The Assessment of Groundwater Quality in Rural Communities: Two Case Studies from KwaZulu-Natal

Heidi Michelle Sherman

Submitted in partial fulfilment of the requirements for the degree of
Masters of Science in the Department of Geology and Applied Geology
University of Natal (Durban)
1998

PREFACE

This thesis documents the research done by the author, and is the author's own original work, unless specifically indicated to the contrary in the text.

ABSTRACT

The health and life expectancy of populations in developing countries is largely determined by the availability of good quality drinking water. Boreholes and springs generally provide water of better microbiological and physical quality than surface water sources, however, they may cause health and aesthetic problems due to chemical constituents dissolved out of the host rock.

As part of a pilot study to assess the health-related quality of community water supplies, samples were taken from two Quaternary catchment areas in KwaZulu-Natal. The Umkomazi catchment area is located inland from Amanzimtoti, while the Umfolozi catchment area is located north-east of Ulundi. The geology in these areas is significantly different. The Umkomazi area is predominantly underlain by basement rocks of the Natal Structural and Metamorphic Province, while the Umfolozi area is underlain by sedimentary rocks of the Karoo Supergroup.

Geographical information systems (GIS) were used to examine the influence of lithology, rainfall and landuse activities on groundwater quality. Major ion analysis of groundwater samples from the Umkomazi area revealed a linear relationship between borehole and spring concentrations. Dwyka Tillite was found to produce water with the highest concentrations of major ions, while Karoo dolerite produced water with the lowest concentrations of major ions. Samples from basement rocks and Natal Group contained intermediate concentrations of major ions. In the Umfolozi area Karoo dolerite samples showed the lowest concentrations of major ions, while the Vryheid Formation and Dwyka Tillite produced the highest borehole and spring concentrations, respectively. High salinity levels in sedimentary rocks may be due to marine influence during deposition. Piper diagrams show relative enrichment of major cations and anions and Stiff diagrams showed characteristic patterns.

Fluoride is associated with siliceous basement rocks and related to calcium concentrations through the solubility of calcium fluoride. The trace metals, manganese, iron and zinc were found to cause significant aesthetic problems and possibly health problems in sensitive individuals. These constituents are derived from weathering of bedrock and possibly from the corrosion of metal pipes.

There is an inverse relationship between mean annual rainfall (MAR) and electrical conductivity (EC), except near the coast where windblown salinity increases with rainfall. Nitrate, ammonium and *E. Coli* contamination are linked to landuse activities such as occurrence of human and animal excreta near the water source and the proximity of pit latrines. It is recommended that rural communities be educated about the nature and importance of groundwater quality.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

1. INTRODUCTION

1.1 Nature of Project

The availability of good quality drinking water has been recognised by the World Health Organisation (WHO) as the single most significant factor determining the general health and life expectancy of populations in developing countries. Although borehole yield rates are frequently given more attention than groundwater quality, the latter is just as important in determining the suitability of a water source (Hamill and Bell, 1986).

Boreholes and springs generally provide water of better quality than surface sources because they tend to have less microbiological and sedimentary pollution. However, groundwater sources may cause health and aesthetic problems due to chemical constituents dissolved out of the host rock (Punsar and Karvonen, 1979). The objective of this thesis is to establish a relationship between groundwater quality in the rural Umkomazi and Umfolozi study areas and the following variables:

- lithology, e.g. environment of deposition and mineralogy;
- hydrogeology, e.g. type of aquifer and occurrence of discontinuities;
- source type, e.g. boreholes, springs, wells, reticulated systems;
- mean annual rainfall (MAR);
- coastal proximity; and
- landuse activities, e.g. farming, agriculture, distance to pit latrines.

Geographical information systems (GIS) are used to facilitate the spatial visualisation, exploration, querying and analysis of the data.

This thesis originated as part of a pilot study conducted by the Department of Water Affairs and Forestry (DWAF) to assess the health-related quality of community water supplies in two selected areas of KwaZulu-Natal. The pilot study was based on one of the primary goals of the Reconstruction and Development Programme (RDP) of the new South African government which is to ensure that all citizens have access to an adequate supply of safe water as well as appropriate sanitation services. Water is defined as 'safe' when it can be consumed continuously for a lifetime by the most sensitive users without causing detrimental health effects.

Generally, people living in cities have access to treated municipality water, while those in rural communities obtain their water largely from untreated boreholes, springs, rivers, streams and wells. The water quality of these sources is usually unknown. Even the quality of water obtained from boreholes is often unknown as frequently these had been drilled as part of an emergency drought relief programme and the chemical and microbiological quality of the water had not been tested. The aim of the pilot study was to determine the logistics of monitoring and assessing potable water sources in rural areas. It is hoped that in the future the programme could be implemented throughout South Africa.

By testing the water quality in the Umkomazi and Umfolozi study areas, the pilot study hoped to achieve the following objectives (Department of Water Affairs and Forestry, 1996):

1. develop and test guidelines, procedures and techniques to monitor and assess the health related quality of community water supplies;

2. gain an understanding of the logistics involved in implementing and operating water quality systems in rural areas;

3. develop \ create interdepartmental and intersectorial structures to co-operate in the operation of water quality monitoring programmes;

4. obtain information of cost and human resources implications to monitor the quality of community water supplies;

5. gain an understanding of the types and the extent of water quality problems experienced by rural communities; and

6. get an indication of the training needs of provincial staff with regards to sampling, analysis and assessment of the quality of community water supplies.

The author assisted the pilot study with water sampling, data analysis and report writing. Part of the research contained in this thesis was incorporated into the pilot study to achieve the fifth objective, namely, the examination of the types and the extent of groundwater quality problems experienced by rural communities in the Umkomazi and Umfolozi study areas. As this research is limited to groundwater quality other authors of the pilot study report dealt with the problems associated surface water quality.

1.2 Acknowledgement of Collaborating Organisations

The Department of Water Affairs and Forestry (DWAF) is the organisation responsible for managing the South Africa's water resources and ensuring that the potable sources are suitable for long term use. The pilot study was overseen by the Institute for Water Quality Studies (IWQS), a department of DWAF. During a previous pilot study in the Northern Province, DWAF realised the importance of collaborating with other organisations and individuals involved in the health related water quality field. Thus in KwaZulu Natal DWAF involved their Regional Office in Durban, the Department of Health and Umgeni Water. CSIR was utilised as private contractors. The responsibilities and contributions of the collaborating organisations follow (Institute for Water Quality Studies, 1996 b).

The IWQS, represented by Dr A. Kuhn, was responsible for the overall co-ordination. The IWQS helped with the training of samplers, supply of sample containers and preservatives, supply of GPS and microbiological equipment, sampling and faecal coliform analysis, macro chemical analysis, trace metal analysis, data assessment, storage and final report writing.

The DWAF-regional office, represented by Ms G King, supplied GIS maps with the locations of known domestic water sources, helped train samplers, and provided electrical conductivity and pH meters.

The Department of Health in KwaZulu-Natal supplied GPS, bacteriological laboratory equipment, vehicles, 1:50 000 topographical maps, and most importantly they provided locally based samplers, Environmental Health Officers, in the catchment areas W22J (Black Umfolozi) and U10M (Lower Umkomazi). The Health Officers were familiar with the location of the domestic water sources and knew community members through previous programmes. The health officers collected samples for faecal coliform analysis and macro and trace metal inorganic chemical analysis. Faecal coliform analysis was conducted on location, while the chemical samples were sent to IWQS and Umgeni Water for analysis.

Umgeni Water provided the following assistance in the Umkomazi area: training of samplers, supplying appropriate sample containers and preservatives, participation in the sampling exercise and analysis of trace and macro inorganic chemical constituents.

2. DATA ACQUISITION AND ANALYSIS

2.1 Sampling Design

The original sampling design established by the pilot study was to sample all known drinking sources in the U10m catchment (Umkomazi study area) and the W22j catchment (Umfolozi study area). See section 3.1 for discussion on selection of these areas. In theory, water samples from a given catchment area have more in common than water samples from different catchments. In practice, when looking for water sources out in the field it was difficult to determine in which catchment the source was located in. Thus, a large number of samples were taken outside the intended catchment areas. Rather than discarding these samples they were accepted as buffer zones.

As lithology was one of the variables believed to influence groundwater quality in the two catcment areas a relationship was sought between concentration of groundwater constituents and lithology. Because of the uneven distribution of lithology under the study areas and the tendency for water sources to be cluster around villages, the groundwater samples did not evenly represent each lithology. This problem was partially over come by analysis of mean and median values, however, in cases where only two or three samples were taken from a given lithology there is limited statistical significance in the resutls.

2.2 Sampling Methods

Both Umgeni Water and IWQS provided analysis of samples as well as specific sample bottles and procedures. The sampling methods varied slightly depending on which organisation received the samples. Preservatives were added according to the sampling protocol of these laboratories (Umgeni Water, 1996 and Institute of Water Quality Studies, 1996 a).

Umgeni Water provided 3 different sample bottles. Samples for inorganic analysis (sodium, potassium, calcium, magnesium, pH, conductivity, chloride, sulphate, fluoride, phosphate, ammonium, nitrate and alkalinity) were collected in 350ml white plastic sample bottles with blue caps. Because the samples could not be delivered to the lab within 24 hours they were preserved with ampoules of mercury(II)chloride. Samples to be analysed for trace metals (e.g. aluminium, arsenic, boron, barium, cadmium, iron, copper, manganese, mercury, lead and zinc) were collected in 350ml red plastic bottles with red caps. These samples were not preserved. Samples for microbiological analysis (faecal coliforms) were collected in sterile glass bottles. Samples were kept in coolboxes with ice.

The IWQS provided 2 different bottles for macro chemistry samples, a 1 litre glass bottle and a 2 litre plastic bottle, both without preservatives. They also provided 2 different bottles for trace metals, a 500 ml plastic bottle with 0.1 % nitric acid for preservative and a 250 ml plastic bottle with 0.1 % hydrochloric acid for preservative. Microbiological samples were collected in 500 ml glass bottles with lids covered in aluminium foil sealed in a plastic packets. These bottles were preserved with 1 % sodium thiosulphate.

The importance of obtaining representative water samples was stressed and care was taken to avoid contamination of these samples (Crowley, *et al*, 1985). Bottles without preservatives were rinsed three times in the source water before a sample was taken. In order to remove stagnant water and collect groundwater sample representative of the *in situ* groundwater, boreholes were purged prior to sampling. The pump outlets were sterilised by flame from a gas burner or swabbed with 50 % alcohol if plastic (in which case it was noted on the observation sheets). It is clear that borehole water may have become further contaminated before consumed through corrosion of pipes, and microbes on the tap and in the collection containers.

When samples were taken several observations were recorded on special forms (see Appendix 1). These included, district, village name, date, time, topographical sheet number, drainage region, co-ordinates, sample point type, whether or not the equipment was operational and if the source was protected and formalised. Landuse activities were noted, e.g. mining, agricultural, distance to nearest dwelling and pit latrine. The samplers recorded their names and departments on the sheets.

2.3 Labelling Methods

In an attempt to standardise the unorganised water data in South Africa the Department of Water Affairs developed a ZQC No. system which consisted of 9 letters and numbers. The first 4 letters were identical for all samples in the pilot study - they were ZQCZ. These letters conveyed that the samples were part of a non national study, that they were quality samples, that they were part of community water supply and that they were from KwaZulu-Natal. The next 3 letters were the first 3 letters of the community or village name from which the sample was taken. Prefixes were not included because of the large number of village names starting with the same prefixes. Following the village name was a number indicating if that sample was the first, second, third, etc. sample taken in that village. Some samplers interpreted this number to indicate if it was the first, second etc. sample of the *same source type* for a given village . The final letter indicates the type of source:

B = Borehole
F = Fountain / Spring
R = River
P = Pan
S = Reticulated System

There was confusion among samplers who thought that *S* stood for *S*pring, rather than Reticulated System. Also it was sometimes difficult to distinguish formalised springs from boreholes, and there was general confusion about reticulation systems, which originally were only intended to include boreholes. The letter W was added to stand for wells. Unlike in American usage, where the terms well and borehole are interchangeable, in this context a well is a hand dug hole in the ground - usually in a dried up river bed. Photographs of a typical borehole, reticulated system and hand dug well are shown in Plates 2.1, 2.2 and 2.3, respectively.

Plate 2.1 Retrieving water from a manually operated borehole.

Plate 2.2 This reservoir is part of a reticulated system.

Plate 2.3 Ephraim Mokena (From the IWQS) samples a hand dug well.

2.4 Positioning Methods

The coordinates (latitude and longitude) of each sample were recorded with global positioning systems (GPS). GPS is a word-wide navigation system which relies on 24 US Defence Force satellites which are about 20 000 km above the equator. These satellites broadcast short wave radio pulses (0.19 m band) at pre-calculated time periods. Once a receiver has located at least four satellites it calculates its own position. Samplers used the convenient hand held Magellan GPS 2000, which is user friendly but has a limited accuracy of one second (approximately 300 m). Latitude and longitude were recorded in degrees, minutes, seconds (DMS) to make it easier for the samplers to find the locations of the known water sources which were provided by DWAF as overlays. However, the Health Officers knew the sample locations from past work in the areas and thought that using the maps in the field was too time consuming. Without the use of the GPS it would have been impossible to accurately locate the samples and later use GIS to plot their location on a geological map. However as some of the samples plot out to sea, there were obviously problems with obtaining the correct co-ordinates. Some GPS may have been initialised incorrectly or more likely the co-ordinates were either recorded incorrectly or illegibly.

