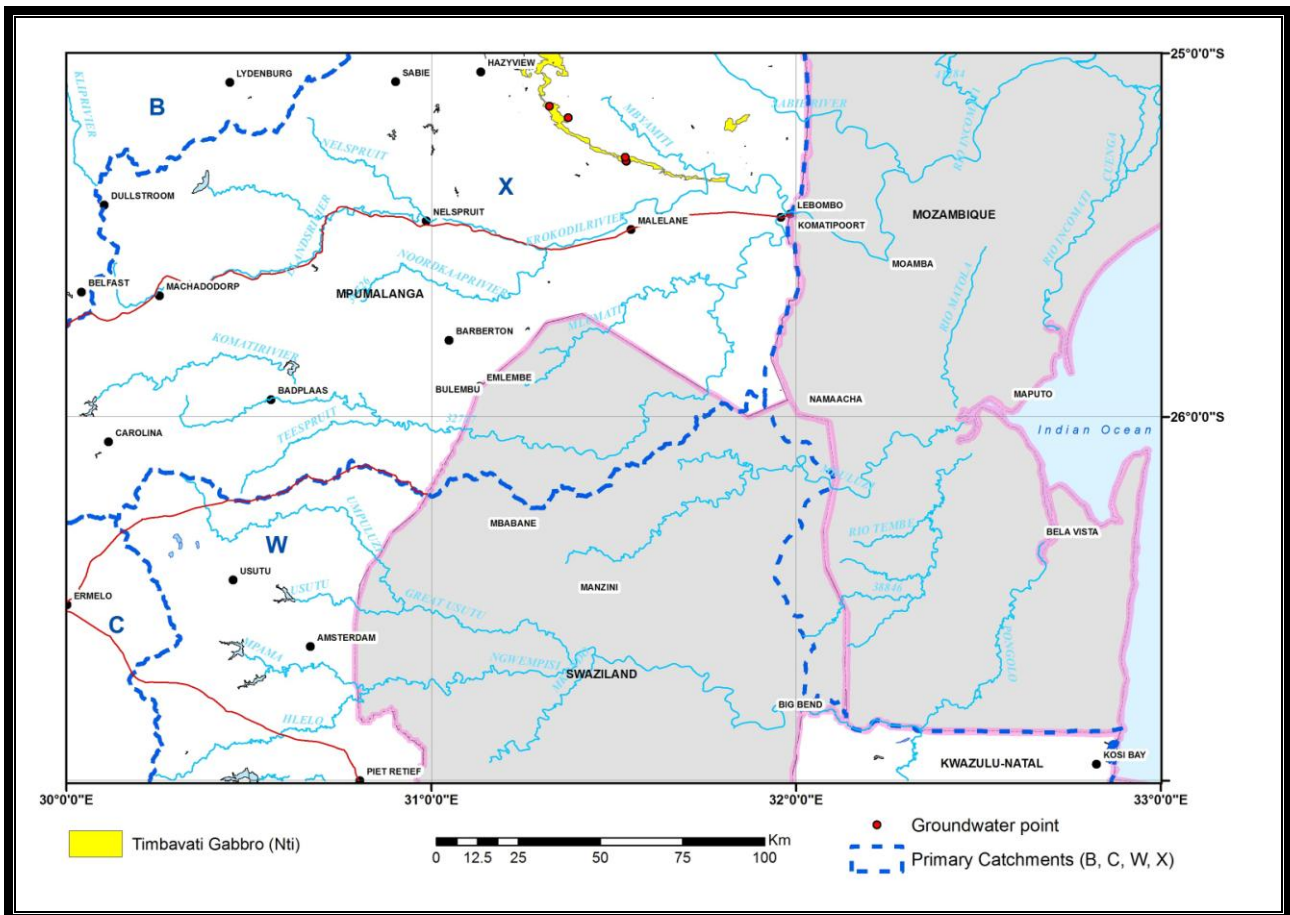


Figure 87: Geographical distribution of the Timbavati Gabbro (Nti) and associated groundwater sampling points.

The unit extent is small as it underlies only 0.04% of the map area. Maximum yield data was available for 8 sources. Most boreholes (37.5%) are within the yield range 0.5-2l/s. The high percentage (37.5%) of low yielding boreholes (less than 0.5l/s) indicates that borehole sites must be chosen carefully. High yielding boreholes are possible as 12.5% of the yields are more than 5l/s. Data from the adjacent hydrogeological map (sheet 2330 Phalaborwa) indicates that the unit is regarded as an average aquifer for groundwater development and that most of the strikes depths were within the first 30m (84%) and the rest between 30-60m. Contact zones and deep weathered and fractured zones are the main targets to explore when developing groundwater sources.

Only 6 chemical analyses were available for the Timbavati Gabbro (Nti). The water quality is acceptable for domestic use for all the parameters analysed except the magnesium (Mg) concentration. In all the samples the magnesium concentration falls within the maximum allowable domestic water quality range (Mg = 70 to 100mg/l).

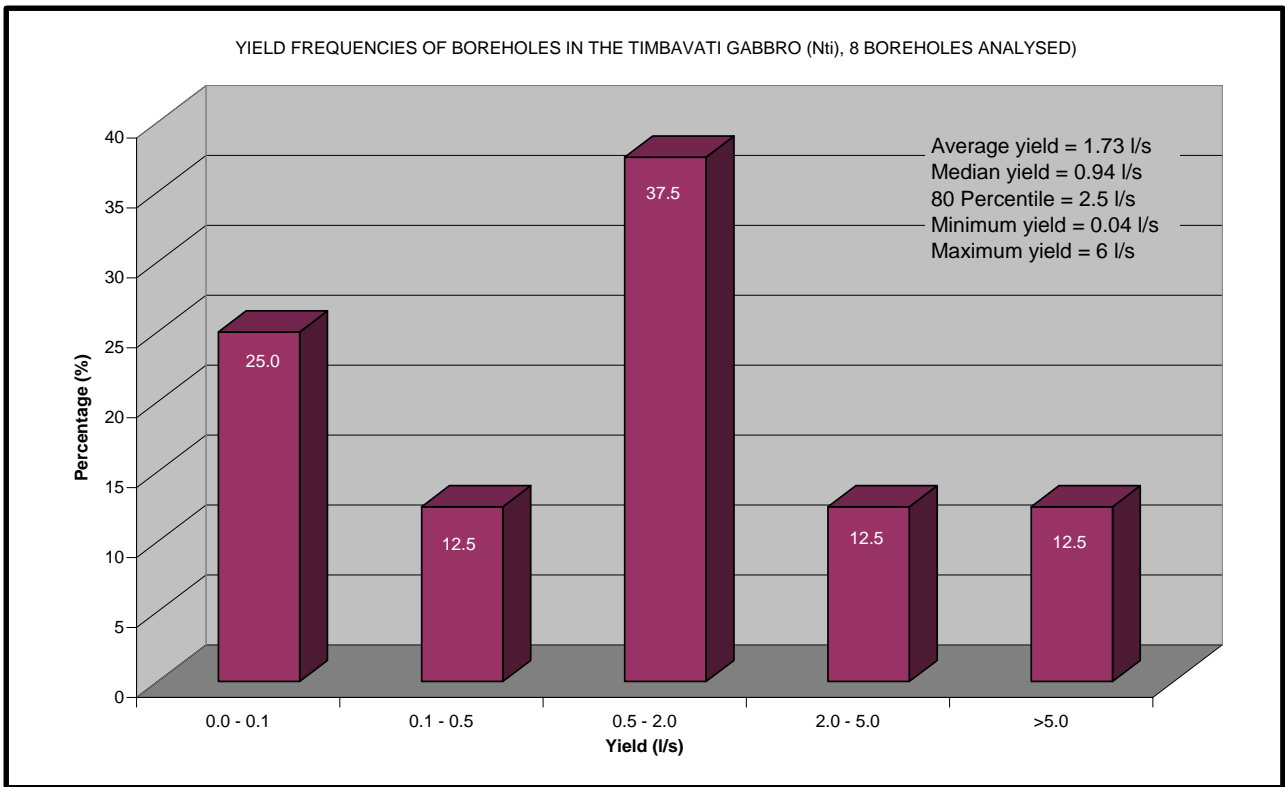


Figure 88: Yield frequency of boreholes in the Timbavati Gabbro (Nti).

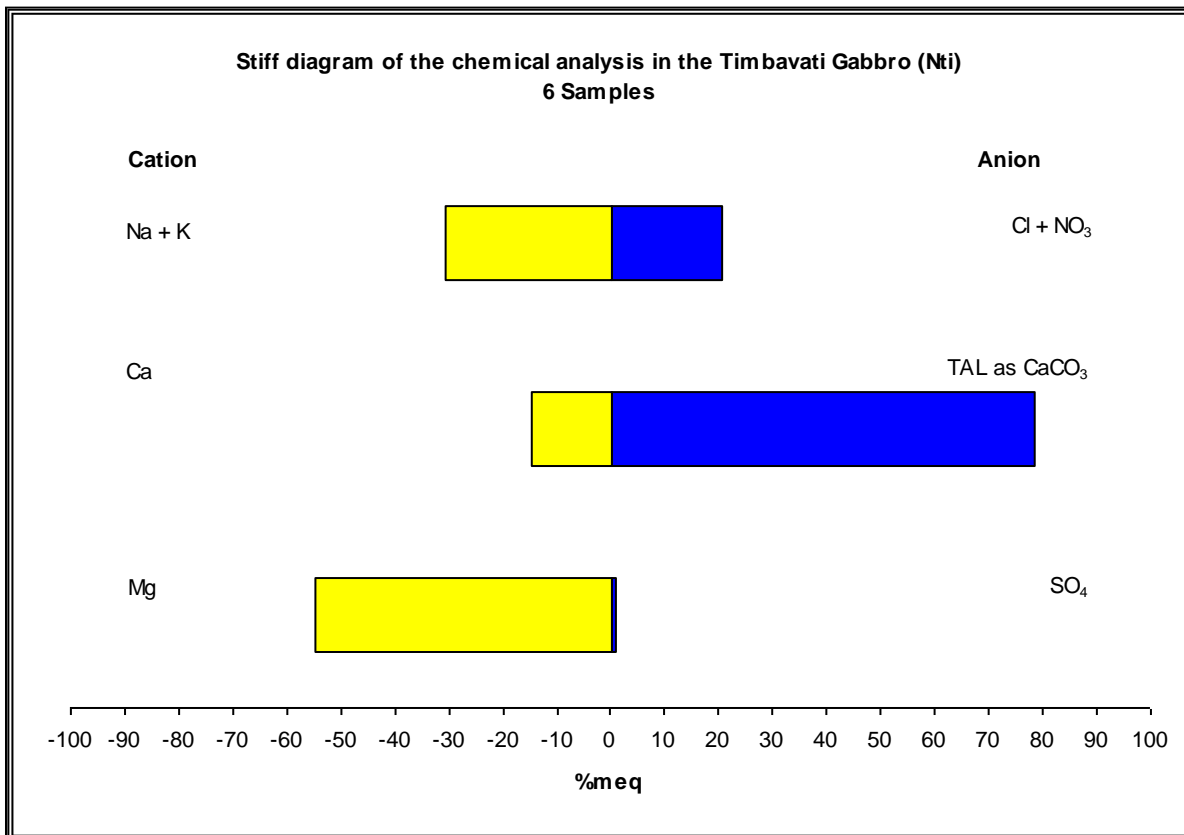


Figure 89: Stiff diagram representing chemistry for the Timbavati Gabbro (Nti).

3.3.4.24 Ecca Group (Pe), intergranular and fractured aquifers

The aquifers of the Ecca Group are classed as fractured as well as intergranular and fractured. The fractured aquifers of the Ecca Group are discussed in detail in section 3.3.2.4, p55. The intergranular and fractured aquifer unit underlies a large portion of the map area (13.92%) and occurs in the east and south-eastern sector of the map area. The Vryheid Formation consisting of sandstone, shale, mudstone, and subordinate coal forms the bulk of the unit. The topography is more or less flat and covered with grasslands.

A major ecological feature is the numerous shallow lakes and pans without inlets and outlets found in the Chrissiesmeer area. Chrissiesmeer is the largest natural fresh water body in South Africa covering approximately 1500ha. The formation of these depressions is speculative with the most accepted theory being that it is remnants of dried up river systems. Another theory is that the depressions extended in size and depth over time by animals visiting surface watering holes and removing material (mud) that stuck to their feet.

The area is known as the watershed area of South Africa with four major rivers starting in the area. They are the Komati, Olifants, Vaal and Usutu Rivers. Increased coal mining is a major economic activity in the unit but can be a threat to water quality.