Difficulties in collecting samples included poor infrastructure and hilly topography. Much time was wasted negotiating rough dirt roads while attempting to locate water sources - each vehicle (containing 2 or 3 samplers) was only able to collect about five samples per day. Sometimes glass bottles were broken in transit and the source would have to be resampled the next day.

2.5 Sample Analysis

The microbiological samples were analysed each day by the Health Officers and other samplers, including the author. In order to save time and expense only the indicator *Escherichia coli* was tested for. *E coli* is a faecal coliform which is harmless and occurs naturally in the intestines of humans and livestock. However, its presence is used as an indication that other more harmful bacteria are likely to be present. 100 ml from each microbiological sample was removed and forced through a membrane filter by a hand held suction pump. The filter was then removed with sterilised forceps and placed in a petrii dish containing MFC agar. The samples were incubated over night at 44.5 °C to encourage *E coli* growth. The following afternoon the blue *E coli* colonies would be counted. Reports of Too Numerous To Count (TNTC) were not tolerated so samples suspected of having high counts (i.e. surface water) were diluted or a smaller volume was used, which was taken into account in the final analysis. The chemical analysis was performed by the Institute for Water Quality Studies and Umgeni Water.

2.6 Geographic Infomation Systems (GIS)

Geographical information systems (GIS) were incorporated to facilitate the spatial visualisation, exploration, querying and analysis of the data. Although people have been using maps to analyse geographic information for thousands of years, the recent development of GIS has contributed an unprecedented power for solving geographical problems by uncovering and analysing patterns and trends. GIS is sometimes combined with geostatistical procedures, such as kriging, to interpolate values at any given site (Dutlow, 1996).

The majority of the work was done with ArcView® 3, a GIS programme by Environmental Systems Research Institute, Inc. (ESRI, 1996). In order for the samples to be plotted in ArcView the degree-minute-seconds were converted into decimal degrees. Each degree contains 60 minutes and each minute contains 60 seconds. One second is approximately equal to 300 m. The latitudes were given a negative sign to indicate location in the South Hemisphere. Data base files were constructed with fields for *ZQCZ* No. and the decimal degree co-ordinates. Other tables (e.g. laboratory results) were converted into data base files and opened in ArcView. ArcView has the ability to join tabular data based on a common field (e.g. *ZQCZ* No.), even when the fields do not show the same ordering. This allowed the decimal degrees to be joined with the lab results. The plotted samples comprised a theme and the resulting table was the theme's attribute table.

The points were plotted by opening a view and adding an event theme. The longitude field was selected for the x -axis and the latitude field for the y-axis. ArcView allows for a variety of view projections. The area visible in the view is easily changed by the zoom tool. The sample points were symbolised by source type as well as the chemical concentrations of each constituent. When the sample point theme was active the individual points could be identified with the identification tool as the cursor. All the information listed in the attribute table related to that sample point could be displayed in a box on the screen. This included all the chemical data, as well as date and time of sampling, village name etc. When certain points were selected in the view these would also be selected in the attribute table and could be promoted to the top of the screen for easy editing. Edits made in the attribute table were reflected in the view.

The digitised geology covers were created with Atlas® and TNTMIPS® GIS technologies from geological maps. The Umfolozi and Umkomazi covers were digitised from Sheet 2830 Dundee and Sheet 3030 Port Shepstone, respectively. First, the outlines of the geological formations were copied onto tracing paper. Then the tracing paper was scanned through an A0 scanner. The resulting raster image was imported into TNTMIPS and georeferenced, in other words, know co-ordinates were identified allowing the co-ordinates of all points to be calculated. The raster data was converted to vector data and automatically filtered. Once each polygon was closed and all excess nodes were removed the vector data was imported into Atlas for coding. Each polygon was coded with the appropriate lithology and geological name. The data was converted to an ArcView shape file format and imported into ArcView. Each lithology was assigned an appropriate colour based on the original geological maps. These colours were saved as a legend.

The sample point themes were overlain on top of the geology shape files. Building queries allowed points with definable attributes to be identified e.g. all boreholes with a fluoride concentration above 1.5 mg/l and drilled into Natal Group Sandstone. Because the original geology maps were based largely on outcropping surface rocks the sample points were also associated with these outcropping rocks, however, boreholes may have been drilled through hidden sills and contacts. Though the geology of each sample point could be identified by examining the view, it was much easier and faster to use ArcView's select by theme function. This function facilitated selecting the feature of an active theme that intersected, or was a given distance from, the selected features of another theme.

Other GIS covers, including roads, rivers, rainfall, lineaments, known discontinuities and demographic statistics were obtained from the Department of Water Affairs. These covers were combined with the geology shape files and sample point themes. Thus, a mean annual rainfall (MAR) value was associated with each sample point as well as a lithology and chemical analysis. ArcView enabled one field to be normalised by another. For instance, total population was normalised by area to give population density. Finally, charts and layouts were also created through ArcView.

3. DESCRIPTION OF STUDY AREAS

3.1 Location and Demographic Framework

The areas selected for investigation are centred on two Quaternary catchment areas, the Lower Umkomazi (U10M) and the Black Umfolozi (W22J) and incorporate surrounding buffer zones (Figure 3.1). The Umkomazi and Umfolozi River Valleys are shown in Plates 3.1 and 3.2, respectively. The Umkomazi study area is 290 km^2 (Crook, 1997) and located inland from Amanzimtoti, between 30° 06' south and 30° 23' south and 30° 40' east and 30° 75' east and includes the village of Dududu and the rural areas of Embumbulu, Maoabeni and Vulamehlo (Figure 3.2). The Umfolozi study area is 540 km^2 and located north-east of Ulundi, bounded by 28° 00' south and 28° 35' south and 31° 46 east and 31° 46' east and includes the rural areas of Nongoma, Mahlabaini and Hlabisa (Figure 3.3). These two areas were selected because no large conventional water treatment schemes are planned for the areas and they have high population densities (for rural areas) with poor or non existent sanitation infrastructure. In addition, these communities drink untreated water from rivers, springs and boreholes and the quality of this water is largely unknown. Population densities and high unemployment rates are displayed on Figures 3.2 and 3.3.

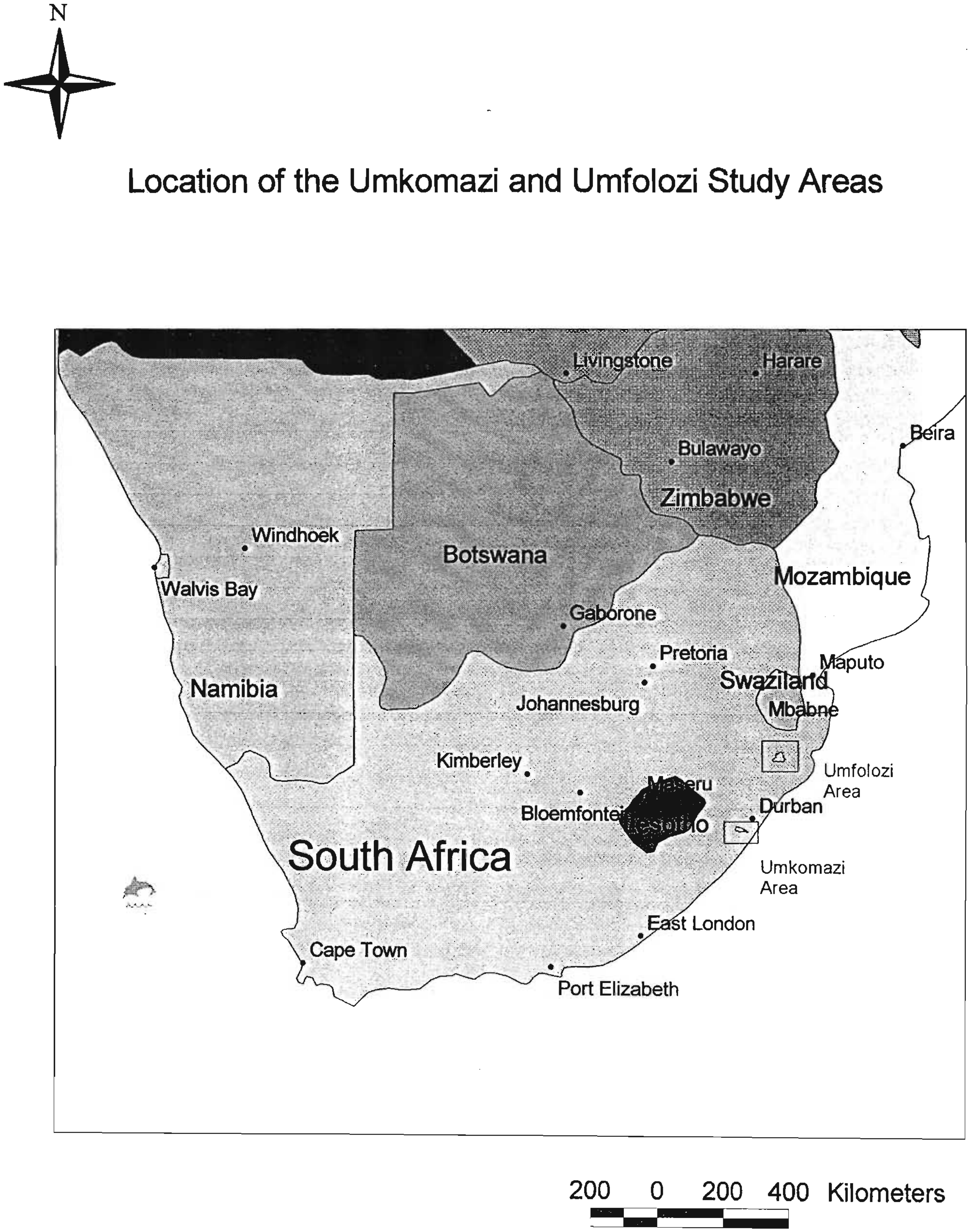


Figure 3.1 Location of study areas.

Plate 3.1 The Umkomazi River Valley.

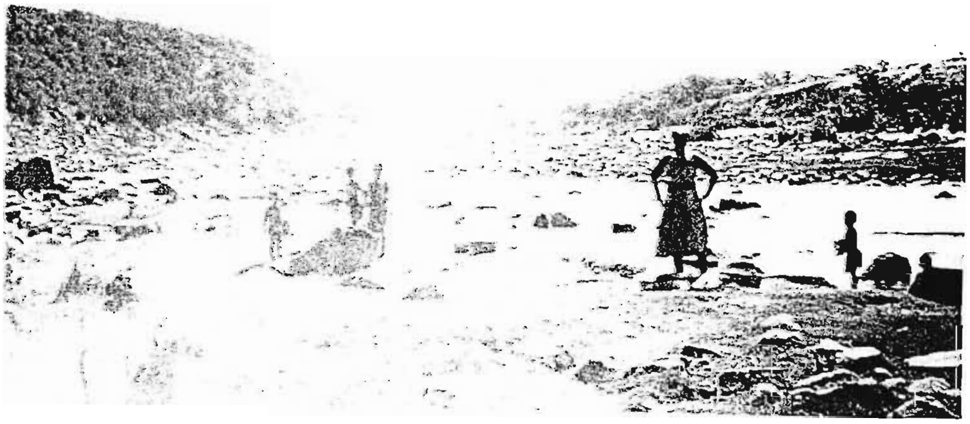


Plate 3.2 The Black Umfolozi River Valley.

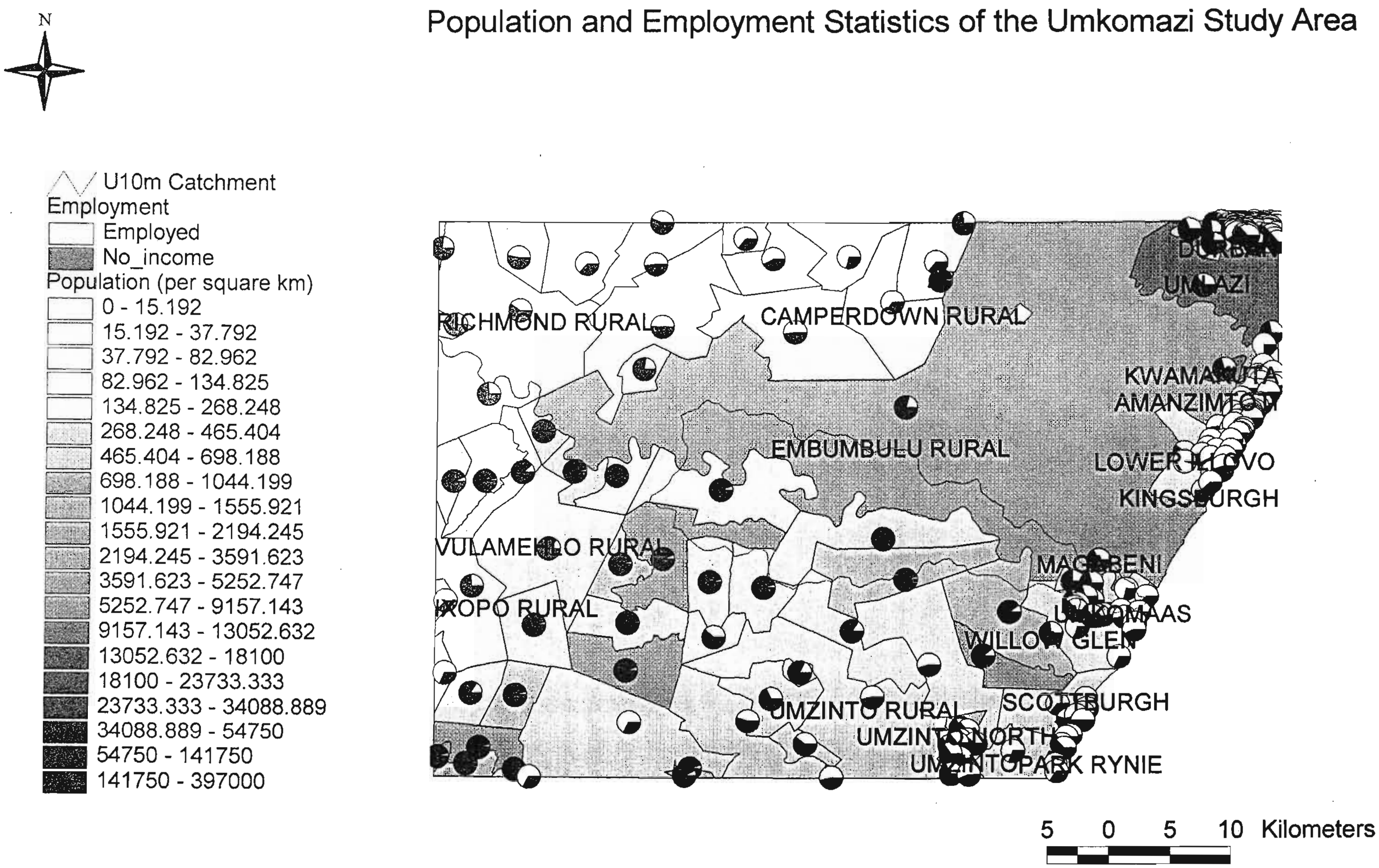


Figure 3.2 Population and employment statistics of the Umkomazi study area.

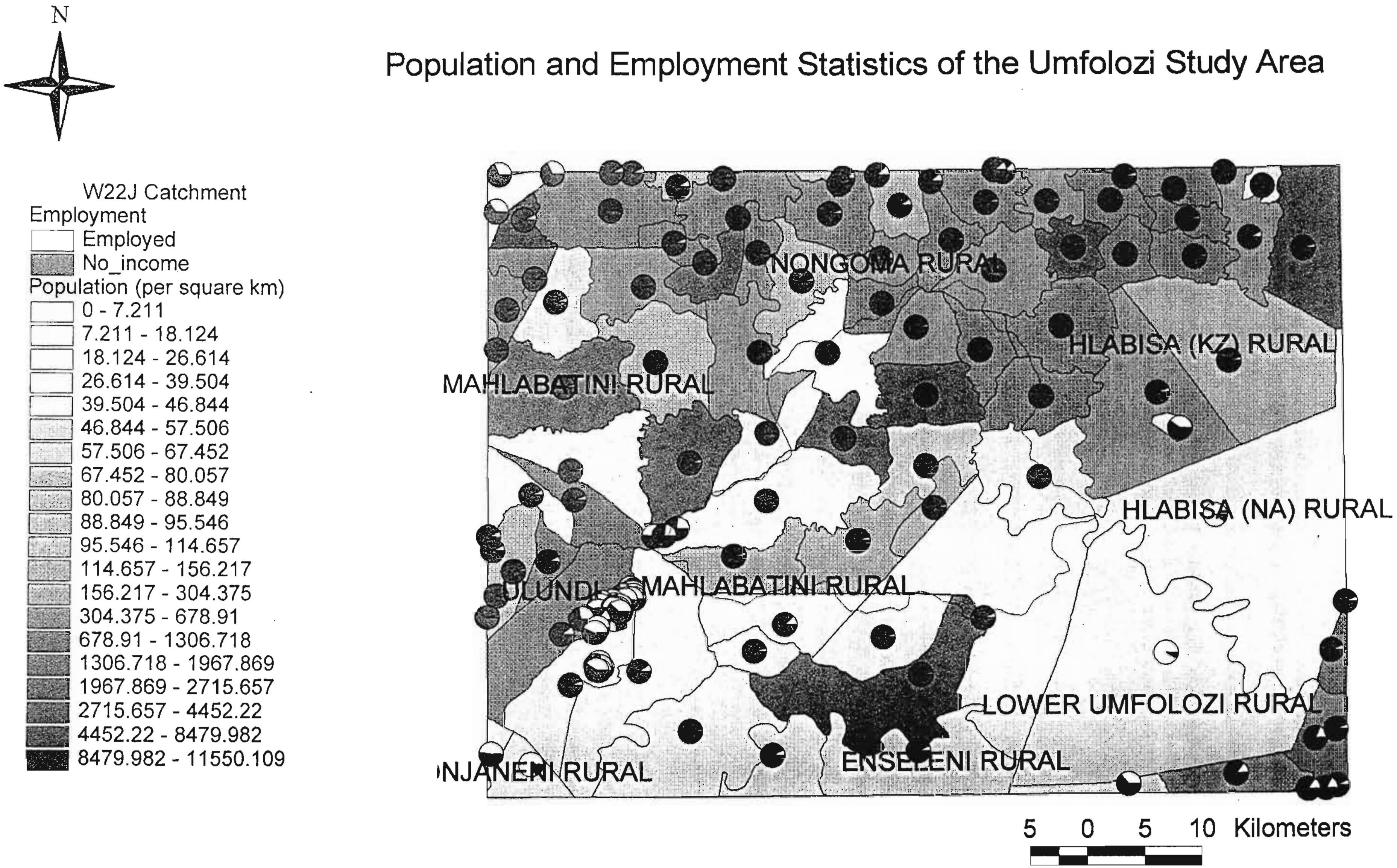


Figure 3.3 Population and employment statistics of the Umfolozi study area.

3.2 Lithostratigraphy

The two catchment areas selected for investigation contain significantly different lithologies. The Umkomazi catchment area is underlain predominantly by Late Proterozoic basement rocks of the Natal Structural and Metamorphic Province. In places the basement is overlain by Palaeozoic sedimentary rocks including the Natal Group sandstone and the conformable Karoo Supergroup (Figure 3.4). In the Umfolozi catchment area, the basement rocks of the Archaean Kaapvaal Province are almost entirely overlain by Karoo sediments, particularly sandstones and shales of the Vryheid Formation (Figure 3.5). Karoo dolerite intrusions are common in the area, especially in rocks of the Ecca Group. Quaternary alluvial sediments are associated with major river valleys. The simplified stratigraphic column is given in Table 3.1.

Table 3.1 Simplified Stratigraphic Column

System	Supergroup	Group	Formation	Lithology	Symbol
Quaternary			Alluvium	Sand, silt, clay	Q
Jurassic	Karoo		Dolerite	Dolerite	Jd
Permian		Ecca	Volksrust	Shale	Pvo
			Vryheid	Sandstone with lesser shale	Pv
			Pietermaritzburg	Black Shale	Pp
Carboniferous			Dwyka	Tillite (Diamictite)	C-Pd
Ordovician and Silurian		Natal		Sandstone, lesser Shale and Basal Conglomerate	O-Sn
Precambrian Basement Rocks					

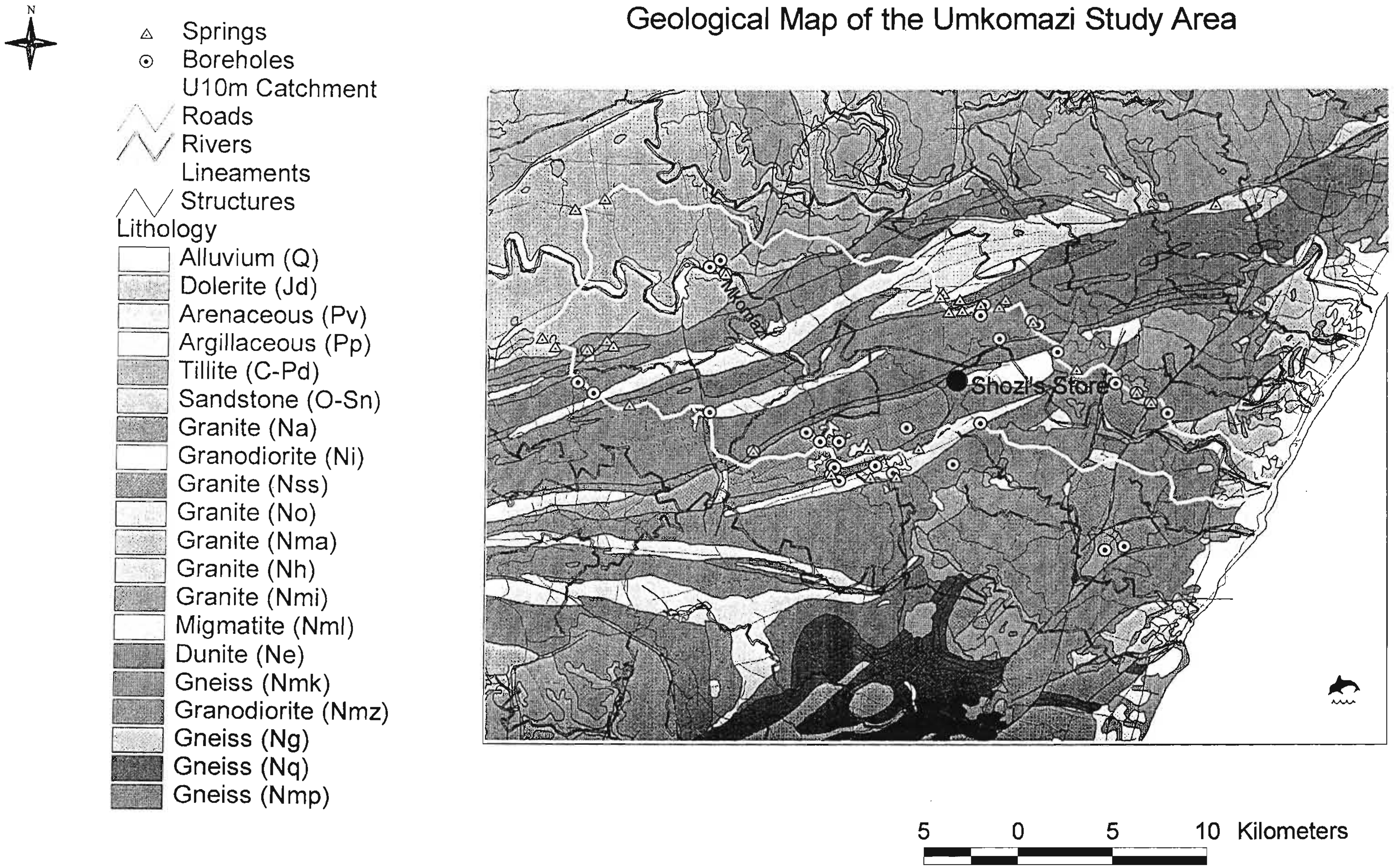


Figure 3.4 Geological map of the Umkomazi area.