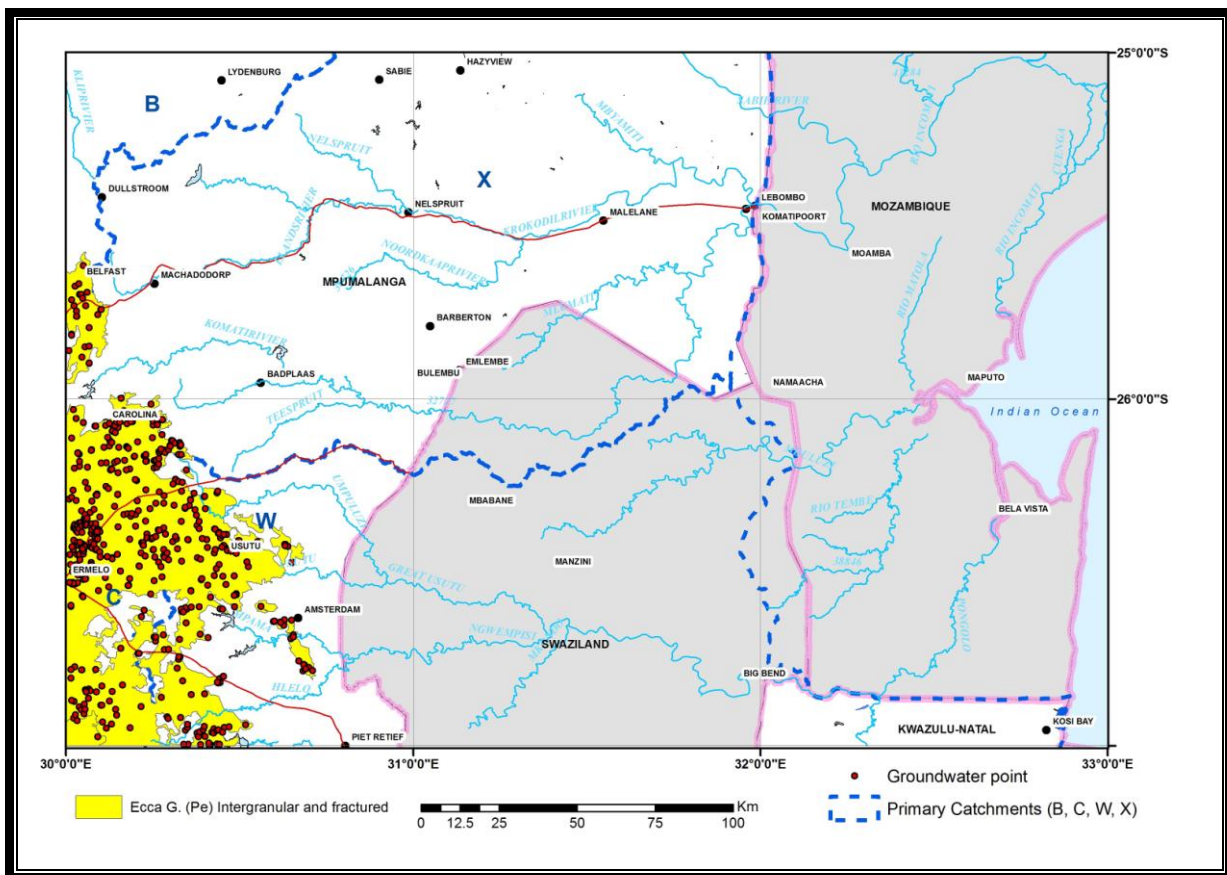


Figure 90: Geographical distribution of the intergranular and fractured aquifers of the Ecca Group (Pe) and associated groundwater sampling points.

The yield frequency diagram represents 169 sources with maximum yield data. Low yielding boreholes less than 0.5l/s comprises 50.1% of the available yield data, 33.1% of the sources yield between 0.5-2l/s, 14.8% are between 2-5l/s with only 3% of the sources yielding more than 5l/s. Water strike depths were available for 17 boreholes ranging from 11-68m with an average of 36.89m. Borehole depth information was available for 98 sources. The borehole depths range from 13.4-145m, with an average of 59.11m. Static water levels were available at 122 sources ranging from 0.4-100m averaging 15.15m. Eleven boreholes have recorded water

levels deeper than 40m and up to 74m. The very deep water levels (>60m) were recorded at 4 boreholes.

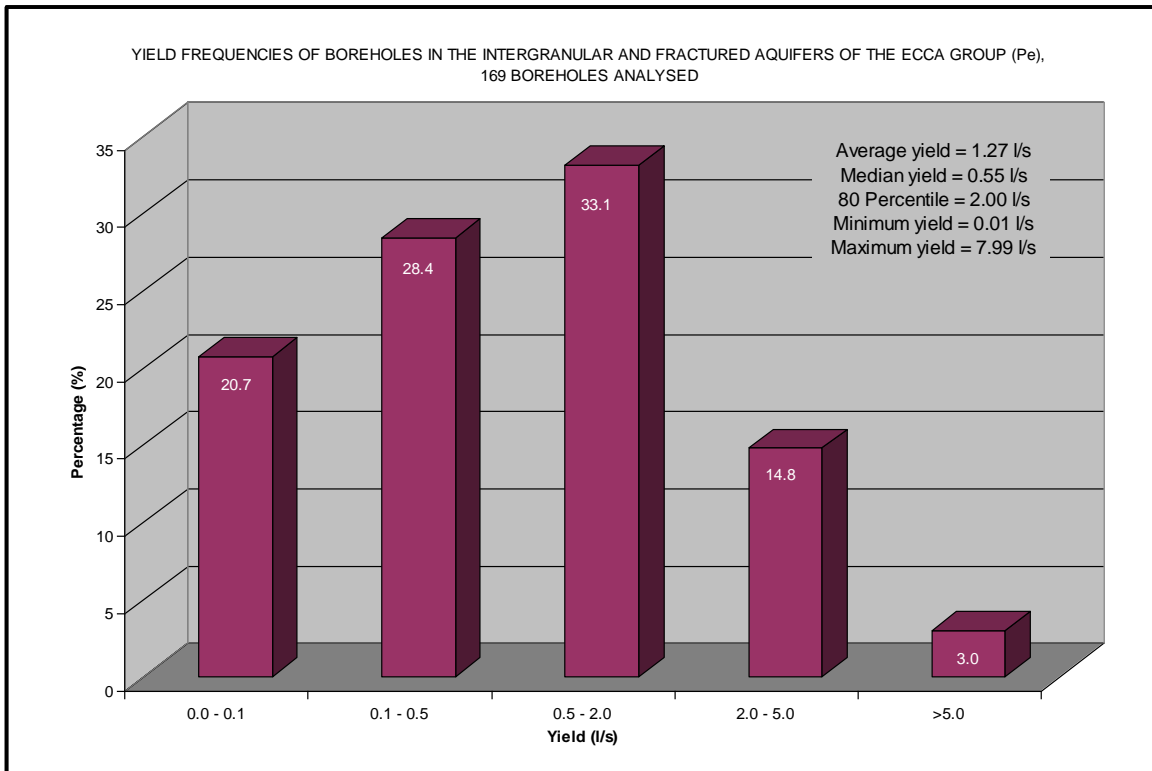


Figure 91: Yield frequency of boreholes in the intergranular and fractured aquifers of the Eccca Group (Pe).

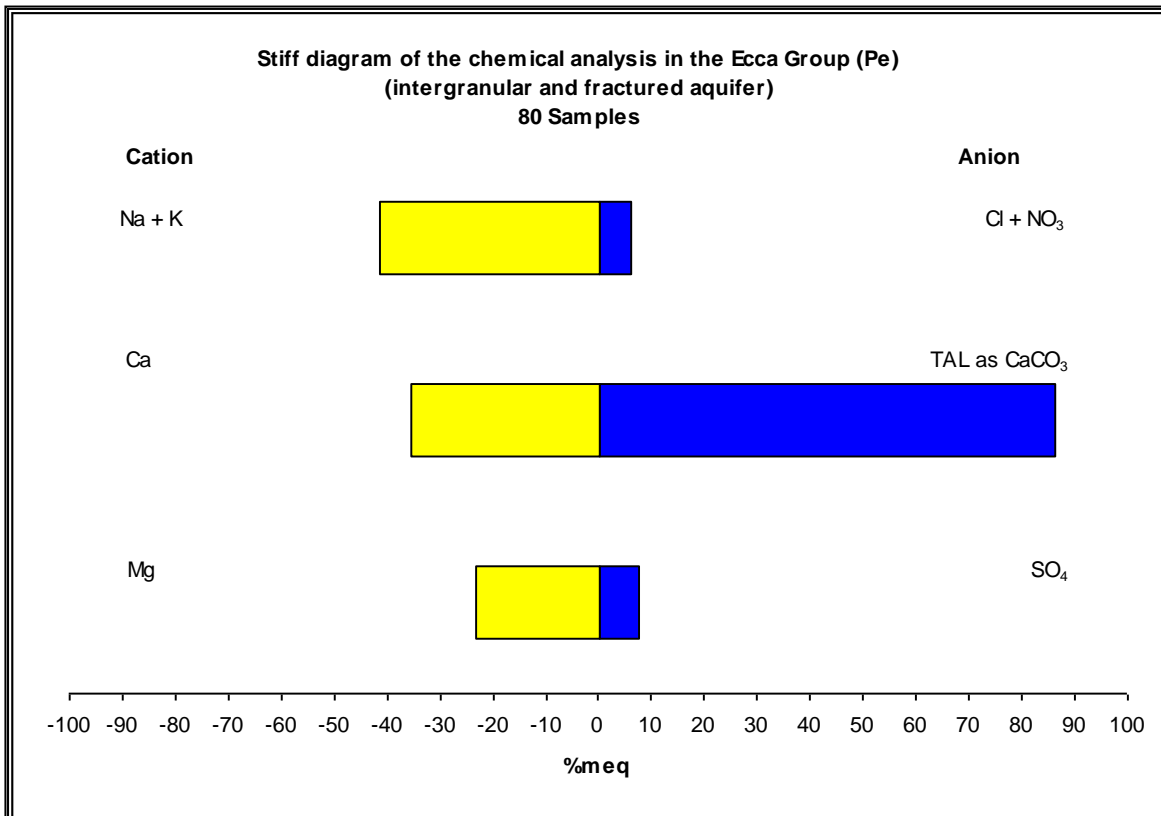


Figure 92: Stiff diagram representing chemistry for the intergranular and fractured aquifers of the Eccca Group (Pe).

Figure 92, p110 represents the dominant cations and anions in a Stiff diagram. The water type is sodium-calcium-magnesium-bicarbonate. The EC values of 93.8% of the samples fall within the ideal water quality range and the remaining 6.2% in the acceptable range for domestic use. Fluoride concentrations in 3.9% of the samples are unacceptable ($F > 1.5\text{mg/l}$) and 1.32% of the samples are unacceptable due to the sulphate concentration ($\text{SO}_4 > 600\text{mg/l}$).

3.3.4.25 Clarence Formation (Trc)

The unit occurs in a thin band striking south to north at the base of the Lebombo Mountain Range along the Mozambique border. It dips to the east at approximately 20° overlying the fractured aquifers of the Ecca Group (Pe). It consists of white to light cream coloured fine-grained homogenous sandstone. It forms prominent hills and contains calcareous concretions between 10 and 50cm at places (Wilson, 1977).