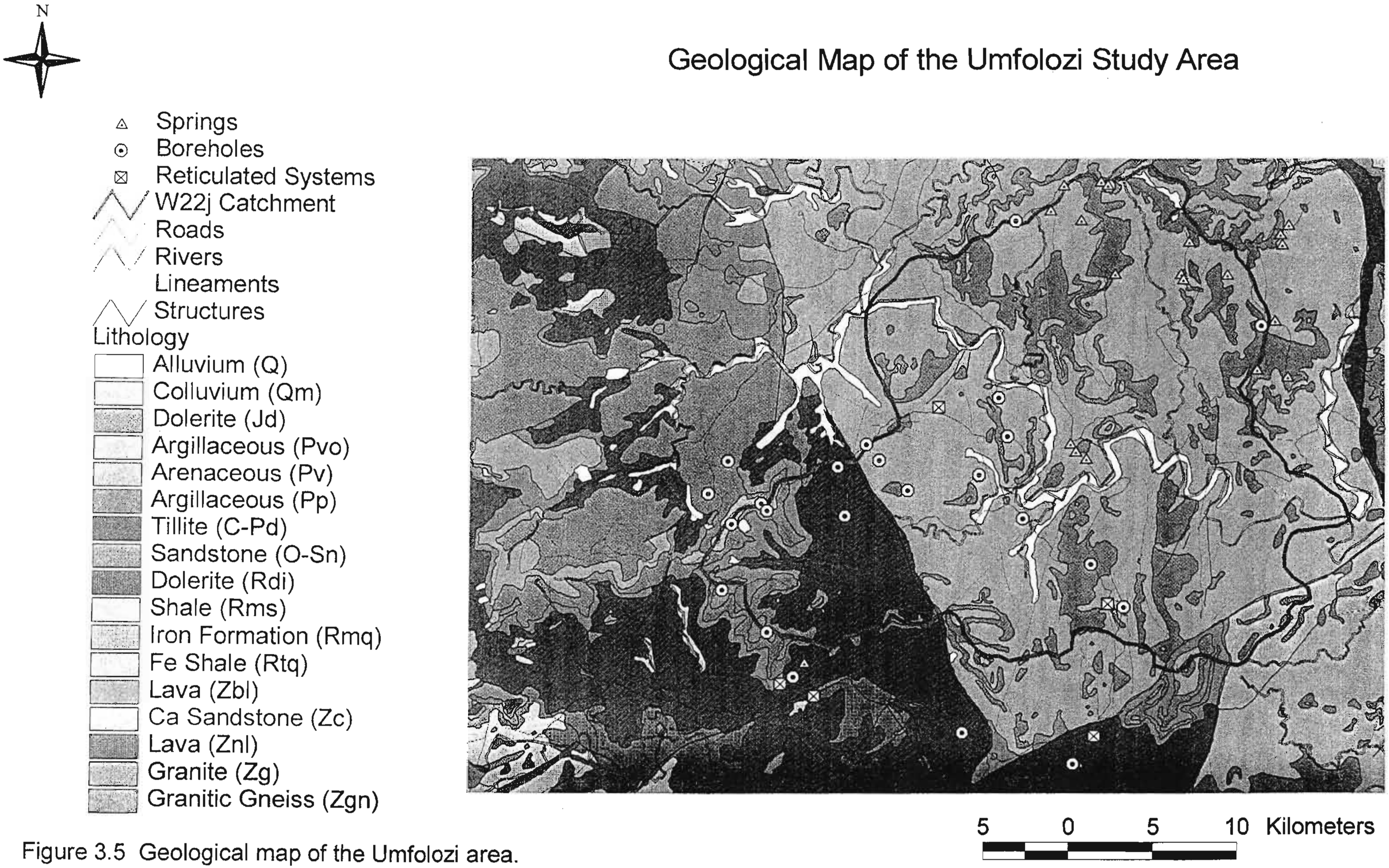


Figure 3.5 Geological map of the Umfolozi area.

3.2.1 Umkomazi Study Area

The basement rocks of the **Natal Structural and Metamorphic Province,** also known as the Natal Mobile Belt, are approximately 1 000 Ma-old. Thomas (1988) further subdivided these rocks into the older supracrustal gneisses, the Mapumulo Metamorphic Suite, and the younger, intruding plutonic rocks, which are mainly granitic in composition.

While the Mapumulo Metamorphic Suite comprises eight lithographic units, only the Mpambanyoni Formation (Nmp) and the unnamed streaky, pink acid gneisses (Ng) crop out in the Umkomazi study area. The Mpambanyoni Formation (Nmp) comprises mainly high-grade metapelitic gneisses which form north-east to south-west trending belts and are part of a south-westerly plunging isoclinal anticlinorium. The core of the anticlinorium is comprised of intrusive rocks of the Umkomazi Suite (discussed below). Rocks from the Mpambanyoni Formation that outcropped in the Umkomazi River bed (North of Shozi's store) tend to be more mafic and contain biotite and hornblend.

The streaky, pink acid gneissses (Ng) are often in contact with the Mpambanyoni rocks and form similar belts. These gneisses may have originated as quartzose sediments, or as acid-volcanic rocks.

The rocks of the Mapumulo Metamorphic Suite are intruded by plutonic rocks. While these intrusive rocks have been subdivided into 15 lithostratigraphic units (Thomas, 1988), only those units that crop out in the Umkomazi study area are described.

The pre-tectonic Mzumbe Suite (Nmz) are the oldest of the plutonic rocks (Davies Lynn and Partners, 1995 a). In the Umkomazi area this suite outcrops in east-west running belts. These grey, generally acidic, gneisses are believed to be granitoids, rather than part of the supracrustal sequence, as they include mafic xenoliths (Thomas, 1988).

Rocks of the Umkomazi Gneiss Suite (Nmk) are exposed in the Umkomazi River Valley. These garnet-biotite augen gneisses and foliated granites are inter-layered with the metapelites of the Mpambanyoni Formation. It is believed that the Umkomazi Gneisses were intruded into the

Mpambanyoni Formation since the former contains enclaves of the latter (Thomas, 1988).

The gneissose garnet-leucogranite phase is the only significant phase of the syntectonic granitoids of the Margate Complex (Nml) in the Umkomazi area. The gneissic granites belonging to the Mzimlilo Suite (Nmi) are generally pink in colour, less frequently grey, and medium to coarse grained. This suite forms east-north-east to west-south-west-trending belts. Field relationships show that this suite is younger than the gneiss sheets of the Margate Complex, but older than the granites of the Oribi Gorge sheet (Thomas, 1988).

The Mahlongwa Suite (Nma) comprises strongly, though variably, foliated coarse-grained, pink megacrystic granites. Named for outcrops along the Mahlongwa River, this suite is also known as the Dududu pluton and forms the high country north of Dududu. Outcrops tend to have a strong penetrative fabric indicating an early or syntectonic age (Thomas, 1988).

The post-tectonic Oribi Gorge Suite (No) comprises very coarse-grained porphyritic granites and charnockites. Named for outcrops in the Oribi Gorge, these rocks are also significant in the Umkomazi area where the river cuts into the extensive KwaLembe batholith. Modal analysis for this these rocks shows quartz (20%), K-feldspar (35%), plagioclase (30%), biotite (4%), hornblend (3%), olivine (5%), +/- garnet (2%) and accessory ore, apatite, zircon and allanite (Thomas, 1988).

The pinkish grey, medium grained Ingwe Granodiorite (Ni) crops out along the Umkomazi River near Shozi's store. To the east of the river it disappears under the Dwyka Formation, and then reappears along strike.

The basement rocks are further grouped into three lithological units based on hydrogeological properties viz. (i) Natal Mobile Belt acidic metamorphic rocks (e.g. No, Nmk, Nml, Nmz), (ii) the basic metamorphic rocks (e.g. Ne, Nmp) and (iii) massive granite and gneisses (Nma, Nmi, No) (Davies Lynn and Partners, 1995 a).

In the Umkomazi area the Ordovician to Silurian age **Natal Group (O-Sn)** rocks are predominantly red, cross-bedded, micaceous arkoses, feldspathic sandstones, grits, siltstones and mudstones. Further south, the Natal Group is represented by a sequence of grey coloured sedimentary rocks. The Natal Group generally rests on the basement rocks, though in places it is over stepped by the Dwyka Formation. The Natal Group comprises fluvial sediments which accumulated in a system of braided rivers in a low trough formed during an Early Palaeozoic failed rift, before the actual break up of Gondwanaland (Linstrom, 1987). Material was transported from the north and north-east (Truswell, 1970). Resistant horizons in the Natal Group sandstone formed plateaux above the deeply incised river systems that have cut down into the basement rock. Before entering the study area and cutting through the KwaLembe Batholith, the Umkomazi River flows through Natal Group rocks, which reaches a thickness of 600 m in the valley.

In the Umkomazi study area the conformable **Karoo Supergroup** consists of the basal Dwyka Formation and three formations of the Ecca Group. It is interesting to note that Karoo strata has also been found in Botswana, Zimbabwe, Zambia, Malawi, Namibia, Mozambique, Angola, Kenya, Tanzania, Uganda and the Congo. Equivalent strata were developed in South America, the Falkland Islands, Antarctica, the Malagasy Republic, India and Australia. Distinctive features such as the basal glaciation, specific fossils and the capping of basaltic lavas have been found in other southern hemisphere continents and India, which has been taken as evidence of continental drift (Truswell, 1970).

The Dwyka Formation (C-Pd) is named after the Dwyka River, a tributary of the Gourits, located in the southern Cape. In the Umkomazi River valley the Dwyka Formation reaches a 300 m thickness (Thomas, 1988). This formation is of geological interest because of its glacial origin. During the Dwyka Glaciation glaciers eroded and transported a large amount of material which was then deposited as moraines. The material was consolidated to form tillite (diamictite). In fresh samples of Dwyka angular clasts are identified in a hard argillaceous matrix (Thomas, 1988). Some of the fragments were scratched or striated from being dragged along bottom of the glacier, others were flattened (Truswell, 1970). As the glacier receded winds picked up the finer material and deposited it as loess. Some of the sediments were transported by melt-water streams. The coarser material was deposited as conglomerates along the rivers, and the finer material was deposited in glacial lakes. These lacustrine silts and clays are frequently banded from the seasonal deposition of coarser and finer material, or material of varying organic content, and referred to as varves - Swedish for periodic repetition. The Dwyka Glaciation developed through Gondwanaland during Carboniferous and Permian, and in South Africa this period formed the base of the Karoo Supergroup. By examining striations on glacial pavement, fragments of rock within the tillite and the fabric of the tillite, four centres of glaciation were recognised. The centre of the Natal Ice Sheet was off the present coast (Truswell, 1970).

Of relevance to the hydrochemistry of water derived from the Dwyka is the consideration of whether the formation was deposited in a marine environment. In the south and west areas of South Africa green shales, which grade upwards into black carbonaceous shales, were deposited above the tillite. In some localities the shales contain phosphate nodules and lenses, suggestive of marine deposition. The shales are capped with a grey chert bed which is taken as the marker between the Dwyka and the conformable Ecca Group above. Away from the south and the west the chert is not developed, and frequently the shales are also believed to be missing (Truswell, 1970). The Dwyka-Ecca contact has been found and studied in the Umkomazi River valley. The boundary is defined as three transition beds which were likely deposited along the edge of a marine ice-sheet, possibly during ice-sheet withdrawal at the end of the Late Palaeozoic glaciation (Thomas, 1988).

The Permian Ecca Group consists of the Pietermaritzburg Formation (Pp) shales, the Vryheid Formation (Pv) sandstones and shales and the Volksrust Formation (Pvo) shales. Karoo dolerite (Jd) dykes and sills commonly intrude the Ecca sediments. These are of much greater significance in the Umfolozi area and are discussed in section 3.2.2.

Alluvium (Q) occurs in association with the Umkomazi River and some its tributaries. Sediment forms small cliffs and contains large boulders. Near the mouth of the Umkomazi the alluvium reaches a thickness of 28 m.

3.2.2 Umfolozi Study Area

The **Pongola Granitic Basement** rocks underlying the Umfolozi study area are part of the Archaean Kaapvaal craton. In the study area they are covered by Palaeozoic sediments, but outcrops of granitic gneiss and homogeneous granite occur on the outskirts of the study area, and thus there is a possibility that some boreholes may have reached the basement. The ultrabasic basement rocks contain chromium rich spinels which result in high chromium levels in the Umfolozi estuary sediments. Unfortunately, chromium concentrations were not tested in this study.

As discussed in section 3.2.1, the **Natal Group sandstone (O-Sn)** rests unconformably on the basement rocks. The Natal Group rocks only crop out on the southern edge of the Umfolozi catchment area and are generally overlain by younger sedimentary rocks.

The **Karoo Supergroup** sediments are represented in the study area by the basal Dwyka Formation tillite and three formations of the Ecca Group: the lower Pietermaritzburg Formation shales, the middle Vryheid Formation sandstones and the upper Volkrust Formation shales. The Dwyka Formation comprises massive tillite (diamictite) and also thin sandstone beds and occasional shales.

The Ecca Group sediments are named for the Ecca Pass north-east of Grahamstown. Truswell (1970) concluded that the Ecca sediments originated from high source areas, most of which were outside the present South African coast line. Characteristics such as the origin of material, as well as the type and thickness of sedimentation has facilitated the separation of the Ecca Group sediments into three facies, namely the Southern, Western and Northern (Truswell, 1970). The Ecca Group sediments found in both study areas are part of the Northern facies. This facies is characterised by lower and upper bluish-black shales and a middle layer containing coal seams.

The Pietermaritzburg Formation (Pp) comprises dark-grey, blue or black, well bedded shales. It conformably overlies the Dwyka Formation with a sharp contact. The shales were probably deposited in a large, shallow body of water, possibly a brackish epicontinental sea (Linstrom, 1987).

The Vryheid Formation (Pv) is the most extensive formation in the Umfolozi study area. The basal beds comprise shales, siltstones and sandstones, which grade into cross-laminated, medium to fine-grained sandstone, overlain by coarse-grained, cross-bedded sandstone and grits. Sediments were transported from the east and north-east and deposited in river systems and related deltas during several regressive cycles. Accumulation of rotting vegetation in swampy environments gave rise to coal deposits. One coal mine is situated in the study area, but is no longer in production. Thin bands of green-coloured complex ironsilicate glauconite occur and are indicative of marine formation. It has been suggested that periods of short-lived marine incursions may have occurred in the general fluvio-deltaic conditions (Truswell, 1970).

The Volkrust Formation (Pvo) rests conformably on the Vryheid Formation and like the Pietermaritzburg Formation, was probably deposited in an extensive, shallow body of water (Linstrom, 1987). The rocks are blue-grey and black, well-laminated, fissile shales, with thin lenses of siltstone and phosphate nodules.

The general tectonic setting of the Ecca Group was that of a stable shelf slowly subsiding. The variation between detrital material and coal seams indicates a fluctuation in the balance between rates of sedimentation and subsidence (Truswell, 1970). *Glossopteris* flora are preserved as fossils. The occurrence of *glossopteris* fossils throughout the now separated continents of Gondwana indicates that the Gondwana continents were still joined together, or at least not far apart, at the time the Ecca was deposited (Truswell, 1970).

Jurassic Karoo dolerite (Jd) sills and dykes are common in the area, especially in rocks of the Ecca Group. To a lesser extent intrusions are found in the Natal Group, while the basement rocks are devoid of intrusions. It is thought that the more competent granites and the massive Dwyka Formation only permitted the dolerite magma to rise vertically creating dykes, while the horizontal bedding of the overlying Ecca Group, also having less overburden pressure, permitted the magma to spread laterally creating sills (Thomas, 1988). Sills have a greater influence on the topography than the corresponding dykes. The mechanisms of sill and dyke intrusion is related to factors such as fracture growth, stress distributions and intensities, dilation, intrusion rates and host rock effects (Kattenhorn, 1994). Though several different types of dolerite have been recognised they are chemically similar (Linstrom, 1987). The dolerite is dark blue-grey, fine- to medium-grained and composed mainly of calcic plagioclase and pyroxene with occasional olivine. Thicker sills that had longer cooling times showed some differentiation. Olivine and pyroxene crystallised out early and sank to the bottom of the sills where they became concentrated. Toward the top of the sills the plagioclase is more sodic and the pyroxenes more iron rich (Truswell, 1970). **Alluvium (Q)** is associated with the Umfolozi River and its tributaries.

3.3 Geological Structure

3.3.1 Umkomazi Study Area

The orientation of geological structure and lineaments in the Umkomazi study area are shown in Figure 3.4. These structures are generally part of a large arcuate fault system which is concave south-eastward. This fault system can be traced continuously through southern Natal until it passes out to sea south of Durban. Davies Lynn and Partners (1995 a) described the fault system as trending just west of north and swinging through north to north-east.

Downthrow is on the outer (convex) side. Dips are toward the concave side, except on the margins where they dip westward. The fault occurs mainly in the Natal Group. The pattern of faulting indicates seaward tilted step-fault blocks and horst-and-graben structures that effectively lowered the interior rocks of the Karoo Supergoup to sea level (Davies Lynn and Partners, 1995 a).

Minor faults occur parallel to the coastline and form a chord of the arcuate fault system. These minor faults swing eastward and pass out to sea.

Dips are to the south-east, while downthrow is divided between the north-west and south-east sides. These faults are responsible for outcrops of Karoo Supergroup rocks along the coast.

Davies Lynn and Partners (1995 a) cited transcurrent faults off the coast, as well as a combination of extensional and compressional tectonic features, as evidence that the coastal Natal faults were part of a dextral strike-slip system. These faults are possibly the result of assumed dextral lateral forces experienced in Natal during the crustal separation and retreat of the Falklands Plateau during the break up of Gondwanaland. However, according to Davies Lynn and Partners, while numerous extensional features were observed in the study area, compressional features were not found which supports the theory that locally the area experienced extensional stresses directed approximately perpendicular to the coast.

3.3.2 Umfolozi Study Area

Drennan Maud and Partners (1995 a) identified three major structural features in the Umfolozi study area (Figure 3.5) and surrounding regions.

1. The Lebombo Monocline comprises a northward trending belt of lavas along the Lebombo Mountains.
2. The Empangeni Fault System comprises a rotational fault system which begins 30 km south of Empangeni with a south-south-west strike, increases in throw toward the north-east and continued south-westward until Greytown. This fault is obviously significant as it lowered the Karoo Supergroup in the north to the level of the basement rocks in the south.
3. The Vryheid Arch comprises a long seaward limb and a shorter western limb. Beginning at New Hanover it runs north-north-east to Nqutu before continuing past Vryheid. The arch is defined as the base of the Karoo Supergroup.

Extensional structures are those that trend at high angles to the least principal stress, σ_3. Extensional structural features are frequently open and thus, the most hydrogeologically significant of the discontinuities (E. Martinelli and Associates, 1995). Depending on the subdomain, extensional structures in the Umfolozi area trend north-east, east-north-east and north-south (Drennan Maud and Partners, 1995 a).

3.4 Hydrogeology

The primary or syngenetic hydrological properties of rocks are those inherent characteristics unaffected by later epigenetic processes such as faulting and jointing. In the study areas, primary aquifers only occur locally in alluvium deposits associated with major rivers. Where sand deposits are approximately 5 metres deep and hydraulically connected to rivers, there exists the potential for water abstraction (E Martinelli and Associates, 1995). However, because the deeply incised rivers are actively down cutting into the bedrock there is restricted development of such sand deposits. This is indicated by frequent outcrops of bedrock along the river banks and the river beds.

Though the primary porosity and permeability of the Basement Complex and the cemented and compacted sedimentary rocks of the Natal Group and Karoo Supergoup is negligible these properties are briefly discussed for perspective. Igneous rocks such as the basement rocks and the Karoo dolerite developed several kinds of interstices during solidification. These include small cavities in some of the crystals, intercrystal spaces, vesicles produced by gaseous material escaping and cavities formed by the moment of the lava while it was solidifying. Although igneous rocks in other parts of the world form important aquifers, in South Africa water is only obtained from these rocks if weathering and fracturing has occurred (Van Wyk, 1963).

South African sandstones show remarkable low porosity compared to sandstones in other parts of the world (Frommurze, 1953). Mudstones and shales are generally not considered good aquifers. Sandstones have low porosities due to the cementing of silica, sericite and kaolinite in the original pore-spaces between individual grains. While shales generally contain little cement they are found to have reduced porosity due to compaction caused by the pressure of overlying beds during the conversion from clay. Further, shales can show high absolute porosity but minimal effective (connected) porosity. Attempts have been made to establish porosity depth relations, such as assuming that the porosity of a shale is a negative exponential function of its depth of burial. Ecca shales of northern Natal are tentatively believed to have been buried at a depth of 1,500 to 2,100 metres (Van Wyk, 1963). While shales have higher porosities than corresponding sandstones their low permeabilities reduce their yields.

The secondary or epigenetic hydrological properties are of much greater significance than the primary properties because the study areas are almost exclusively underlain by secondary aquifers. These secondary properties form as a result of geological, physical, chemical, climate and topographical conditions which acted on the rock after formation. These secondary processes take place in two stages. In the first stage openings are formed through major geological and physical processes. In the second stage the openings formed in the first stage are modified through weathering and fluid transport.

The first stage processes are further divided between near-surface physical processes and the deep-seated geological processes (Van Wyk, 1963). The surficial processes include unloading, thermal expansion and contraction, frost action and organic activity and are important because of their role in increasing chemical weathering, soil formation and infiltration.

The deeper processes include jointing, faulting and dolerite intrusion and are of importance because of their direct influence on the storage capacity of the rocks and borehole yields. Water sources associated with discontinuities frequently have higher resistivity values because they represent recharge areas (Isiorho and Nkereuwem, 1996). Joints occur in most consolidated rocks and are highly significant for water abstraction. Joints are formed by dolerite intrusion, compression, tension and torsion. Minor joints, associated with the surficial processes discussed above, are responsible for the development of basins of decomposition in the igneous rocks. The main joints are partings in the rock without displacement. They are generally near-vertical and frequently very deep. Joints are often not visible from the surface due to soil coverage, and in steep mountainous regions where they are visible weathering rarely extends below the watertable so the joints are not open.

Faults act as dams and conduits and influence the position and distribution of aquifers. Boreholes drilled along dykes frequently produce high yields. However, Van Wyk (1963) reported no high yields associated with boreholes drilled in faults, possibly because of the impermeable clayey gouge often developed along fault-planes. Springs in the area are not fault controlled.

The influence of the Karoo dolerite dykes and sills on the movement and storage of groundwater in the study areas has been discussed in several papers and reports (Van Wyk, 1963, Davies Lynn and Partners, 1995 a, Drennan Maud and Partners, 1995 a, E. Martinelli and Associates, 1995, etc). As mentioned above, the dolerite dykes are mainly intruded into the Karoo Supergroup shales and sandstones, and to a lesser extent into the Natal Group sandstone. These host rocks invariably experienced a certain amount of alteration, in the form of baking and contact metamorphism, which caused hardening and toughening. Sandstone and grit were converted to quartzite and arkose rocks and the shale and mudstone were hardened and developed a buff or white colour. While baking was found to lower the porosity of the host rock through cementation, recrystallisation and infiltration of magmatic silica, the permeability of the baked zone was significantly increased due to the development of tension-joints during cooling. These joints are closely spaced near the contact but absent outside the baked zone. Thus, the baked zones represent target areas for water extraction.

Van Wyk (1963) studied the occurrence of these intrusion-related joints in coal mines and found that at depth the joints were rarely visible or open fractures. This observation was supported by drillers who reported that boreholes which intersected the contact zone more than 70 m below the watertable produced poor yields. It is thought that at depth the joints are only lines of weakness and without the process of weathering the joints are not sufficiently open to support good borehole yields.

The width of the baked zone was found to be variable but roughly equal to the width of the intrusion. The width of the baked zone is also dependent on the type of host rock. The Beaufort mudstone developed a small baked zone of generally only a few inches, even when the dyke was 30 feet wide. The Dwyka Tillite and Ecca Shales produced the widest baked zones, often 3 to 4 times the width of the dykes (Van Wyk, 1963). Apparently igneous host rocks did not develop the high permeability zones, possibly because they were of similar composition as the dyke and thus experienced minimal contact metamorphism.

Following the surficial and tectonic physical processes of the first stage, the existing openings are further modified by the secondary processes of weathering and water circulation. Weathering is a selective and self-intensifying process. Deep basins of decomposition form in the igneous rocks, which are more susceptible to weathering than the sedimentary rocks. The maximum depth to which rocks are permeable is a function of the depth of weathering. Although weathering generally extends only down to the watertable, weathering of joint and faults extends much deeper effectively making these discontinuities valuable water sources. Below the depth of weathering high borehole yields are not obtained. The depth of weathering was found to be a function of past climatic and physiographic factors rather than present rainfall and climatic factors, which were found to have no effect (Van Wyk, 1963).

Weathering also develops laterally along discontinuities, especially in areas where surficial processes have created a network of interconnecting joints. Rolling topography coupled with few outcrops and good soil coverage indicates the rocks underlying KwaZulu-Natal are readily susceptible to weathering processes.

In a granular, pervious material the water table is the surface between the zone of saturation and the zone of aeration and flow is described by Darcy's Law (Domenico and Schwartz, 1990). However, because the rocks underlying South Africa are almost entirely impermeable it has been debated whether a water table actually exists (Van Wyk, 1963). If the water table is taken to be the surface of the water occurring in the fractures, a water table may be present in the secondary openings, but interrupted by the fresh rock. In places of greater weathering an uninterrupted water table could be present. The water-table is frequently encountered at 9 to 12 metres below the surface. Perched water tables are common in sedimentary rocks.

Location of the water table is further complicated by the finding that boreholes tap confined water, meaning that the water levels observed are pressure or piezometric surfaces and not, strictly speaking, the water table. As large quantities of water are pumped from conduits of small storage capacity it is suggested that these conduits must be linked to other water sources, possibly slightly permeable places in the confining beds themselves (Van Wyk, 1963). This interconnected nature of the permeable and slightly permeable zones is indicated by the effects of rainfall on recharge. Rainwater percolates down through the soil and decomposed rock in a generally continuous sheet but is soon constricted to movement down the discontinuities. Upon reaching the water table the infiltrating water forms mounds, which quickly disperse.

Drennan Maud and Partners (1995 b) examined borehole yields of different hydrogeological units and listed the range values as well as the median values. (Table 3.2).

Table 3.2 Statistics of Reported Borehole Yields (after Drennan Maud and Partners, 1995 b)

Hydrogeological Units	Range of Estimated Borehole Yields (l/s)	No. of Records	Median
Intrusive rocks, dolerite sheets and dykes	0.0-10.0	886	0.46
Basement Rocks	0.01-25.6	197	0.5
Pietermaritzburg and Volksrust Formation shales (and Beaufort Group mudstone and sandstone)	0.01-23.2	428	0.5
Vryheid Formation sandstone	0.01-26.0	330	0.5
Dwyka Formation tillite	0.01-3.8	36	0.3
Natal Group sandstone and conglomerate	0.02-5.0	82	0.8

3.5 Soils

Soils are broadly classified according to characteristics such as morphology, parent material and vegetation. Open textured sandy soils encouraged rain infiltration, particularly in relatively flat areas, while clayey soils resulted in water stagnation and limited groundwater recharge.

3.5.1 Umkomazi Study Area

The major soil types found in the Umkomazi study area are described in Table 3.3.