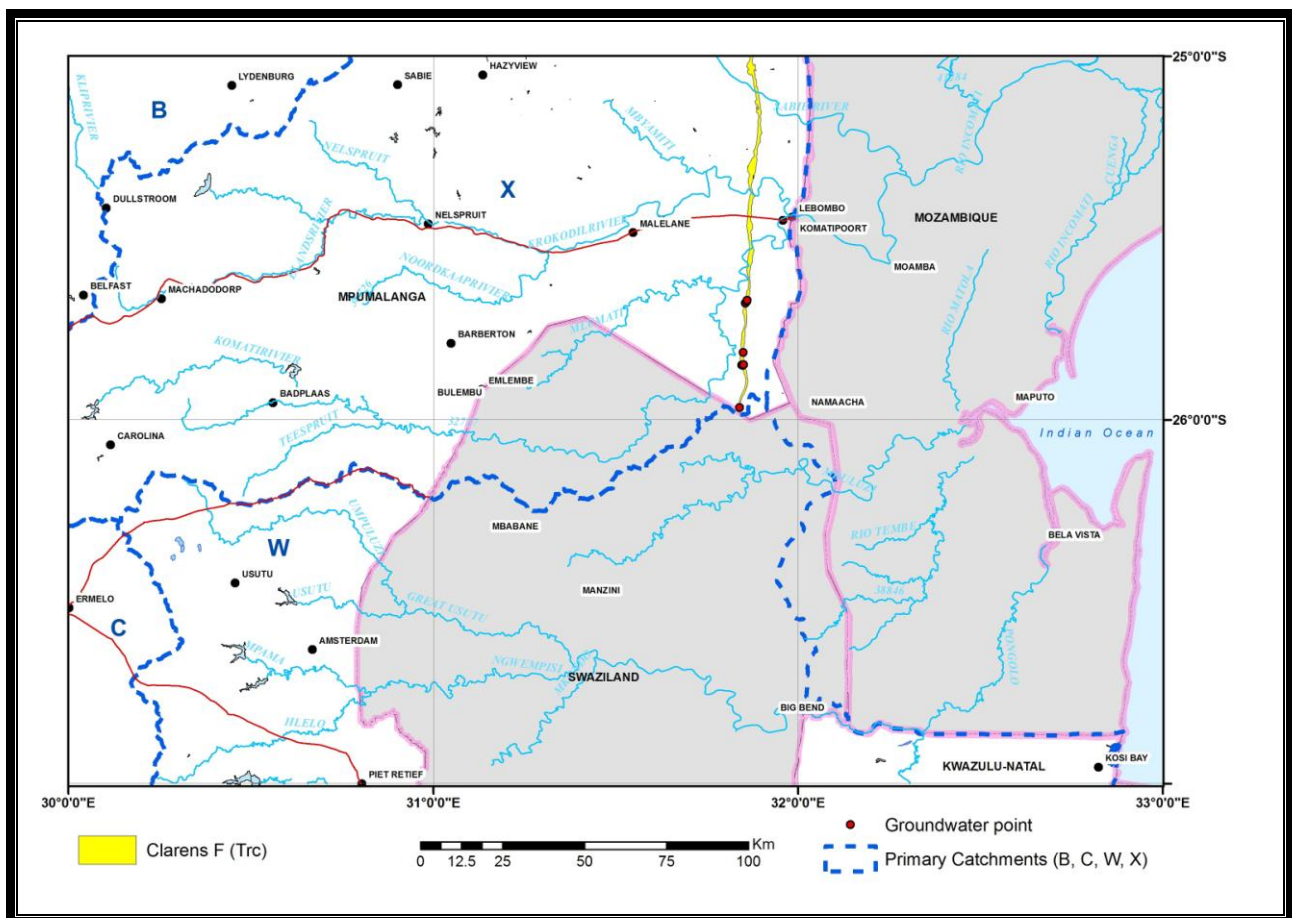


Figure 93: Geographical distribution of the Clarence Formation (Trc) and associated groundwater sampling points.

Poor data point distribution and lack of quality and yield data affected the hydrogeological evaluation of the unit. However, Du Toit (1998) concluded that the Clarence Formation displayed a considerable residual primary water bearing character. This characteristic was also found in the Tshipise Sandstone south of Alldays in a recent study. Groundwater is generally obtained in fractured sandstone as well as on the contact with overlying basaltic rock and underlying sediments. Dolerite intrusions in the form of dykes and sills also created secondary fractures and joints at the contact with the host rock. Water also occurs in fault zones transecting through the sandstone. The residual primary porosity is expected to make a considerable contribution as well. The Clarence Formation can be regarded as having a moderate to high groundwater development potential. Data from the adjacent hydrogeological map sheet i.e. 2330 Phalaborwa, comprised of 10 data points of which 70% have maximum yields between 0.5-2l/s and drilling depths ranging between 47.15-90m; the average depth is 67.03m. No data is

available on the thickness of the unit. The static water levels are known at 8 boreholes ranging from 3.21-8.36mbgl.

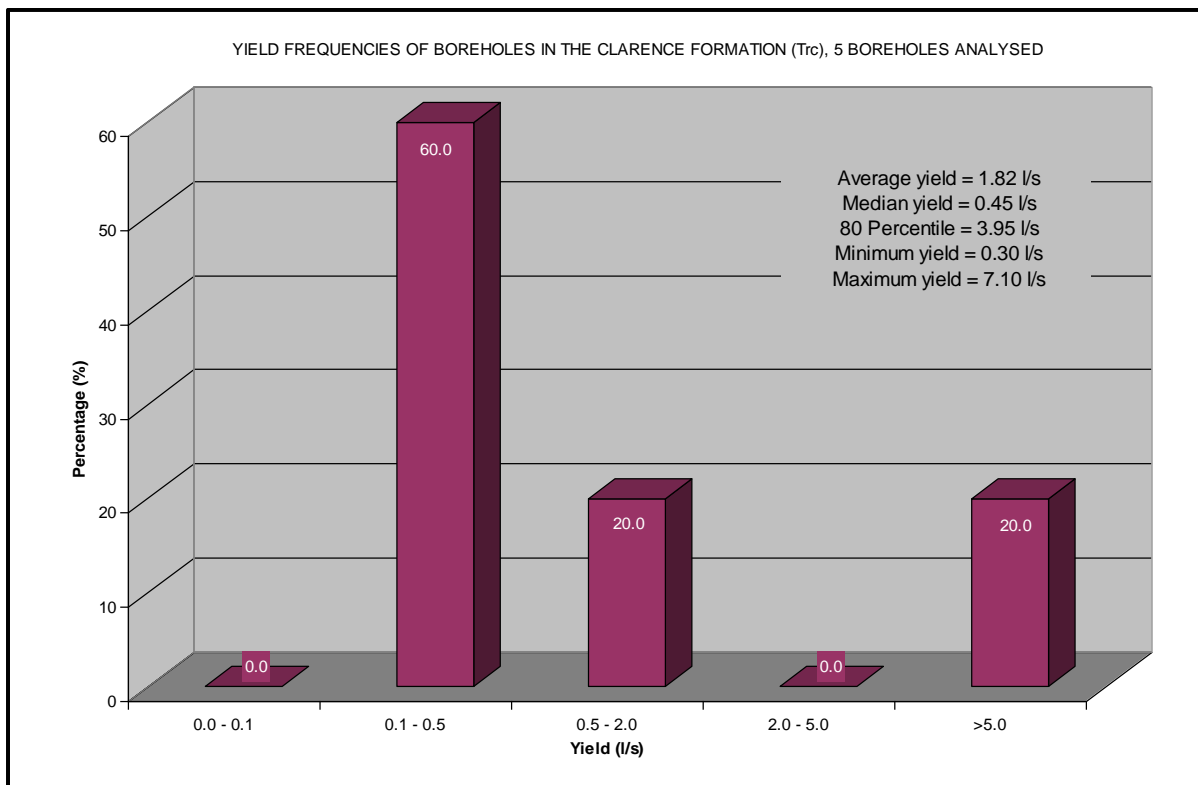


Figure 94: Yield frequency of boreholes in the Clarence Formation (Trc).

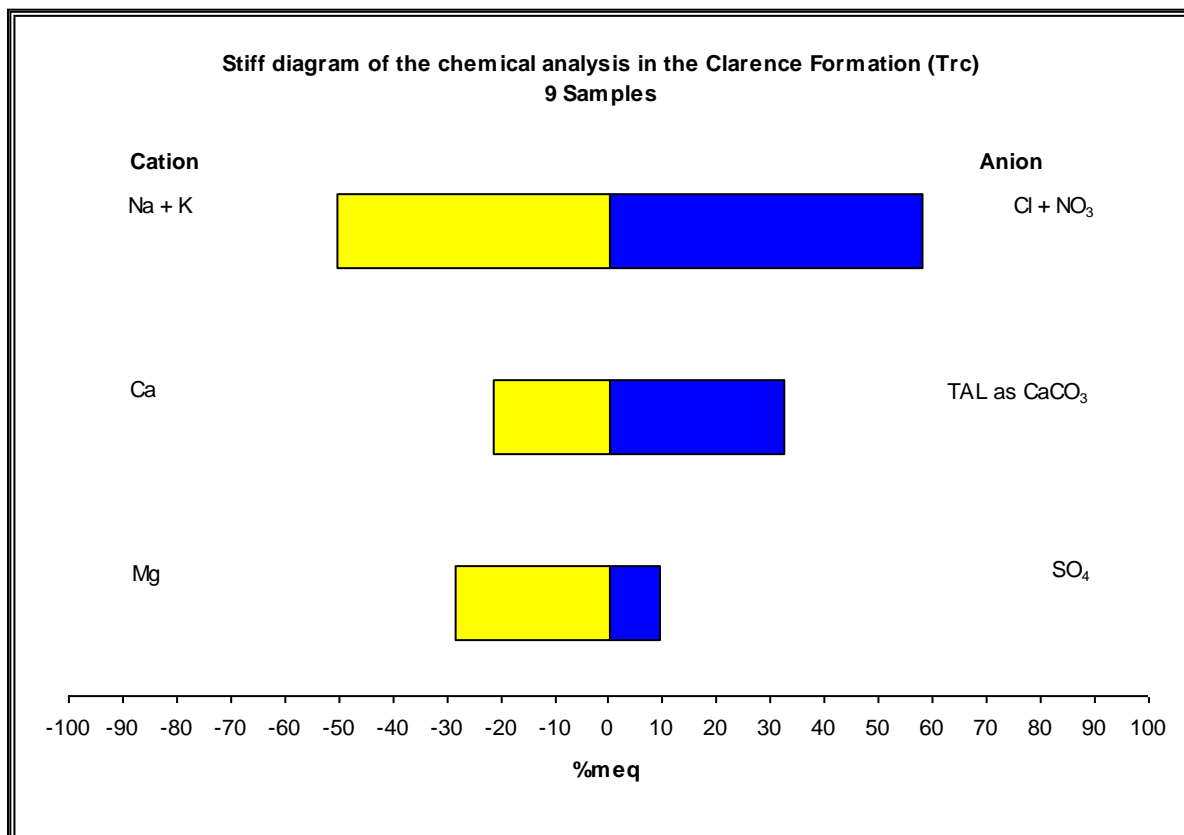


Figure 95: Stiff diagram representing chemistry for the Clarence Formation (Trc).

From the Stiff diagram, (Figure 95, p112), which represents chemical analysis of 9 samples the water is a sodium-bicarbonate-chloride water type. The sodium-bicarbonate 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^- . A predominance of Na^+ and Cl^- indicates an end point of discharge or stagnation of water. Water quality problems occur. The EC exceed the maximum allowable limit in 45% of the samples ($\text{EC} > 370\text{mS/m}$); nitrate in 33.3% ($\text{N} > 20\text{mg/l}$); magnesium in 55.6% ($\text{Mg} > 100\text{mg/l}$); sodium in 55.6% ($\text{Na} > 400\text{mg/l}$) and chloride in 6.7% ($\text{Cl} > 600\text{mg/l}$).

3.3.4.26 Lebombo Group (JI), intergranular and fractured

The outpouring of lava marked the end of the sedimentary deposits of the Karoo Supergroup. Two formations of the Lebombo Group occur within the map sheet along the eastern part of the map sheet forming the border with Mozambique. The youngest, the **Jozini Formation**, is a fractured aquifer as discussed in section 3.3.2.5, p57. The **Letaba Formation** exhibits intergranular and fractured aquifer characteristics and represents this unit.

The **Letaba Formation** consists of basic volcanic rocks varying between basalt and limburgite with increasing interlayered rhyolite nearer to the top of the formation. The formation dips at 5° to 35° to the east and is estimated to be more than 2000m thick within the map area (Walraven, 1986).