Table 3.3 Major Soil Groups (after Davies Lynn and Partners, 1995 a)

Parent Rock	Soil Series	Soil Description
Amphibolite	Dansland	Dark grey brown loam. Good fertile soil.
Granite Gneiss	Glenrosa Mayo	Dark reddish brown clay loam. These soils occur in drier areas viz. Rain shadow valley Dark grey gritty loam.
Natal Group	Cartreff Trevanian Katspruit Inanda	Youthful, Weathered Transitional pre-weathered Hydromorphic: drift Ferralitic soil - mist belt
Dwyka Formation	Williamson Waldene	Dark greyish brown, fine sandy loam Hydromorphic soil. Dark grey, fine, sandy loam
Pietermaritzburg Shale	Milkwood	Very dark grey, clay loam
Karoo Dolerite	Hutton	Reddish, silty loams

3.5.2 Umfolozi Study Area

According to the classification scheme developed by Van Wyk (1963) and adopted by Drennan Maud and Partners (1995 a) there are two main soil types in the Umfolozi study area: Unleached Subtropical Soils and Lateritic Soils. The unleached subtropical soil cover the majority of the study area and comprise shallow reddish brown sandy soils of residual nature. Minor amounts of brown to reddish brown ferruginous lateritic soils are present.

According to the classification system adopted by E. Martinelli and Associates (1995) the study area is primarily underlain by dark Glenrosa and Mispah Soils. These soils are associated with Karoo shale and tillite. Black and red smectitic clays are also associated with the Karoo mudrocks and these impermeable layers result in water stagnation and poor internal drainage. The thornbush *Acacia* genus is associated with this soil type. Lesser amounts of Upland Duplex and Undifferentiated Soils and possibly minor amounts of a freely drained red-yellow soil occur in the study area.

3.6 Vegetation and Agriculture

The natural vegetation is closely related to altitude and climatic variations in addition to coastal proximity. In the Umkomazi study area vegetation comprises Coastal Forest and Thornveld, Valley Bushveld and Highland Grassveld (Davies Lynn and Partners, 1995 b). Agriculture is largely subsistence farming, with minor amounts of sugar production. The vegetation of Northern Natal is given below in Table 3.4.

Table 3.4 Natural Vegetation of Northern Natal (after Drennan Maud and Partners, 1995 a, and Van Wyk, 1963).

Type of Vegetation	Occurence and habitat	Species
Coastal Evergreen Bush		
• Low forest and scrub	This vegetation type extends from the coast to an altiude of approximately 500 m.a.s.l.*	*Millettia caffra, Celtis kraussiana* and *Canthium spp*
• Taller bush and forest	Occur in valleys sands and hill slopes	*Celtis kraussiana, Alberta magna, Combretum spp*. And *Ficus spp.*
• grasses		*Aristida junciformis, Bothriochloa spp* and *Chloris gayana*
Dry Thorn or Bush veld	The Dry Thorn Veld extends up most of the river valleys from the coast to an altitude of just over 1000 m.a.s.l. It extends over the greater part of the basins of such rivers as the Tugela, the Umfolozi and the Pongola.	
• Trees		*Acacia Arabica, Acacia Karoo* and various other acacia species.
• Grasses		*Mainly Chloris gayan, Digitaria spp* and *Ergrostis superba*
Temperate Forest on Broken Country	This vegetation type occurs at altitudes between 1100 and 1400 m.a.s.l. on the Eshowe	
• Trees		*Posocarpus spp, Scolopia*

Type of Vegetation	Occurence and habitat	Species
	hills. The country is dissected and the soils resistant to erosion.	*mundtii* and *Cussonia spicata.*
Highland Sour Veld	The sour Veld occurs at an altutude of 1500 to 2000 m.a.s.l. There ae a few isolated high lying areas with this type of veld in the surroundings of Nongoma. The country is undulating continuous. The soils are resistant to erosion.	
- very dense cover of short grass		*Tristachya hispida, Themeda triandra and Monocymbium cerisaeforme.*

* m.a.s.l. = metres above sea level.

4. WATER QUALITY PARAMETERS

Water quality analysis is only as reliable as the scientific knowledge for each constituent and is dependant on the accuracy and precision of the laboratory methods used to determine concentrations. It is becoming evident that the absolute concentration of a particular element is perhaps not as significant as the chemical form in which the element exists and its interactions with other constituents (Kempster *et al*, 1982). Also other routes of exposure, e.g. through food, should be considered for a complete health analysis. Further, while a large number of constituents are toxic at high concentrations, they may be essential to normal health in small amounts and nutritionists are discovering that diseases resulting from elemental deficiency can be as serious as those resulting from excess consumption (Kempster *et al*, 1982). A brief discussion of the determinants used in this study is given below.

4.1 Microbiological Quality

Escherichia coli faecal coliform bacteria are themselves harmless and exist naturally in the animal gut. Because it is relatively inexpensive and easy to analyse for *E. coli*, they are used as an indicator of faecal pollution and as an indicator of the potential presence of more harmful bacteria.

4.2 Physical Quality

Total dissolved salts (TDS) is the summation of the individual anions and cations from a total macro analysis, or it can be calculated from electrical conductivity (EC). Total dissolved salts is closely related to total dissolved solids (also referred to as TDS) and in practice they are used interchangeably. In a more rigorous analysis total dissolved solids would be determined by evaporation. A discrepancy occurs when an unusually high concentration of a non-ionic substance, such as dissolved organic compounds, are present. The relationship between the electrical conductivity and total dissolved salts in the two study areas is shown in Figure 4.1. The lower limit for DWAF Class 1 (1000 mg/l) is primarily aesthetic, whereas the upper limit for Class 2 (2450 mg/l) is based on health considerations and may lead to salt overload in sensitive individuals, e.g. those with impaired renal function or those with immature kidneys (refer to Table 4.1 for DWAF Classification).

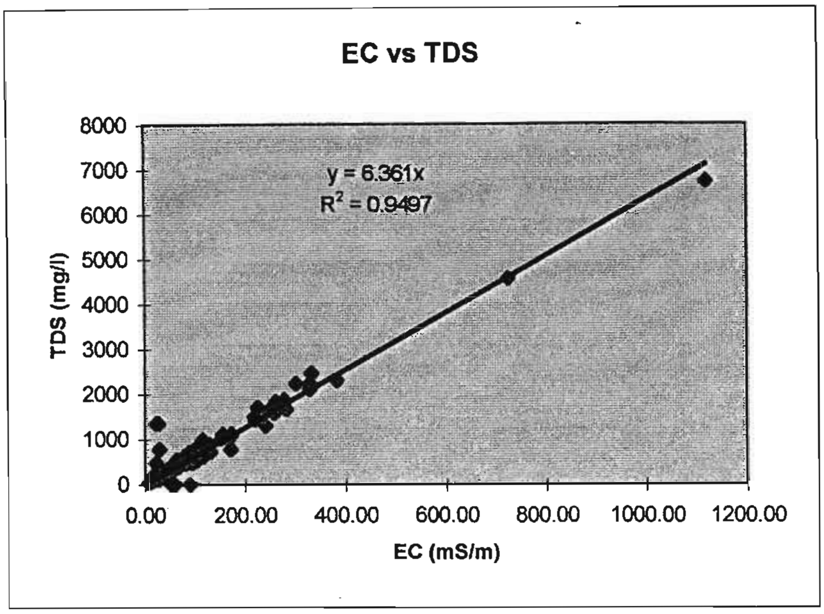


Figure 4.1 The relationship between electrical conductivity (EC) and total dissolved salts (TDS).

pH = - log [H], or the negative logarithm of the hydrogen ion activity. In a rigorous analysis of the corrosive potential of water pH should be considered along with redox potential (Eh), temperature, electrical conductivity and major ions. In general, metals tend to be more soluble in low pH (acidic) water, increasing the risk of ingesting toxic corrosion products, e.g. cadmium from galvanising. Alkaline (high pH) water, especially above a pH of 10, may lead to mucous membrane irritation.

4.3 Chemical Quality

4.3.1 Major ions

Sodium is an essential constituent in low concentration, but at higher concentration (200 - 400 mg/l) it causes an unpleasant salty taste and may be unsuitable for individuals with salt restricted diets such as those with congestive heart failure, hypertension due to salt retention, or immature kidneys. Water sources that contain sodium concentrations above 400 mg/l are generally considered unsuitable, especially for infants.

Potassium is also an essential element for good health and is the seventh most common element in the earth's crust. Potassium is generally considered non-toxic, however, at very high doses it disturbs the electrolyte balance of the body (Kempster *et al*, 1982).

Calcium standards for industry are low as this element causes scaling. However, for drinking purposes the criterion is high as calcium is non-toxic and calcium phosphate is an integral constituent of bone. The body uses up to 2 g per day. Calcium enriched water reduces the harmful effects of high fluoride concentrations though the precipitation of calcium fluoride (CaF_2) and reduces the harmful effects of heavy metals by hindering their adsorption. It has been noted that fish populations in calcium rich water experience reduced effects from lead and zinc (Kempster *et al*, 1982). Thus in low calcium water stricter guidelines for heavy metals need to be adhered to than in high calcium water.

Magnesium is required by humans, animals and plants. Combined with calcium, magnesium is responsible for water hardness, which causes scaling and impairment of lather. At a concentration of 70 mg/l a bitter taste becomes noticeable, and diarrhoea may occur in infants. Above 100 mg/l the bitter taste is more pronounced and diarrhoea is more common. Magnesium has also been linked to ischaemic heart disease (Leary, W.P. *et al*, 1997).

Chloride is associated with sodium and reflects the salinity of the water. Above concentrations of 200 mg/l water will have a distinctive salty taste. Above 600 mg/l the water will not quench thirst. Because most plants do not have salt excreting mechanisms the criterion for irrigation water is only 100 mg/l. Chloride is difficult to remove, requiring processes such as distillation, reverse osmosis or ion exchange.

Sulphate is toxic to sensitive individuals at high concentrations due to its purgative effects. At concentrations between 200 to 400 mg/l diarrhoea may occur in non-adapted users. At concentrations between 400 to 600 mg/l an unpleasant taste may be noticed and diarrhoea is common, though most users will adapt. However, at concentrations above 600 mg/l water is not considered suitable for drinking purposes, particularly for infants for whom diarrhoea may be life threatening.

Alkalinity is mainly due to bicarbonate species and reflects the acid neutralising capacity of the water sample. Total alkalinity is referred to as TAL and is commonly measured in major ion analyses. Alkalinity effects the corrosive potential of water.

4.3.2 Minor ions

Fluoride is beneficial at low concentrations (≅ 1.0 mg/l) because it prevents dental caries and it is therefore added to toothpaste and city water supplies through fluoridation schemes. At concentrations two to three times the beneficial level fluoride is responsible for tooth mottling and skeletal damage in people (Rudolph, M.J, *et al*, 1997) as well as livestock (Meyer, *et al*, 1997). This contrasts with other trace elements, e.g. manganese and zinc, where beneficial levels differ greatly from harmful levels. Thus, fluoridation of municipal water supplies has been surrounded by controversy (Hileman,1988, Du Plessis, 1997). High fluoride concentrations can occur naturally in groundwater (McCaffrey, 1997, Jha and Jha,1982) or from waste water (Ginster, *et al*, 1997). The ideal concentration of fluoride is dependant on average daily intake. Average daily intake is dependant on the average maximum air temperature. In other words, people that live in warm climates drink more water than those that live in cold climates. Thus ideal fluoride concentrations are dependant on air temperature. For an average maximum air temperature of 16°C a fluoride concentration of 1 mg/l is recommended, whereas for an average daily maximum of 30°C only 0.7 mg/l is recommended (Kempster *et al*, 1982). The fluoride ion has a radius of 1.36 A which makes it isomorphous with the hydroxyl ion (OH-), with has a radius of 1.40 A. Thus fluoride replaces the hydroxyl ion in many silicate and phosphate minerals (Fleischer, 1972). Fluoride also replaces the hydroxyl ion in tooth enamel through the conversion of hydroxyapatite to fluoroapatite:

$$Ca_{10}(PO_4)_6(OH)_2 + 2F^- \rightarrow Ca_{10}(PO_4)_6F_2 + 2OH^-$$

Because fluoroapatite is less easily dissolved by mouth acids it is more resistant to decay than hydroxyapatite. Bacteria convert sugar in the mouth into acids which cause the tooth surface to demineralise. At low pH levels the calcium and phosphate ions move from the enamel into the plaque, while at neutral pH levels they move from the plaque back into the enamel. Fluoride ions in the saliva help prevent the conversion of sugars into acids and thus reduce tooth demineralisation. Also, fluoride ions in the saliva may be incorporated into the enamel during remineralisation. Negative effects of fluoride are manifested in tooth fluorosis, which in severe cases causes stained, pitted, brittle teeth likely to fracture. At concentrations of over 3.5 mg/l long term consumers are susceptible to skeletal fluorosis. In advanced stages of skeletal fluorosis, or crippling skeletal fluorosis, movement in joints becomes difficult, extremities become weak and vertebrae fuse together. However, fluoride-magnesium interactions have been shown to reduce these harmful effects (Mokrzynska, 1995).