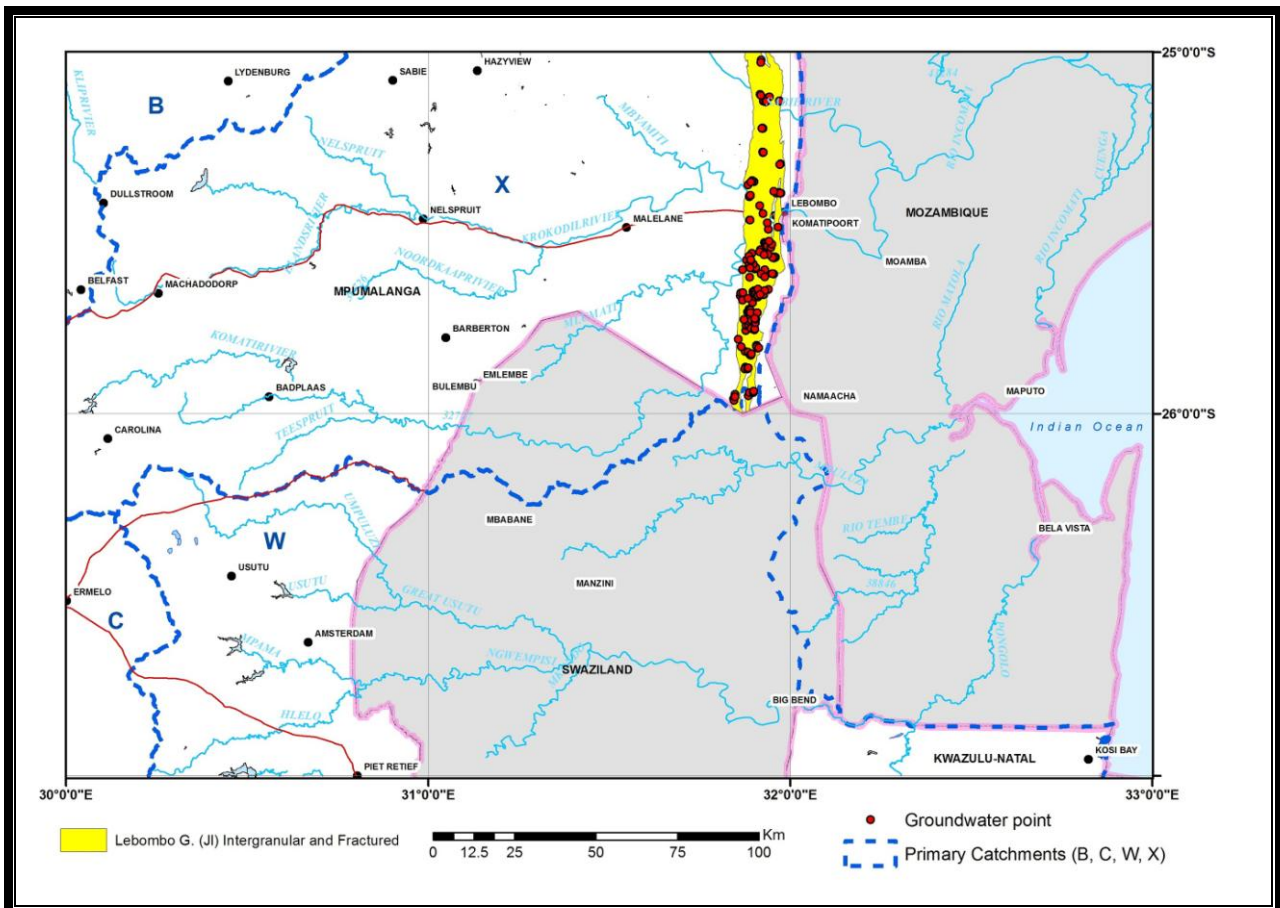


Figure 96: Geographical distribution of the intergranular and fractured aquifers of the Lebombo Group (JI) and associated groundwater sampling points.

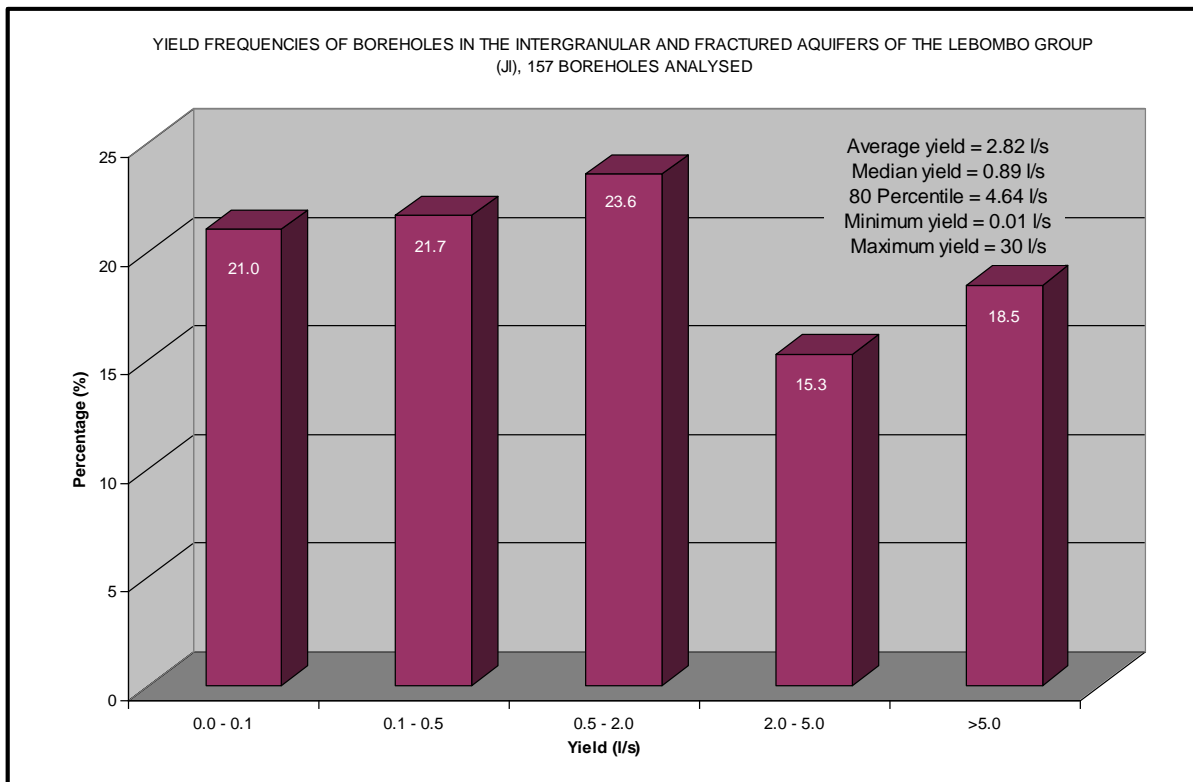


Figure 97: Yield frequency of boreholes in the intergranular and fractured aquifers of the Lebombo Group (JI).

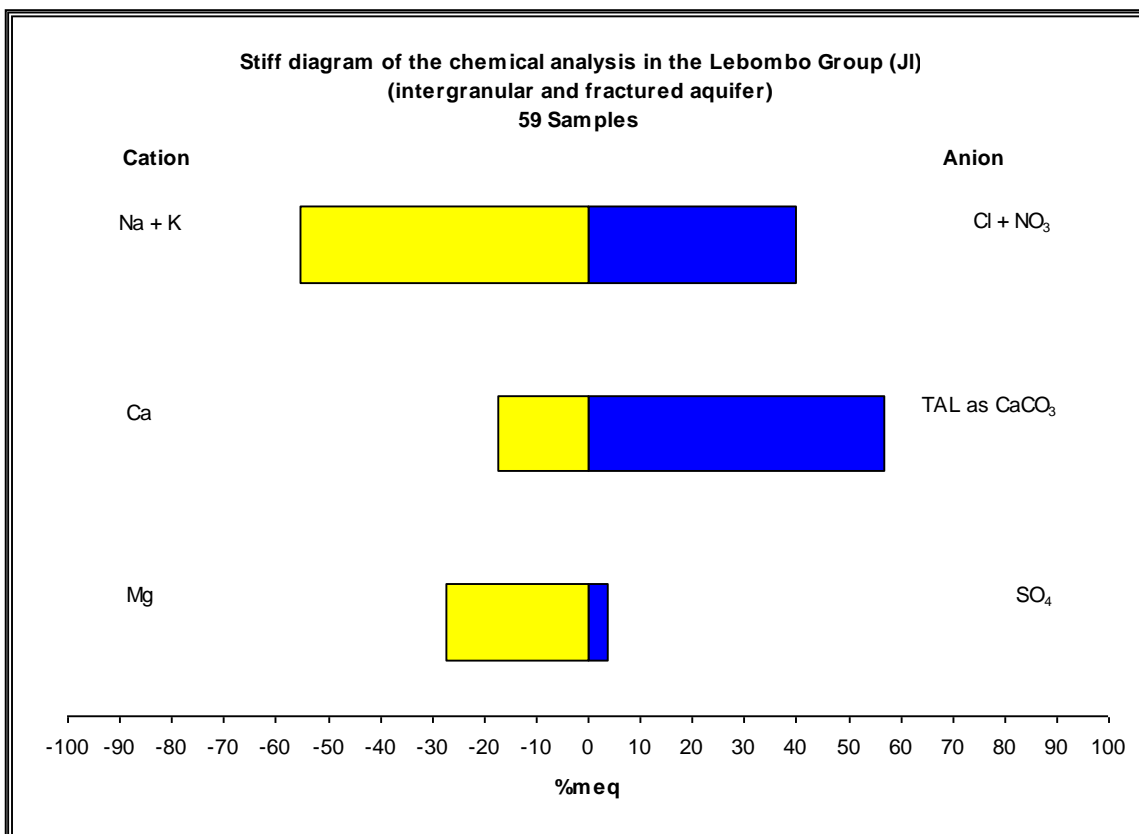


Figure 98: Stiff diagram representing chemistry for the intergranular and fractured aquifers of the Lebombo Group (JI).

The yield frequency diagram (Figure 97, p114) represents maximum yields of 157 sources of which 66.3% yield less than 2l/s. Analysis of the yield data shows that this is the only unit where there is a 15% chance of finding any of the yield ranges used in the frequency diagrams.

Water strike depths were available for 38 boreholes with 10m being the shallowest strike recorded and 71.25m the deepest. The average was calculated as 32.29m. Analysis of the strike depth shows that strike depths between 10-20m dominates; it decreases almost linear with 5% for every 10m depth increase up to the deepest strikes 70-80m. Nine boreholes yielded more than 5l/s and seven boreholes more than 2l/s with strike depths ranging from 11-40m and 10-71.25m respectively. Static water levels ranging from 0.55-40.94mbgl were available at 69 boreholes. The average water level was calculated as 10.30m.

The stiff diagram *Figure 98*, p114 represents the dominant cations and anions of 59 samples. The water type is sodium-magnesium-bicarbonate-chloride water. Water quality problems exist in this unit with 5.1% of the EC values exceeding the maximum allowable limit for domestic water (EC > 370mS/m). Other problematic concentrations exceeding the maximum allowable limit is nitrate in 50.9% (N > 20mg/l), chloride 8.47% (Cl > 600mg/l), sodium 6.8% (Na > 400mg/l), fluoride 6.8% (F > 1.5mg/l) and magnesium in 3.4% (Mg > 100mg/l) of total samples.

3.3.4.27 Dolerite (Jd)

Dolerite intrusions occur predominantly as sills throughout the Karoo Sequence. Outcrop is more abundant in the south-western section of the map sheet. Due to map scale and the GIS methodology followed, no dykes and only the prominent sills are shown on the map. The occurrence of dolerite dykes are addressed in section 2.4.1.10, p27.

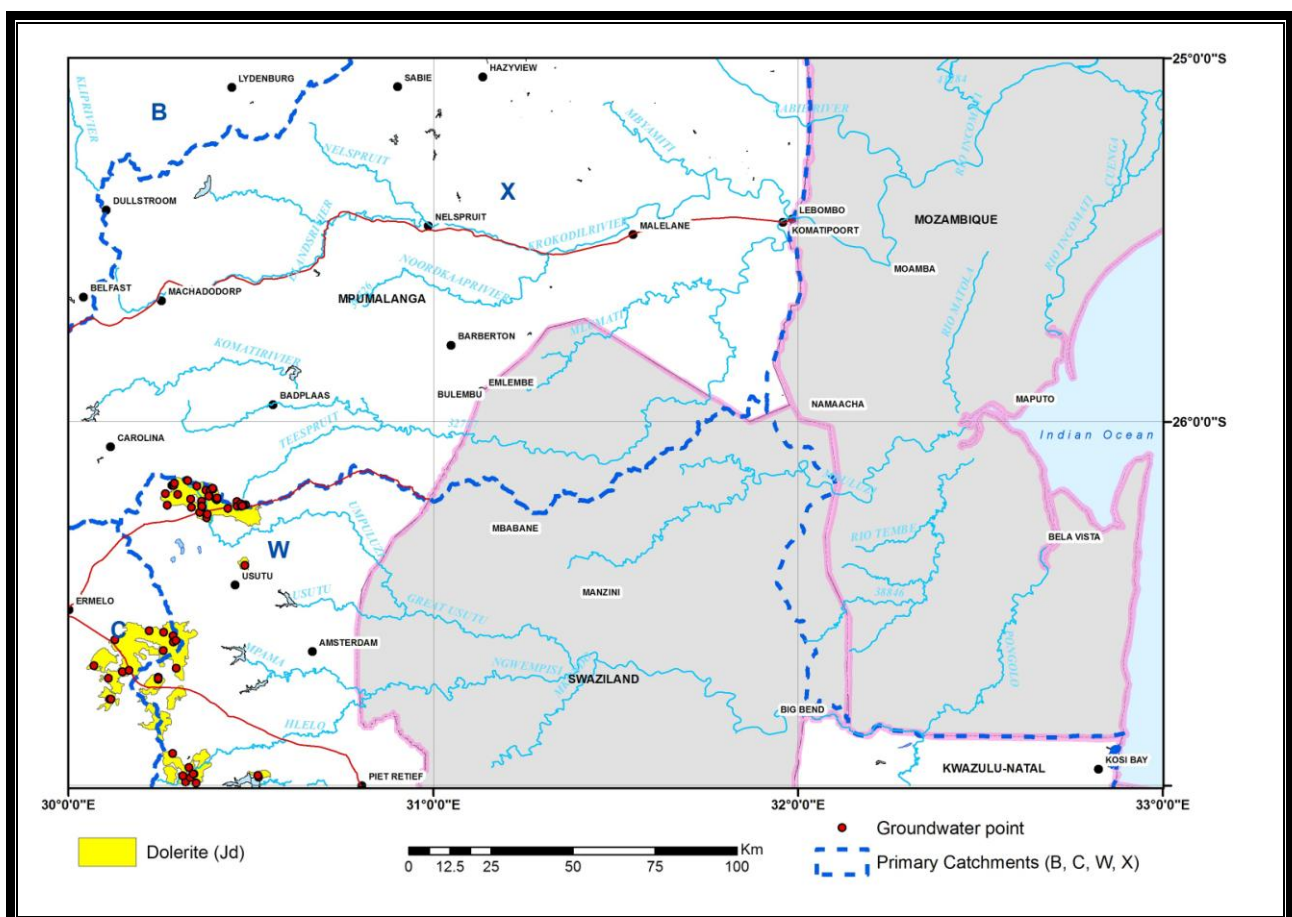


Figure 99: Geographical distribution of the Karoo Dolerite (Jd) and associated groundwater sampling points.

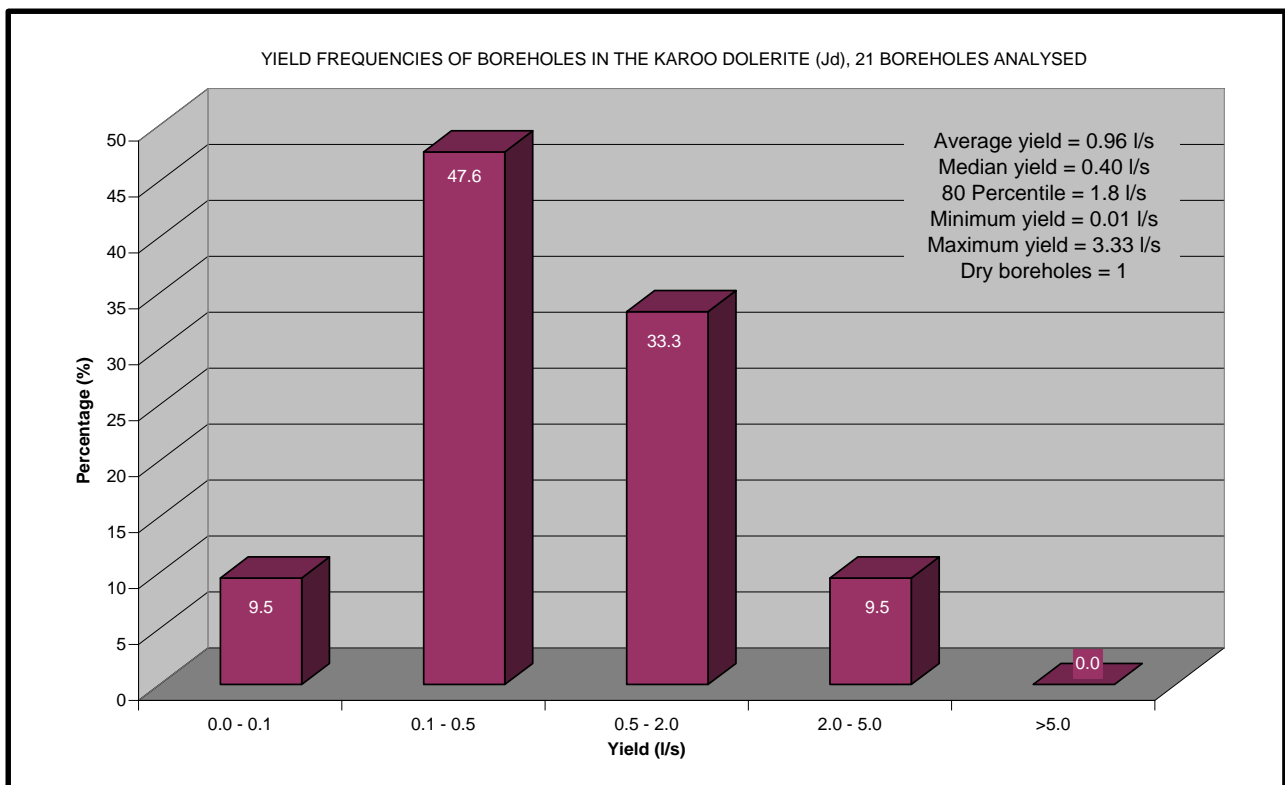


Figure 100: Yield frequency of boreholes in the Karoo Dolerite (Jd).

The yield frequency diagram (Figure 100, p116) represents the maximum yield of 21 sources. Most of the yields are less than 2l/s (90.4%) and the highest yield on record is 3.33l/s. Water strike depths are available for 3 sources that range between 17-66m. Static water levels are available at 7 sources ranging from 0.85-26mbgl with an average of 10.57mbgl. Borehole depth data is available for 11 boreholes ranging between 30.5-140m and averaging 87.37m.

Sills are considered difficult targets when developing groundwater sources especially if the sill underlay an extensive area and the contact (side of sill) with the adjacent geological formation cannot be targeted. If the contact (side of the sill) can be targeted, the factors to consider will be more or less the same as when targeting a dyke i.e. dip, recharge potential, static water level, the type of host rock, and the distance to drill from the contact zone. When a source needs to be developed on a sill three main targets must be investigated i.e. the upper weathered and fractured zone, the upper contact zone, and the lower contact zone. Factors that will influence the success rate on such a sill environment are as follows:

- The depth of the buried sill and the static water table – the overlying formation must be weathered and fractured to a depth that exceeds the static water table in the area. The depth of the upper contact zone must also exceed the static water level.
- The type of rock overlying and underlying a sill.
- The thickness of the sill - if the sill is too thick it will not be economical feasible to target the lower contact for possible secondary fracturing.
- The weathering and fracturing pattern of the upper part of the sill.
- The possibility of geological lineaments transecting the sill such as fault zones and younger intrusions.

Intrusive dolerite dykes are usually very good targets to explore wherever they occur. Knowledge of the width and dip of the dyke is important when choosing a drilling site. The occurrence of secondary fractures can differ along the strike of a dyke or on either side. Other important factors to consider when targeting dykes is the type of host rock, visible fracturing along or within the dyke and the expected depth of the static water table.

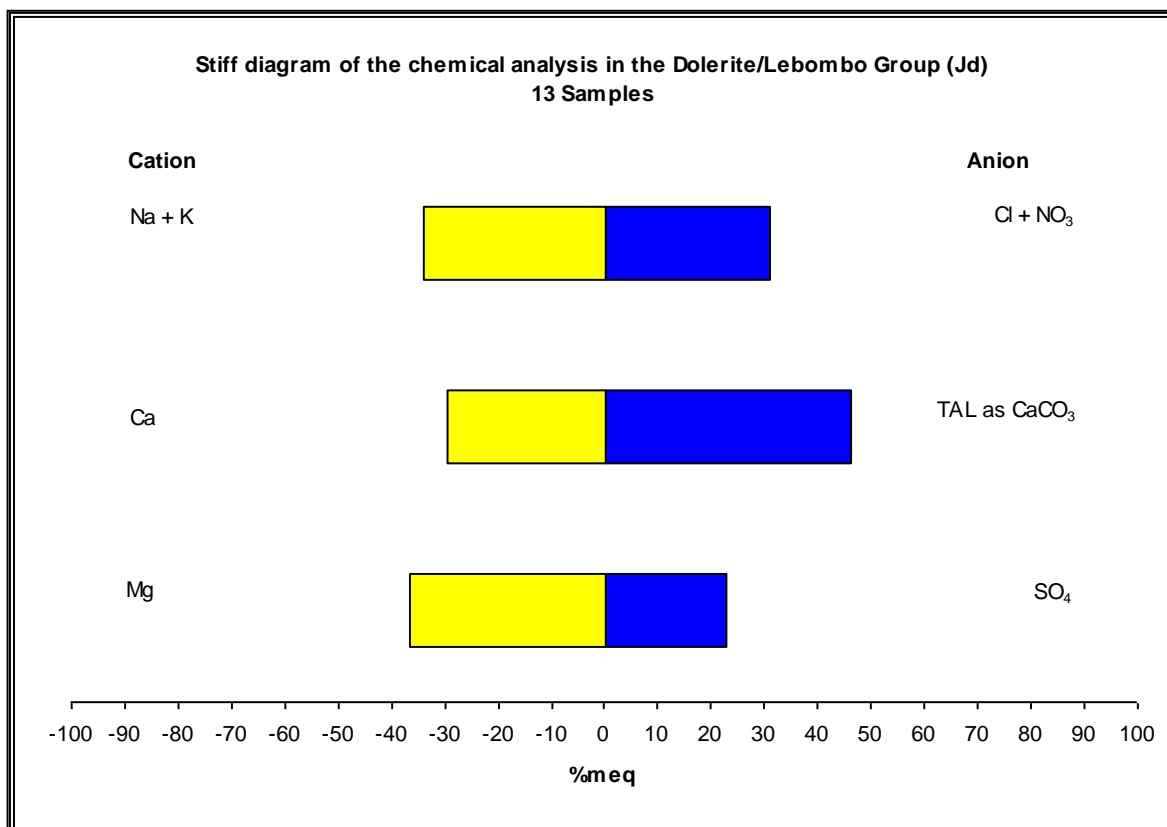


Figure 101: Stiff diagram representing chemistry for the Karoo Dolerite (Jd).

A combined plot of the available 13 water samples indicates magnesium-sodium-calcium-bicarbonate-chloride water type. Thirty eight percent of the samples failed the ionic balance calculation used for quality checks. Plotting the Stiff diagram with and without the poor data resulted in the same water type identified, thus all the samples were used for the compilation of the diagram. The water quality is good with all the EC values and most of the main macro element concentrations falling within the ranges for ideal domestic water quality. The only exception is with two samples or 15.38% with nitrate concentrations falling within the acceptable range (N=10-20mg/l). The ionic balance in very good to good water quality samples can be influenced by only one parameter not analysed for. The quality of analyses of the remaining parameters can be within acceptable accuracy.

3.3.4.28 Zululand Group (K-Tu)

The unit occurs on the Makatini flats in the south-eastern sector of the map sheet within the KwaZulu-Natal Province. The unit is a sedimentary deposit overlaying the Lebombo Group. The thickness of the group progressively increases to the north. The deposit is ascribed to a marine transgression from the north during the fragmentation of Gondwanaland (Tankard *et al.*, 1982). The Group is made up of three formations; at the base the Makatini Formation consisting of conglomerate with pebbles of volcanic and quartzitic rocks, together with cross-bedded sandstone and siltstone overlain by the Mzinene Formation composed of glauconitic siltstone and fine-grained sandstone followed by the St. Lucia Formation consisting of a thin bed of conglomerate at the base overlain by glauconitic siltstone and interbedded sandstone with shelly beds at various horizons (Explanation: Geological map 1:1 000 000, 1989, p164).

No maximum yields were available for the unit within the map area and the description for the unit was obtained from the adjacent hydrogeological map sheet i.e. 2730 Vryheid. "The Mzinene and St. Lucia Formation are notoriously poor aquifers with yields generally less than 0.1l/s. The Makatini Formation is slightly better with an average yield of 0.4l/s. On water quality the following was reported: The water quality is highly saline (EC > 800mS/m)".