Nitrate and **nitrite** are generally reported together as mg/l N. They result from the bacterial oxidation of organic nitrogen which comes from sewage effluent and fertiliser runoff from agricultural fields. Nitrite is unstable in water and oxidised by bacteria to nitrate. Nitrate poisoning causes methaemoglobinaemia (blue baby) in infants and may be linked to stomach cancer in adults. Infants are especially at risk when they are bottle fed, have iron deficiency anaemia, insufficient vitamin C intake, or achlorhydria (high stomach pH) as well as elevated nitrate concentrations in their water sources. The Department of Water Affairs recommends a concentration below 10 mg/l and considers 20 mg/l unfit from infant consumption. However the World Health Organisation lists 45 mg/l as the maximum permissible level and other research suggests that up to 90 mg/l is safe for adults (Connelly and Taussig, 1994).

Ammonium exists under acidic conditions and is converted to the more toxic ammonia under alkaline conditions through the reaction:

$$NH_4^+ \rightarrow H^+ + NH_3$$

High ammonium concentrations indicate the presence of sewage effluent or nitrogen based fertilisers.

Phosphate incorporates phosphorus, which is the eleventh most common element in the earth's crust and exists in the form of phosphate minerals. Phosphate is non-toxic and combined with calcium it is a necessary component of bones. However, phosphates are an indication of pollution from detergents, fertilisers and sewage and thus are associated with more dangerous pollutants.

4.3.3 Trace Metals

Arsenic is classically regarded as a highly toxic element because of its use in the middle ages as a poison. Arsenic was also one of the first chemical agents determined to be carcinogenic. However, depending on the chemical form in which it is present, arsenic can be non-toxic, or even beneficial. At concentrations of 0.01 to 0.05 mg/l there is a slight chance of skin lesions from long term use. At concentrations above 0.2 mg/l skin cancer becomes a risk. Fatality may occur with chronic exposure to concentrations over 1.0 mg/l.

Cadmium can potentially be highly toxic to higher life-forms as it is a cumulative poison. Cadmium is usually an industrial pollutant and occurs in association with zinc and lead. Cadmium is very water soluble and will only precipitate under alkaline conditions. Kidney damage is anticipated with exposure to concentrations over 0.02 mg/l.

Iron, the fourth most common element in the earth's crust, is a necessary constituent of haemoglobin. Most drinking water criterion are based on aesthetic effects as iron in water is responsible for yellowish-brown discoloration (British Geological Survey, 1988). However, rare health effects may occur in sensitive individuals at a concentration range between 0.2 and 2.0 mg/l. Above 2.0 mg/l negative health effects are especially likely in infants.

Manganese is necessary for both animal and plant life. Similarly to iron, manganese causes severe aesthetic effects through discoloured water.

Long term intake of high manganese concentrations may lead to serious neurotoxicity.

Zinc, a common industrial pollutant, causes water to have a bitter taste above 5 mg/l, and may cause toxicity above 10 mg/l. Though zinc is generally non-toxic to humans it is commonly associated with highly toxic cadmium (Kempster *et al*, 1982).

4.4 Water Quality Standards

The Department of Water Affairs and Forestry Classification of water quality is frequently referred to in this thesis (Department of Water Affairs and Forestry, 1996). The pilot study samples were placed in four classes: Class 0 reflects water ideal for potable use, Class 1 samples are suitable for potable use for a life time, Class 2 are suitable for short term use and Class 3 are not suitable for potable use. Health effects are based on the most sensitive individuals. Aesthetic effects are also considered. Samples are assigned an overall classification based on the highest classification of the individual constituents. The classification is summarised in Table 4.1.

Table 4.1 Department of Water Affairs and Forestry Classification, unit of measurement is mg / l unless otherwise stated. (after Kempster *et al*, 1996).

Constituent	Class 0 Ideal (Blue)	Class 1 Potable (Green)	Class 2 Short term (Yellow)	Class 3 Not suitable (Red)
Total dissolved salts	0 - 450	450 - 1000	1000 - 2450	>2450
Electrical conductivity (mS / m)	0 - 70	70 - 150	150 - 370	>370
Nitriate plus nitrite as N	0 - 6	6 - 10	10 - 20	>20
Fluoride	0 - 1.0	1.0 - 1.5	1.5 - 3.5	>3.5
Sulphate	0 - 200	200 - 400	400 - 600	>600
Magnesium	0 - 30	30 - 70	70 - 100	>100
Sodium	0 - 100	100 - 200	200 - 400	>400
Chloride	0 - 100	100 - 200	200 - 600	>600

Constituent	Class 0 Ideal (Blue)	Class 1 Potable (Green)	Class 2 Short term (Yellow)	Class 3 Not suitable (Red)
pH (pH units)	6.0 - 9.0	5.0 - 9.5	4 - 5 or 9.5 - 10	<4 or >10
Iron	0 - 0.1	0.1 - 0.2	0.2 - 2.0	>2.0
Manganese	0 - 0.05	0.05 - 0.1	0.1 - 1.0	>1.0
Zinc	0 - 3.0	3.0 - 5.0	5.0 - 10.0	>10.0
Arsenic	0 - 0.010	0.010 - 0.050	0.050 - o.2	>0.2
Cadmium	0 - 0.005	0.005 - 0.010	0.010 - 0.020	>0.02
Faecal coliforms (No / 100ml)	0	0 - 1	1 - 10	>10

The South African Standard for Drinking Water (SABS 241/1984) are frequently used by private consultants and the Department of Water Affairs and Forestry to determine the quality of drinking water in South Africa and are given in Appendix 2 A.

Several standards used by the Drinking Water Directive of the **European Community** (Maximum Admissible Concentration), the **United Kingdom** (Prescribed Concentration Value), the **United States** Environmental Protection Agency Primary and Secondary Drinking water Environmental Protection Agency Primary and Secondary Drinking Water Regulations (Maximum Contaminant Levels) and the **World Health Organisation** (Drinking Water Guide Values) are summarised in Appendix 2 B (after Davies Lynn and Partners, 1995 a). Additional information on US water quality standards can be found on the Internet (City of Los Angeles Water Services, 1995 a and b and 1996).

A Summary of World Opinion is given by Kempster *et al* (1982) who examined 27 sources on existing water quality criteria to give a general picture of the world opinion as regards the limits for water quality constituents. The lowest criterion reported (minimum value), the most commonly reported criterion (median value) and the highest reported criterion (maximum value) were given. Kempster *et al* (1982) presented criterion for 15 water uses. Summarised drinking water criterion are given in Appendix 2 C.

Bond (1946) classified the different types of groundwater derived from the principal geological formation in South Africa into 5 main groups. He explained that due to their mineralogical composition and past geological history certain formations yielded characteristic water. Bond's groups were subsequently modified by Van Wyk (1963) and Drennan Maud and Partners (1995a). The modified Bond Classification is given in Appendix 2 D.

5. PREVIOUS HYDROCHEMICAL STUDIES

Bond (1946) examined the relationship between the hydrochemistry of groundwater samples and the geological formations from which they were derived. He produced a generalised water quality map of South Africa. According to Bond the apparent chemical difference between water derived from the same formation was merely one of concentration e.g. absolute concentrations varied, but relative concentrations were similar. Bond has been criticised (Van Wyk, 1963, Drennan Maud and Partners, 1995 b) for the generalised nature of his work and for basing his analysis on spring samples instead of borehole samples.

Subsequently, Van Wyk (1963) studied groundwater in the northern section of KwaZulu-Natal and compiled a more detailed water quality map. Van Wyk found that factors such as rainfall and proximity to the coast had more of an influence on groundwater quality than did geological factors, as the boundaries on his water quality map do not coincide with the boundaries of lithological units.

More recently the KwaZulu-Natal branch of the Department of Water Affairs and Forestry commissioned a series of hydrogeological surveys including those contracted to Davies Lynn and Partners (1995 a and b), Drennan Maud and Partners (1995 a and b) and E. Martinelli and Associates (1995). In general very little connection was found between boreholes in a particular geological formation and high concentrations of dissolved material, however, interpretation was frequently compromised by use of simplified hydrogeological maps and inaccurate location of sample points.

Specific references made by the above authors to the hydrochemistry of water samples which were obtained in the vicinity of the Umkomazi and Umfolozi study areas and derived from the basement, Natal Group, Dwyka Formation, Ecca Group and Karoo dolerite rocks are discussed below. These studies are summarised in Table 5.1 at the end of this section.

5.1 Basement Rocks

Bond (1946) characterised the water derived from Natal basement rock (Natal Old Grey Granite) as having a low average total dissolved salts (360 mg/l) but a high percentage (31% of TDS) chlorine . Bond suggested that the high chloride content was a result of salt laden mists blown inland by the prevailing winds which had deposited salts (particularly magnesium chloride) in the soil. Bond reported silica content as moderately high while fluoride was low (the highest being 0.4 mg/l). The CaO : MgO ratio was 1 : 1.25 - a result of the nearby ocean. Sulphates were low. The water was found to be more corrosive than scale forming. Iron was recorded as under 5 mg/l, however it was noted that some of the samples, especially those with a low pH, deposited iron oxide when left standing. Bond classified the samples from this formation in the Slightly Saline Group.

Davies Lynn and Partners (1995 a and b) examined groundwater samples in and around the Umkomazi study area. Though the authors found little connection between high chemical concentrations and lithology, they did note that basement rocks lose iron from the ferromagnesian minerals during weathering and that one should expect high iron concentrations in boreholes drilled in deeply weathered zones of granites, gneisses and basic rocks. Davies Lynn and Partners used Piper diagrams to examine relative concentrations of major ion. (see Section 6.2.1 for construction of Piper diagrams). Davies Lynn and Partners separated the basement rocks into the Granite Gneiss and the Natal Maphumulo Suite. For the former the cations were characterised by a tight cluster in the sodium-potassium sector, while the anions clustered between bicarbonate and chloride. Sulphate concentrations were relatively low. The central field showed a well spread cluster which was interpreted as the sodium bicarbonate and sodium chloride transition. The Natal Maphumulo Suite was characterised by a tight cation cluster in the Sodium-Potassium sector, while the anions clustered towards the chloride sector. Sulphate concentrations were also low. The points in the central field fell in the sodium chloride sector.

E. Martinelli and Associates (1995) described the quality of water originating from the Basement Granites near the Umfolozi study area as generally good. They reported TDS values near 1000 mg/l in the low-lying (<500m) area north of the White Umfolozi River, but contributed this to a relatively low mean annual rainfall (MAR) of 600 mm/annum. They explained that rainfall increases with elevation. E. Martinelli and Associates reported the pH as slightly acid to alkaline (pH 6.3-8.5). Thermal waters were reported as strongly alkaline (pH 9.4). Relative analysis of major ions showed the groundwater was a sodium bicarbonate water with a trend toward sodium chloride. E. Martinelli and Associates described the water quality from the Pongola and Nondweni rocks as generally excellent. They reported a high value of 136 mg/l magnesium which occurred in a banded ironstone. They described the hydrochemistry of the Pongola and Nondweni rocks as very similar to the granites. This similarity was reflected in Piper diagrams plots. E. Martinelli and Associates explained that in igneous rocks the dominant reactions producing brackish waters are the hydrolysis of feldspars and ferromagnesium-rich minerals as well as the dissolution of salt from pores (e.g. fluid inclusion) and grain boundaries.

Drennan Maud and Partners (1995 a) examined hydrochemical trends near the Umfolozi study area. They produced contour maps of Electrical Conductivity and Chloride Distribution which they superimposed on a simplified lithostratigraphical base map. They noted frequent abrupt lateral variations in EC and chloride, which indicated that saturated fracture zones and saturated decomposed rock were not interconnected on a regional scale, and which made it difficult to contour and interpret hydro-chemical trends. Drennan Maud and Partners found low TDS in the basement complex south of Empangeni and Eshowe, which they explained by the high rainfall (MAR >1000 mm/annum), which effectively removed dissolved solids. No satisfactory explanation was given for the low TDS values in the Pongola River area, where the rainfall was 600 mm/annum to 800 mm/annum. Drennan Maud and Partners found that samples from the basement rocks tended to yield fresh to slightly saline water and contained between 126mg/l and 905mg/l dissolved solids. Chloride content was reported between 2.5%

and 5.5%. Magnesium was averaged at 22.1 mg/l, and believed to originate from the silicate minerals in the dark-coloured ultrabasic rocks. The acid rocks were identified as the source for the high silicon levels which averaged at 24.4mg/l.

More generally, basement aquifers underlie approximately one third of the developing world (Herbert, 1994) and are especially important for water supply in arid and semi arid regions. Thus a substantial body of research has been collected on the importance of crystalline basement aquifers (weathered, igneous and metamorphic) to rural water supply projects. A relevant example is the case study published by Taylor and Howard (1994), who examined the groundwater quality in rural Uganda and extrapolated hydrochemical considerations for the development of aquifers within the basement complex of Africa. The authors investigated concerns about water quality expressed by a quarter of the user population and found the concerns were supported by chemical analysis. 150 samples, primarily from deep boreholes, were taken from two catchment areas which had different bedrock geology as well as topography and climate. The samples were examined for major ions and trace metals. The samples were found to be characteristically Ca - HCO_3. The inorganic constituents were not high enough to pose health risks, however, nitrate and chromium concentrations exceeded health guidelines set by the World Health Organisation (WHO) in several sites. Concentrations of aluminium, chloride, iron, manganese, zinc and hardness frequently exceeded the WHO aesthetic limits. The authors explained that the trace metals (Al, Cr, Fe, Mn, Zn) occurred in the groundwater due to weathering of the bedrock matrix and also from the corrosion of borehole rising mains. High nitrate levels were contributed to sewage treatment facilities and pit latrines. While the contamination from human sources could be reduced, the natural contamination of groundwater from the weathering of the basement was found to be unavoidable. Thus the authors warned that in developing basement aquifers the potential for unpalatable drinking water must be considered.