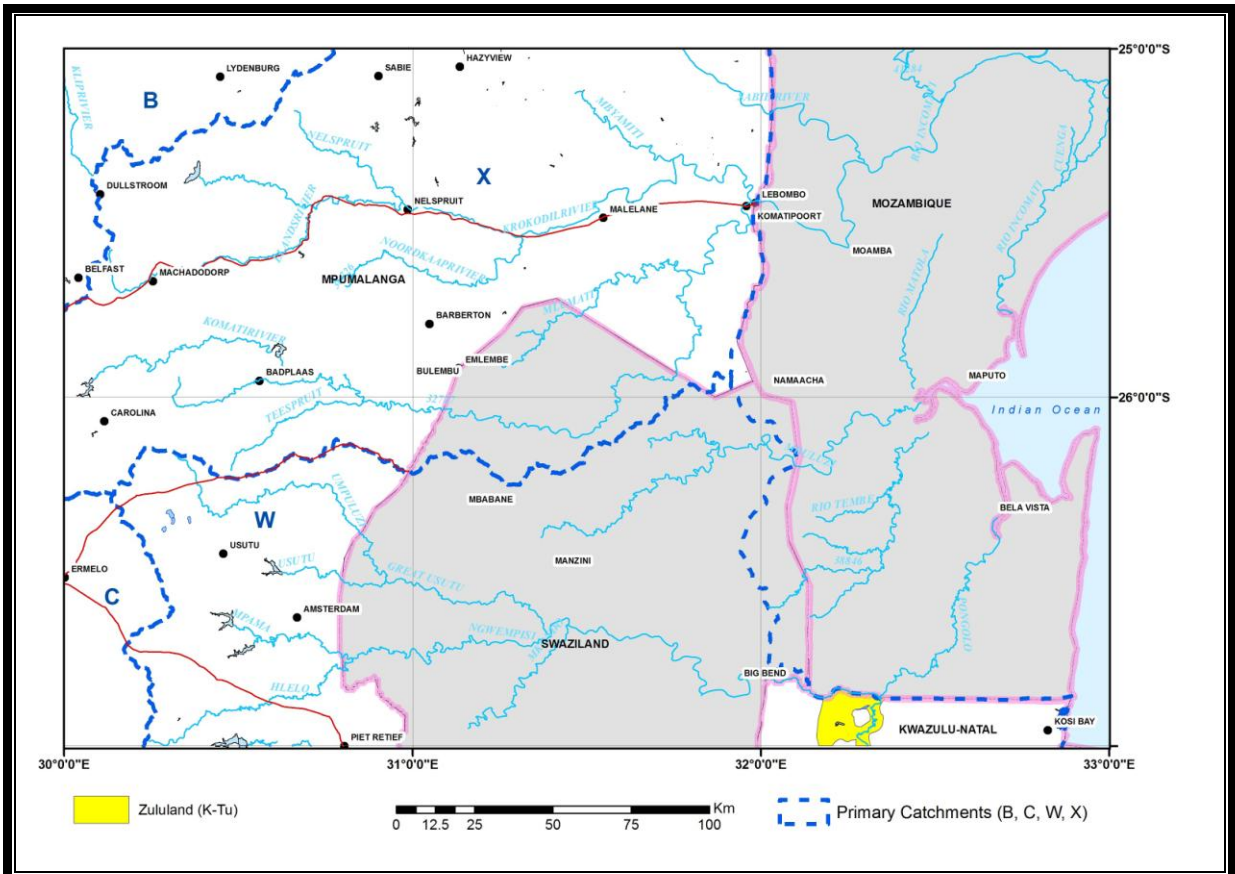


Figure 102: Geographical distribution of the Zululand Group (K-Tu) and associated groundwater sampling points.

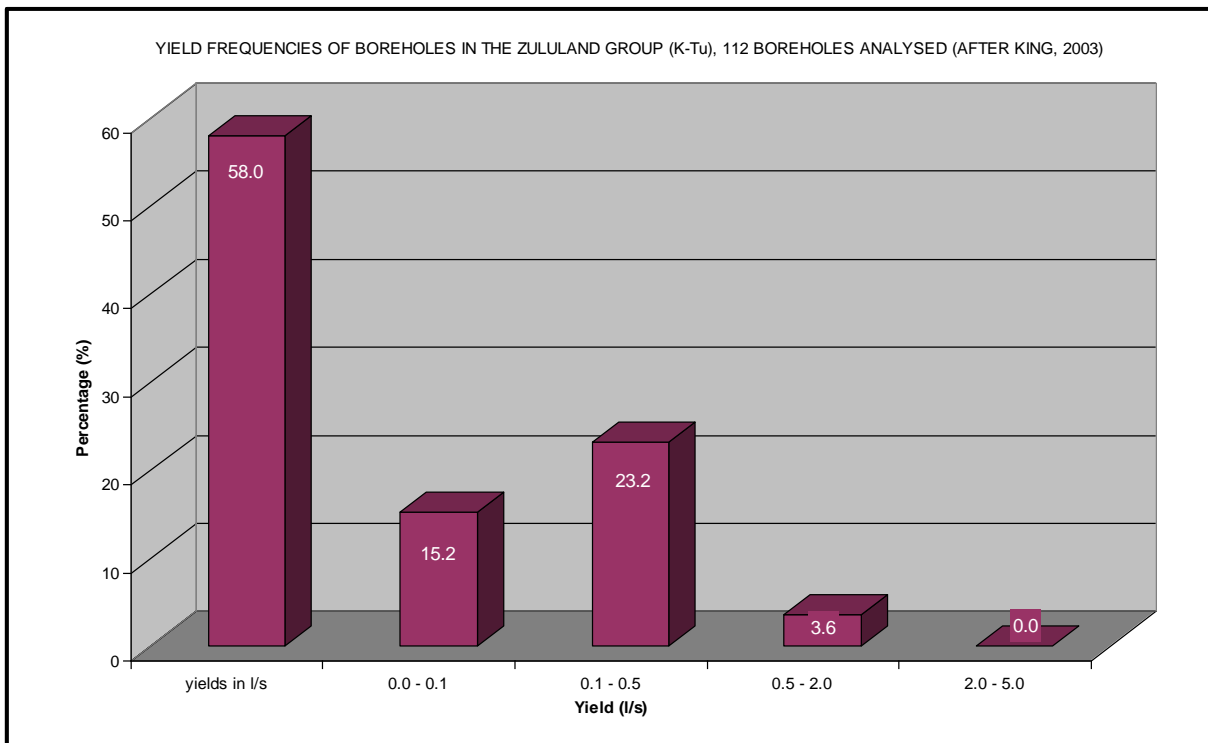


Figure 103: Yield frequency of boreholes in the Zululand Group (K-Tu), after King 2003.

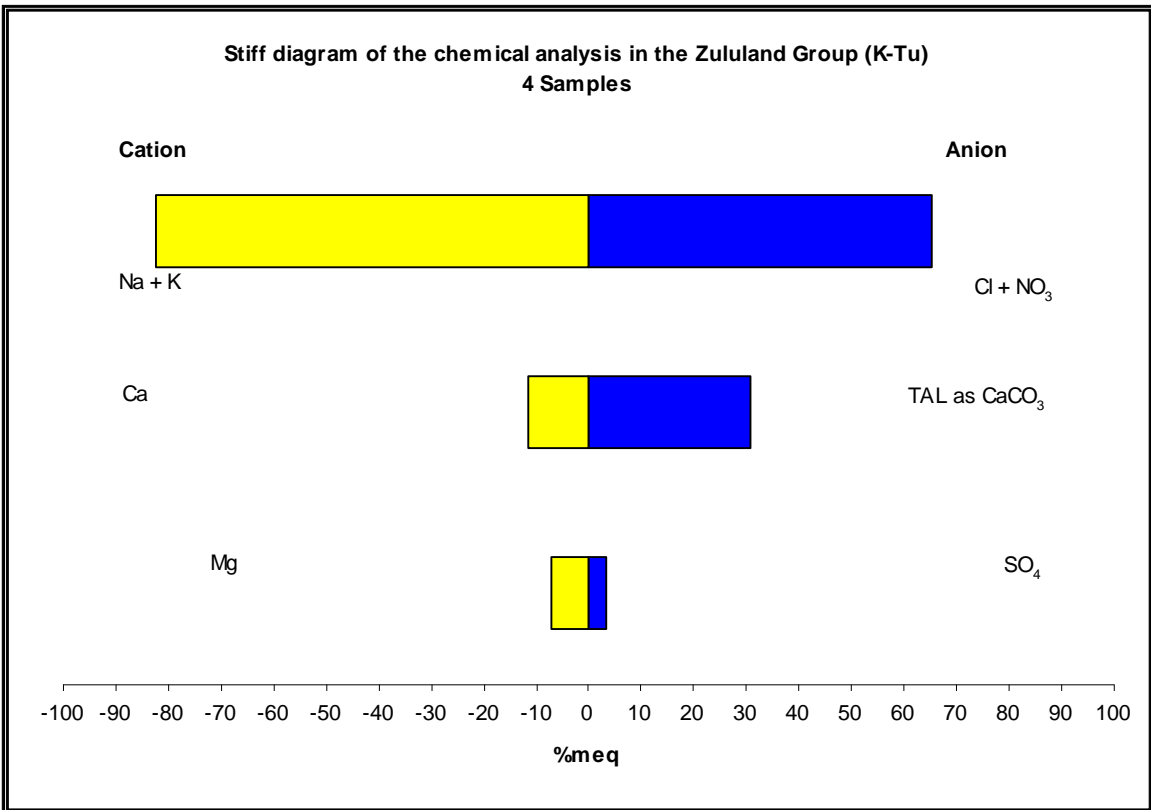


Figure 104: Stiff diagram representing chemistry for the Zululand Group (K-Tu).

The Stiff diagram representing chemical analysis of 4 samples within the Zululand Group (K-Tu) shows that the unit is characterized by a dominant sodium-chloride type of water. A predominance of Na⁺ and Cl⁻ indicates an end point of discharge or stagnation of water. As part of the study the chemistry was plotted on a Piper and a Durov diagram that confirms the natural saline water character of the 4 available samples.

The sodium concentration exceeds the maximum allowable limit for domestic use in one of the four samples, (Na > 400mg/l).

4. SPRINGS

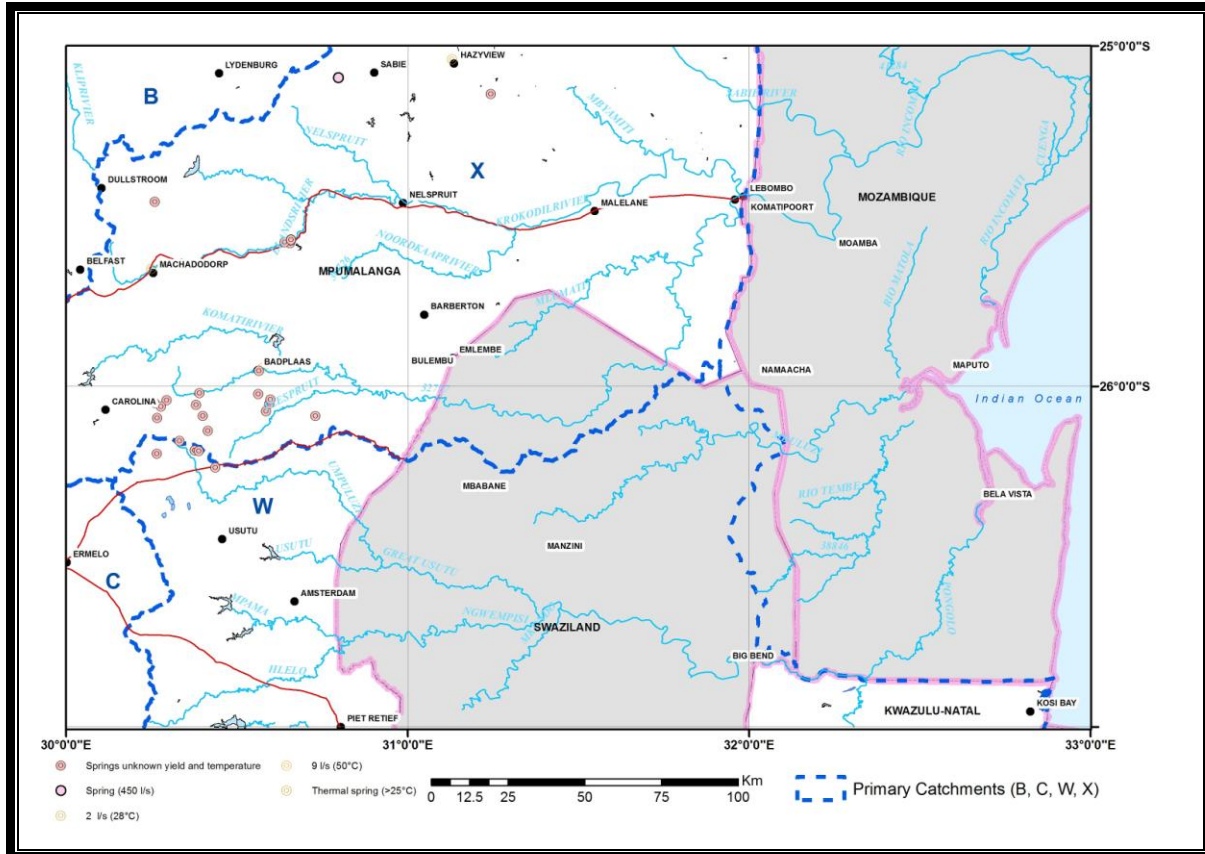


Figure 105: Non-thermal and thermal springs as well as listed springs without any data.

Research done on the occurrence of springs within the map area during the compilation of the brochure was hampered by the lack of data on yield, temperature and geological setting. The map (Figure 105, p120) shows the geographical distribution of non-thermal, thermal and springs without any data.

4.1 Non-thermal Springs

Photo 15, p120 shows the only non-thermal spring depicted on the Nelspruit map.

Photo 15: The presence of groundwater and subsequent subsidence in the Malmani dolomites seriously hampered mining activities in Glynn's Lydenburg Gold Mine just outside of Sabie. To continue mining, the mine had to pump water from the waterlogged South Shaft area at a rate of 82 000m³ per day. To solve the problem a drainage tunnel 5 kilometres long was driven underneath the mine. Springs in the mining area stopped flowing almost overnight after the tunnel was connected with the South Shaft area in 1940. Flow was measured at a rate of 477l/s. As a result of this tunnel, the flooded workings dried sufficiently to make renewed mining possible. Although mining stopped a long time ago groundwater is still flowing from the tunnel at an estimated rate of 500 l/s. The Sabie municipality obtains water from this source (photo and explanation W. H. Du Toit, 2006).



Figure 105, p120 shows all the non-thermal springs (temperature < 25°), as listed on the Groundwater Archive. Springs listed with no information on yield or temperature, are included. Additional springs not shown are known to exist along the Drakensberg Escarpment and in areas underlain by the hydrogeological unit Undifferentiated Black Reef Formation and Chuniespoort Group (Vh-Vbl), as well as within the rocks of the Pretoria Group and Bushveld Complex. The flow of springs is affected in forestry areas related to the gradual lowering of the static water level as plantations mature.

4.2 Thermal Springs

Six thermal springs (temperature > 25° C) are depicted on the Nelspruit map. The best known is the thermal spring at Badplaas which was the reason for the establishment of the town. The spring flows at 9l/s and has a temperature of 50° C. Another thermal spring at Machadodorp flows at 2l/s with a temperature 28° C. Two springs are located near Hazyview and another two between Lydenburg and Machadodorp. No information is available on yield, temperature or quality.

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.

5. GROUNDWATER RELATED MATTERS

5.1 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 (WUA) 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.

5.1.1 *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.

5.1.2 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.

5.1.3 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 of protection required for the water resource and to state the extent to which the water can be used. The classification is used to define the present status of the resource unit and to define the state towards which the water resource needs to be managed sustainably (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 quantity, monitoring abstraction and compliance of licensed water users. Availability and demand must be managed in an integrated manner to maintain the resource quality objectives.

5.1.4 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. No information was available or could be obtained on any monitoring boreholes by government or private institutions.

5.1.5 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 Nelspruit map sheet is dependent on effective rainfall defined as the fraction of rainfall that will infiltrate to the saturated zone after evaporation, transpiration, run off and interception 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.

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. Fresh dolomite has a very low primary porosity but as openings are formed by solution secondary porosity can be very high.

5.1.6 Borehole positioning

In the search for groundwater various tools are available that can be used to assist in the location of various geological features that might act as storage and/or conduits for subsurface water. A scientific approach is recommended and promoted due to the high development cost associated with groundwater. Geological targets that relates to the occurrence of groundwater are described for some of the hydrogeological units in section 3.3.1, p44-p117. This brochure represents some statistical analysis of data for hydrogeological units within the map area and can be used on a regional scale as a quick reference.

The effective application of geophysical methods in the search for groundwater is to a great extent enhanced by using additional scientific methods such as:

- remote sensed data that includes aerial photographs, LANDSAT images and satellite imagery developed for earth science,
- existing maps including geological and hydrogeological maps,
- previous regional geophysical studies such as aeromagnetic surveys,
- existing information of the area obtainable from the Groundwater Archive or from professionals familiar with an area and last, not least, the experience of the surveyor.

An experienced hydrogeologist will in addition, take vegetation, topographical setting, soil changes, possible recharge zones and other visible signs, into consideration during the survey. Geophysical methods is used to investigate and locate targets associated with the occurrence of groundwater and Table 11, p126 gives a summary on the current status of the development of geophysical methods for various applications. The occurrence of groundwater in Southern Africa is to a large extent related to secondary fracturing and the column showing the development of instruments for the identification of fracture zones and intrusive dykes is regarded as more important than the column named groundwater application. In this column for example the applicability of the magnetic method is shown as 1, (limited use). The magnetic method, although not recommended for the determination of depth of bedrock or in the detection of cavities in Karst environments, is seen in South Africa as essential due to the detectability of igneous dykes. Table 12, p127 gives an indication of the application of each method for a specific hydrogeological unit based on geology and possible targets.

Table 11: Usefulness of near surface geophysical methods after Geomatrix Earth Science LTD

	Application											
	Depth to Bedrock	Stratigraphy	Lithology	Fractured zones	Fault Displacement	Density	Cavity Detection	Groundwater exploration	Porosity	Clay pockets in limestone	Sand and gravel	Basic igneous dykes
Seismic												
Refraction	4	4	3	3	4	2	1	2	0	1	2	1
Reflection-land	2	2	2	1	2	0	2	2	0	0	0	1
Reflection-marine	4	4	2	2	4	0	0	0	0	0	0	0
Cross-hole	2	2	3	3	1	2	3	0	0	0	1	2
Surface waves	0	0	0	3	0	2	3	0	0	1	1	0
Electrical												
Resistivity sounding	4	3	3	2	2	0	2	4	3	0	3	0
Induced Polarization	2	2	3	1	0	0	0	3	3	1	1	1
Electromagnetic (EM) Profiling	3	2	2	4	1	0	3	2	1	2	3	3
Resistivity Imaging	3	3	2	2	2	0	3	3	0	4	4	2
Other												
Ground Penetrating Radar	2	3	1	2	3	0	3	2	1	2	1	2
Gravity	1	0	0	0	2	2	4	1	0	1	1	2
Borehole methods	2	4	4	2	0	4	1	3	3	2	2	0
Magnetic	0	0	0	2	2	0	2	1	0	3	2	4

Notes: Information obtained from Geomatrix website 12/12/2013

0 = not considered applicable

1 = Limited use

2 = Used, or could be used, but not the best approach, or has limitations

3 = Excellent potential but not fully developed

4 = generally considered as an excellent approach, techniques well developed

Table 12: Recommended geophysical survey techniques to use in the search for groundwater for each hydrogeological unit.

Hydrogeological unit as depicted on map		MODE OF OCCURRENCE	Ground geophysical method					
Unit name	Unit symbol		Seismic	Resistivity	Electromagnetic	Ground penetrating radar	Gravity	Magnetic
Quaternary alluvial deposits	Q	Intergranular	4	4	3	2	1	0 (4)
Maputaland Group	T-Qm	Intergranular	4	4	3	2	1	0 (4)
Black Reef Formation, Tshokwane Granophyre	Vbl, Jts	Fractured	3	2	4	2	0	4
Pretoria Group, Ecca Group, Lebombo Group, Clarence Formation	Vp, Pe, JI, Trc	Fractured and Intergranular/Fractured	3	2	4	2	0	4
Undifferentiated Black Reef and Chuniespoort Group	Vh-Vbl	Karst	2	2	3	3	4	2 (4)
Undifferentiated Barberton Super Group, Undifferentiated Tjakastad Subgroup, Undifferentiated Onverwacht, Fig Tree, and Moodies Group,	Zr, Zot-Zoo, Zo-Zd	Intergranular/Fractured	2	3	4	2	0	3 (4)
Unnamed Swazian Rocks, Nelspruit Suite, Nsuzze Group, Kaap Valley Granite, Various intrusive rocks of the Mozaan Group and Nsuzze Group, Dalmein Granite, Hebron Granite, Unnamed Randian Rocks, Boesmanskop Syenite, Salisbury Kop Granodiorite, Mpangeni Granite, Rustenburg Suite, Lebowa Suite, Timbavati Gabbro	Zz, Ze, Zn, Zka, Z-Rg, Zda, Zhe, Rz, Rbs, Rsk, Rmp, Vr, Mle, Nti	Intergranular/Fractured	3	3	4	2	0	4
Undifferentiated Rocks of the Thole and Piet Retief Suite, Undifferentiated rocks of the Mozaan Group, Amsterdam Formation and Usushwana Complex, Mozaan Group	Rth-Rup, Rm-Ru, Rm	Intergranular/Fractured	2	3	4	2	0	3
Wolkberg Group	Vw,	Intergranular/Fractured	3	3	4	2	0	4
Diabase and dolerite intrusions	N-Zd	Intergranular/Fractured	2	3	4	2	0	4
Rustenburg Suite	Vr	Intergranular/Fractured	3	3	4	2	0	4
Zululand Group	K-Tu	Intergranular/Fractured	4	3	4	2	0	2 (4)

Note: Although the magnetic method is not considered applicable to detect cavities or depth to bedrock such as in alluvial deposits it is recommended to be used in all the units due to the speed of data acquisition and the ability to detect intrusive basic dykes. The combination of at least two methods is recommended within all the units.

5.1.6.1 Additional information on the use of geophysical methods as obtained from existing reports:

Electrical Resistivity Soundings: Schlumberger and Wenner vertical electrical soundings (VES) were extensively 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 with shallow weathering i.e. <36 metres. Although the empirical method of interpretation is a quick method the estimated depth to bedrock can be grossly incorrect 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 must be done by qualified and experienced personnel.

Electrical Resistivity Profiling: 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 conducting 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 the 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. 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, 1989). 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 Quaternary alluvial deposits it is used 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. Case studies reported that not all fault zones show 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 rocks of the Bushveld Complex.

Gravity: Preferable method in dolomitic rocks or where sufficient rock density contrasts exist. 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. No reports were available where the gravity method was used on other geological environments within the map area.

Seismic: Due to cost, time and logistical implication this method is not widely used in the map area.

5.1.7 Subterranean water control areas

No subterranean water control area occurs within the area.

5.1.8 Groundwater management

Under 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 are 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. 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 the allocated water user licence requirements is that water users must monitor abstraction and quality at all levels from local authorities such as the Bombela/Nelspruit 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 familiarize 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.

In the licence application no distinction is made between surface water or groundwater use as it is all part of the hydrological cycle. The conjunctive use of groundwater and surface water is recommended.

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.

5.1.9 Groundwater contamination and pollution

Groundwater contamination is defined as the introduction of any substance into groundwater by the action of man. Pollution is defined as the direct or indirect alteration of the physical, chemical or biological properties of a water resource 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.

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 for 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 the coal mines are all potential sources of pollution if not properly managed.

5.1.10 Groundwater utilization

The only area indicated on the map sheet where large quantities of groundwater are abstracted is at Sabie. The water is used for domestic and commercial purposes.

Table 13: Localities where large-scale groundwater abstraction (2-5 m³/a) is taking place.

Locality/area	Use
Sabie town	Domestic and commercial

5.2 Groundwater Availability - Harvest Potential

The National Harvest Potential Map shows the maximum amount of groundwater than can theoretically be abstracted on a sustainable basis. Usually there are factors such as legal, economic, and environmental considerations that prevent this maximum being exploited. The highest Harvest Potential for the Nelspruit map area is > 100 000 m³/km²/annum along the high rainfall zones along the coast line, and the lowest is < 6000 m³/km²/annum along the northern part of the Lebombo Mountain range. The relief and rainfall within the map sheet shows some resemblance to the Harvest Potential.

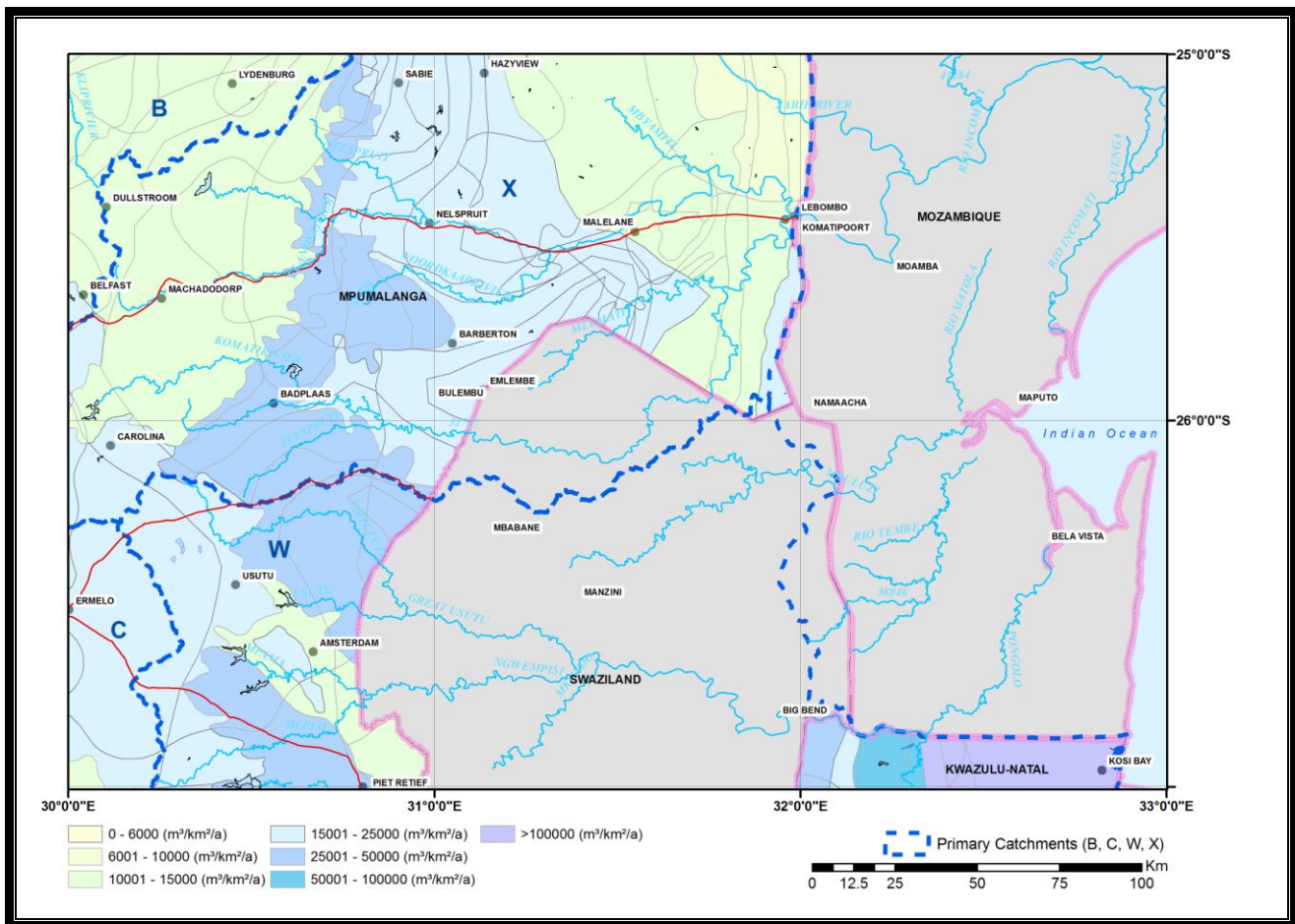


Figure 106: Harvest Potential (after Seward, Baron & Seymour, 1996)

5.2.1 Future groundwater exploration

Groundwater is, and will in future 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 rocks of the Karoo Supergroup (coal mines), the Barberton Mountain land (gold mines) and in the rocks of the Bushveld Complex (PGM, magnetite and chrome). Within the map area over exploitation is less a possibility than possible pollution.

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. Surface water is widely used to supply bulk water to major users such as municipalities. Groundwater can play a role in supplementing these bulk systems.

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. Points to consider are as follows:

- Recharge from earth dams,
- Hydro census and updating of information in areas with poor coverage,
- Municipalities using public money to develop groundwater sources should be committed to ensure the continuous flow of new groundwater data to DWA to be updated on the National Groundwater Archive.
- 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,

6. REFERENCES

- BURGER, P. 1949. *Borehole selection in the Kruger National Park for the Parks Board*. Report No Gh666, Geological Survey of South Africa, Department of Mines.
- BURGER, P. 1949. *Waterdraende eienskappe van die Karoo Sisteem in die Nasionale Krugerwildtuin*. Geol. Opname, Suid Afrika.
- BURGER, P. 1949. *Water conservation in the Kruger National Park*. Geological Survey of South Africa, Department of Mines.
- CSS., 1991. Central Statistical Service, Population census, 1991. *Summarised results after adjustment for undercount*. CSS Report No. 03=01-01 (1991).
- DAVIES, S.N. and DEWIEST, R.J.M. 1966. *Hydrogeology*. John Wiley & Sons, Inc. New York, London, Sydney.
- DAVIS, W.M., 1930. *Origin of limestone caverns: Geological Society of America Bulletin*, v. 41, no.3, p, 475-628.
- Department of Water Affairs and Forestry, 1996. *South African Water Quality Guidelines (Second edition). Volume 5: Agricultural Use: Livestock Watering*.
- Department of Water Affairs and Forestry, 1996. *South African Water Quality Guidelines (Second edition). Volume 4: Agricultural Use: Irrigation*.
- DU TOIT, W.H. October, 1989. *Evaluation of the Applicability of Geophysical Methods for Groundwater Exploration in the Central Limpopo Metamorphic Belt, N.W. Transvaal*. Report GH 3648. Directorate: Geohydrology, Department of Water Affairs Pretoria.
- DU TOIT, W.H. Mei, 1998. *Geohidrologie van die Nasionale Krugerwildtuin gebaseer op die Evaluering van bestaande Boorgatinligting* Volume 1. Tegniese verslag No. GH3806. Direktooraat: Geohidrologie. Department van Waterwese.
- DU TOIT, W.H., LELYVELD M., 2010. *Explanation of the 1:500 000 Hydrogeological Map 2330 Phalaborwa*. Not yet published, final publication data unknown. Department of Water Affairs.
- DU TOIT, W.H., 2011. *Explanation of the 1:500 000 Hydrogeological Map 2326 Polokwane*. Not yet published, final publication data unknown. Department of Water Affairs.
- DU TOIT, W.H., SONNEKUS, C.J., 2012. *Explanation of the 1:500 000 Hydrogeological Map 2127 Messina*. Not yet published, final publication data unknown. Department of Water Affairs.
- HRU, 1981. *Hydrogeological Research Unit. Surface Water Resources of South Africa. Volume 1, Drainage regions A and B. The Limpopo Olifants*. Report No 9/81.
- HEM, J.D. 1970. *Study and interpretation of the chemical characteristics of natural water*. U.S. Geol. Surv. Water-Supply paper 2254.

- JOHNSON, M.R. ANHAEUSSER, C.R. , THOMAS, R.J. 2006. *The Geology of South Africa*. Geological Society of South Africa, Johannesburg, Council for Geoscience, Pretoria.
- KENT, L.E., 1949. *The thermal waters of the Union of South Africa and South West Africa*: Trans. geol. Soc. S. Afr., 51.
- KENT, L.E., 1968. *The thermal waters of the Republic of South Africa*: 23 rd. Int. geol. Congress, 19.
- KENT, L.E. 1969. *The Thermal Waters of the Republic of South Africa*. Report GH 1381. Geological Survey of the Republic of South Africa, Pretoria.
- KING, G.M. 2003. *An Explanation of the 1:500 000 General Hydrogeological Map 2730 Vryheid*. . Department of Water Affairs.
- KRUGER, G.P., 1983. *Terrain Morphological Map of Southern Africa*. Soil and Irrigation Research Institute, Department of Agriculture, Pretoria. Published Map.
- KURLOV, M.G., 1928. *Classification of mineral waters of Siberia*, Tomsk, USSR.
- National Terminology of the Department of Arts, Culture, Science, and Technology in collaboration with Various Subcommittees of the Council for Geoscience and Specialist Professionals., 1996. *Dictionary of Geology*.
- NORMAN, N., WHITFIELD, G. 2006. *Geological Journeys. A traveller's guide to South Africa's rocks and landforms*. Struik Publishers & Council for Geoscience.
- ORPEN, W.R.G., 1994. *A recommended map legend and mapping methodology for the compilation of regional hydrogeological maps of the Republic of South Africa at a scale of 1: 500 000*. Unpublished Report. Directorate: Geohydrology, Department of Water Affairs and Forestry. Consultation provided by WSM.
- PARK, R.G., 1983. *Foundations of Structural Geology*. ISBN 0-216-91312-8. ISBN 0-216-216-91311-X pbk. British Library Cataloguing in Publication Data.
- READ, H.H., Watson, J., 1962. *Introduction to Geology. Volume 1: Principles*.
- REYNEKE, J.L., GHR 612. *Hydrochemistry and Pollution*. Lecture notes. University of the Freestate. Institute for Groundwater Studies.
- SANS 241. 1999. South African National Standards. *Table 1: Physical, organoleptic and chemical requirements, domestic water use*.
- SANS 241. 2005. *South African National Standards, Drinking water*. Edition 6. Standards South Africa a division of SABS.
- SCHULZE, B.R., 1984. *Climate of South Africa. Part 8, General Survey*. Weather Bureau, Department of Transport. WB 28, Pretoria, Fifth edition 1984.
- SEWARD, P., BARON, J., AND SEYMOUR, A. 1998. *The groundwater harvest potential map of the Republic of South Africa (1996)*. Report No. GH3917, Directorate Geohydrology, Department of Water Affairs and Forestry.

- South African Committee for Stratigraphy (SACS),, 1980. *Stratigraphy of South Africa. Part 1 (Comp. I.E. Kent). Lithostratigraphy of the Republic of South Africa, South West Africa/Namibia, and the Republics of Bophuthatswana, Transkei and Venda: Handb. Geol. Surv.S.Afr., 8. ISBN 0 621 06120 4.*
- TRUSWELL, J. F., 1977. *The geological evolution of South Africa.*
- UNESCO., 1983. *International Association of Hydrogeologists (IAH) International Association of Hydrogeological Sciences (IAHS) United Nations Education, Scientific and Cultural Organization (UNESCO). International Legend for Hydrogeological Maps, Revised version, Paris 1983. SC-84/WS/7.*
- VEGTER, J.R., 1995. *Groundwater Resources of South Africa: An Explanation of a Set of National Groundwater Maps. Water Research Commission, Pretoria: Report No. TT 74/95: A1-B33.*
- VISSER, D.J.L., 1989. *Explanation of the 1:1 000 000 Geological map, fourth edition, 1984: The geology of the Republic of South Africa, Transkei, Bophuthatswana, Venda and Ciskei and the Kingdoms of Lesotho and Swaziland. Geological Survey, Department of Mineral and Energy Affairs.*
- Walraven, F. (1989). *The geology of the Barberton area., Geological map series 1:250 000, Counsel of Geoscience, Single map sheet and Explanation, 2530 (Barberton),*
- Walraven, F. (1989). *The geology of the area west of Mbabane, Geological map series 1:250 000, Counsel of Geoscience, South Africa, Single map sheet and Explanation, (Mbabane),*
- Water Research Commission. 1998. *Quality of domestic water supplies. Volume 1: Assessment Guide. Second edition 1998. Second print 1999. No: TT101/98*

ADDITIONAL REPORTS RELATED TO GROUNDWATER IN THE MAP AREA

- DU TOIT, A.L., 1939. *The geology of South Africa. 2nd edition, Oliver and Boyd, Edinburgh and London.*
- ENSLIN, J.F., 1970. *Die grondwaterpotensiaal van Suid-Afrika. Waterjaar 1970. Gepubliseer deur konvensie: Water vir die toekoms.*
- FROMMURZE, H.F., 1937. *The water-bearing properties of the more important formations in the Union of South Africa. Geological Survey Memoir 34.*
- HEM, J.D., 1970. *Study and interpretation of the chemical characteristics of natural water, 2nd ed. U.S. Geol. Surv. Water Supply Paper 1473, 363p*
- JOHNSON, M.R., ANHAEUSSER, C.R. , THOMAS, R.J. 2006. *The Geology of South Africa. Geological Society of South Africa, Johannesburg, Council for Geoscience, Pretoria.*
- JOHNSON, J.H., 1975. *Hydrochemistry in groundwater exploration. Groundwater Symposium, Bulawayo, 1975.*

- MIDGLEY, D.C., PITMAN, W.V., MIDDLETON, B.J. (1994). *Surface water resources of South Africa 1990*. WRC Report no 298/1.1/94, Vol. 1 Appendices (First edition).
- PARSONS, P., Wentzel, J., 2006). *Groundwater Resource Directed Measures-GRDM Manual*. Water Research Commission with support from FETWater. WRC Project K5/1427.
- SIMONIC, M., 1995. *National groundwater quality assessment*.
- VAN WYK, E., 2002. *Sustainable Development of Groundwater Resources*. Draft report. Project IAEA: RAF/8/029, Department of Water Affairs and Forestry, Pretoria
- WOODFORD, A.C., Chevallier, L. 2002. *Hydrogeology of the Main Karoo Basin: Current Knowledge and Future Research Needs*. WRC Report No. TT179/02. ISBN No. 1 86845 851 2. Republic of South Africa
- ZAPOROZEC, A., 1972. *Graphical interpretation of water quality data*. Ground Water Journal, Vol. 10, No 2.

INTERNET SITES

- www.geomatrix.co.uk/tools-applications-methods.php