5.2 Natal Group Sandstone

At the time of Bond's (1946) paper, the Natal Group sandstone had not yet been recognised as a separate formation from the larger Table Mountain Series. However, Bond (1946) still noted the difference in quality between water derived from the Table Mountain Series of the Cape System and the Natal Table Mountain sandstone. In the Cape Province the sandstone was found to produce water of very low average pH (5.7) and coffee coloured spring water, whereas in Natal the sandstone produced water with very low mineral salt content (114 mg/l) and was crystal clear in colour. Silica was found to be 10.4% of total solids. Fluorides were not found. Chloride was 32.1% of TDS due to the proximity to the ocean. Sulphates were 2.1% of TDS. Bond described water from the Natal Group sandstone as very soft. Because of the low CaO : MgO ratio, Bond hypothesised that the formation was not contaminated by entrapped sea water. Owing to the low concentration of salts, Bond classified the water derived from the Natal Group sandstone as Group E: Very Pure Water.

Davies Lynn and Partners (1995 a and b) examined the quality of water obtained from the Natal Group sandstone near the Umkomazi study area. The authors looked at relative concentrations of major ions, but did not assess the significance of absolute concentrations or the relationship between lithology and other constituents. Piper diagrams indicated that the water from the Natal Group was characterised by a well spread cation cluster which tended towards the sodium-potassium field, with an extension towards the magnesium sector. The anions clustered toward the chloride sector, except for a few outliers toward the bicarbonate sector. Relative sulphate concentration was low. The results in the central field was a well spread cluster which was interpreted by the authors as sodium chloride, though some outliers in the calcium bicarbonate sector were identified. The Natal Group samples were described as natural water.

Drennan Maud and Partners (1995 a) analysed water samples near the Umfolozi study area. They found that the Natal Group tended to yield fresh water to saline chloride water. The authors generally discussed range values rather than a central tendency descriptor so that extreme values would not be masked. The dissolved solids ranged between 78 mg/l - 3181 mg/l. Chloride represented 11.0% to 45.0% of TDS and ranged from 13 mg/l to 1256 mg/l. Drennan Maud and Partners explained the wide fluctuation in chloride content was a result of some of the boreholes being situated in fracture/fault zones which allowed greater circulation than boreholes situated in more solid rock. The Natal Group outcropped near Eshowe, which had a relatively high mean annual rainfall of between 1000 mm /yr and 1250 mm/annum that effectively leached out salts that accumulated in the fracture/fault zones. Magnesium averaged at 22.8 mg/l and the silicon averaged at 24.4 mg/l.

As a result of their investigation in an area near the Umfolozi study area E. Martinelli and Associates (1995) found that lithology was not itself a primary control on groundwater quality. The authors did however provide a summary of the hydrochemistry of the various hydrolithostratigraphic units. They described the quality of groundwater from the Natal Group sandstone south of Ulundi as atypical of the formation in general. Martinelli explained that this was a result of the long flow path from recharge areas or possibly because of the overlying Dwyka Formation. In addition it was noted that the area received relatively low rainfall. The EC was given as greater than 100 mS/m and the pH ranged from neutral to alkaline, pH 7 - 8.7. Piper diagrams characterised water from the Natal Group strata as intermediate between Na-HCO_3 and Na-Cl type.

5.3 Dwyka Formation

Bond (1946) explained that the quality of water derived from the Dwyka Formation varied with location. He found that water derived from the Dwyka Formation in the Cape Province and Western Transvaal had such high salinity that many boreholes were abandoned, while in Natal the Dwyka provided relatively fresh water. Water derived from the Natal Dwyka had total solids which average only 440 mg/l, in contrast to 1500 mg/l outside of Natal. Bond attributed this partly to the higher and more regular rain fall in Natal.

Another explanation was that outside of Natal the glacial muds and boulders may have been deposited in the sea or in brackish water or there may have been a marine inundation after the formation of the Dwyka tillite. Otherwise it would have been hard to account for the consistently high chloride and sulphate contents in the Cape samples. The upper Dwyka shales could have originated as black organic, highly sulphured muds in an environment similar to the Black Sea or Gulf of Bothnia today. However, according to Bond, in Natal the upper pyritic shales are missing, which explained the extremely low sulphate content in Natal (1.5%) as compared to 15% in Pondoland Dwyka water and Western Dwyka water. Bond believed the relatively high amount of chlorine found in water derived from the Natal Dwyka was from ocean winds. Bond classified the Natal Dwyka water as slightly saline.

Van Wyk (1963) did not separate the Karoo sediments in his description of water quality. In the Lowveld areas the Karoo sediments were classified as group B, mineralised chloride water, which in most cases had salinity contents too high for drinking. The pH values for the sediments averaged 8.1 and the soda alkalinity (Na_2CO_3 or $NaHCO_3$) was extremely low. Chloride content was relatively high, averaging 40% of total solids. Van Wyk, like Bond, attributed this to salts carried inland from the Indian Ocean by the prevailing winds. Van Wyk cited the work of Bayer (1938) who studied the occurrence of stunted or deformed trees. These trees were bent at a height of 1.5 to 2.4 meters and grew horizontally in the direction away from the prevailing salty sea-winds. Many of these trees, mostly the *Ficus sycamorus*, were found north of Empangeni and inland up to 32 kilometres from the coast. Apparently the deformation was not due to the direct mechanical effect of the wind, but rather due to the salt carried by the winds which killed off young shoots on the exposed side and caused the tree to grow leeward. Van Wyk used two water samples derived from the Dwyka Formation as typical analyses of group B water, but two other Dwyka samples were used as typical analyses of group D, temporary hard (carbonate) water. The latter group is characterised by very little permanent hardness, low chlorides, around 10% of total dissolved solids, high soda alkalinity, and generally more Ca than Mg. It is interesting that although the characteristics of group D were almost opposite of group B, water samples derived from the Dwyka Formation were considered characteristic of both Groups.

Davies Lynn and Partners (1995 a and b) characterised water from the Dwyka Formation near the Umkomazi study area by plotting the samples on a Piper diagram. The cation constituents were characterised by a well spread cluster that tended toward the sodium-potassium endpoint. There were few outliers. The anion constituents clustered in the bicarbonate sector of the field, with a couple of outliers toward the chloride sector. Sulphates were very low. The resultant central plot showed a well spread cluster that was interpreted as being in the sodium bicarbonate sector. The water was described as dynamic, indicating that it was undergoing changes in concentration along its flow path.

E. Martinelli and Associates (1995) described the Dwyka Formation near the Umfolozi area as typical of aquifers found in low-lying and valley areas. Quality of water derived from the Dwyka Formation was fair to poor, mainly due low rainfall and long flow paths. EC, Na, Cl, NO3 and F values were frequently above the South African Standard for Drinking Water (SABS 241/1984) maximum guideline value level (see Appendix 2A). Boreholes near rivers were found to have acceptable quality where they were recharged from the river. The pH values were slightly alkaline to alkaline in character. The Piper diagram characterised the water as intermediate between sodium bicarbonate and sodium chloride, which was similar to the Natal Group, and was interpreted as evidence that, around Ulundi, there was a hydraulic connection between the Dwyka strata and the underlying Natal Group sandstone. E. Martinelli and Associates noted that in sedimentary rocks, such as the Dwyka Formation, the possibility of connate water could not be ruled out. The long residence time of such water would account for the brackish groundwater occasionally found around the Umfolozi valley.

Drennan Maud and Partners (1995 a) interpreted results of water quality analyses carried out on samples near the Umfolozi study area. The authors described the water derived from the Dwyka Formation as fresh water to slightly saline water. Samples contained 75 mg/l to 846 mg/l dissolved solids. The chloride content varied between 17.3% and 56.3% of TDS. Like

Bond (1946) and Van Wyk (1963), Drennan Maud and Partners contributed the relatively high chloride content to the deposition of chloride spray from the Indian Ocean. The variation in concentrations was contributed to the presence of fracture/fault zones. The sulphate content was found to be extremely low due to the generally absence of pyritic and gypsum minerals. The magnesium concentrations were low (averaging 17.9 mg/l) while the silicon concentrations averaged 13.5 mg/l. The former were derived from the dissolution of mafic minerals, while the later indicated the dissolution of felsic minerals.

5.4 Ecca Group

Bond (1946) found very little hydrochemical difference between the Dwyka Formation and the Ecca Group (formerly the Ecca series), which followed conformably on the upper Dwyka shales. Like the Dwyka, the chemical characteristics of the water derived from the Ecca Group also varied geographically. On the Natal coast the samples were characterised by high concentrations of dissolved salts, averaging 1810 mg/l, and like other saline water they had a low silica content. On the Natal coast the Ecca Group produced water with a much lower sulphate content than in the Cape Province. Bond explained that like the Dwyka beds, the Ecca beds were less pyritic in Natal. Water samples from the Ecca beds on the Natal coast were classified in the highly mineralised chloride-sulphate group, and some of these were considered too saline for potable use. In Northern Natal, all types of waters were found, except for extremely saline, thus Bond was not able to average the results and he did not classify the samples into one of his water quality groups. Bond explained that the variation in hydrochemistry of water derived from Ecca beds in Northern Natal may have been a result of the variation between argillaceous and arenaceous rocks and the frequent dolerite dykes in the area, both of which influenced the water chemistry.

As mentioned above, Van Wyk (1963) generally grouped the Karoo sediments together in his discussion of water quality and further, the boundaries of this water quality map did not coincide with lithological boundaries. Van Wyk used two water samples derived from the Vryheid

Formation (Middle Ecca sandstone) as examples of typical analysis of group B, mineralised chloride water. Two other Vryheid samples were used as examples of group C, slightly saline chloride water. Six other Vryheid samples and two Pietermaritzburg Formation (Lower Ecca shales) were used as characteristic examples of group D, temporary hard (carbonate) water. Van Wyk found that factors such as rainfall and proximity to the coast had a greater control on water quality than the lithological units from which the samples were derived.

Davies Lynn and Partners (1995 a and b) examined the quality of water derived from the Ecca Group in two different areas (Mapping Unit 4 and 8), both of which were near the Umkomazi study area. For Mapping Unit 4 the authors only looked at water from the Pietermaritzburg Formation shales. Their analysis was limited to Piper diagrams. The cation constituents plotted in a centrally situated cluster which indicated that there was no dominant cation type. Scatter was seen toward the sodium-potassium field. The anion constituents clustered in the bicarbonate sector, though there was some scatter toward the chloride sector. Sulphates were very low. In the central field most of the points fell in the calcium bicarbonate field, though some extended into the sodium chloride area. The authors interpreted the result as an evidence that the water was fresh and newly recharged. For Mapping Unit 8 Davies Lynn and Partners also plotted water samples from the Pietermaritzburg Formation, the Vryheid Formation and the Volkrust Formation on Piper diagrams. The samples taken from the Pietermaritzburg Formation had a cation constituent characterised by a central cluster, with some outliers toward the calcium sector. The anions clustered in the bicarbonate sector, with only two samples in the chloride side. Very low relative sulphates were recorded. In the central field the points plotted in the calcium bicarbonate sector. Samples from the Vryheid Formation also showed a central cluster of cation constituents, while the anion constituents clustered in the bicarbonate sector. The Vryheid water was also classified as calcium bicarbonate. Like the other Ecca samples, the cations of Volkrust Formation samples plotted in a central cluster, though there were extensions toward the Calcium sector. The anion constituents were clustered in the bicarbonate field. In the central field the points once more were concentrated in the calcium bicarbonate sector.

Drennan Maud and Partners (1995 a and b) examined the water quality of the Ecca Group near the Umfolozi study area (Mapping Unit 3) and near the Umkomazi study area (Mapping Unit 10). A limited number of samples in the southern area showed the Vryheid Formation sandstone produced fresh water though slightly saline water. Samples contained 58 mg/l - 564 mg/l dissolved solids. The chloride content ranged from 2.2% to 25.2% of TDS. Little effort was made to differentiate samples from the numerous dolerite dikes and sills from the sandstone samples, though the authors acknowledged that the dolerite intrusions extended a primary lithological control over the composition and chemical characteristics of the water from the Vryheid Formation.

In their discussion of the Ecca Group in the northern mapping area, Drennan Maud and Partners (1995 a) described the groundwater from the Vryheid sandstone as exhibiting a wide range of electrical conductivity. The authors contributed this to the fact that some of the boreholes occurred in the contact zone between the dolerite and the surrounding sandstone, while other were drilled into the unaltered host sandstone. Like Van Wyk (1963), the authors described the Eshowe-Melmoth-Nongoma escarpment as the western limit of the area affected by marine salinity. The authors found the area to yield fresh water through slightly saline water to saline chloride water and highly mineralised chloride water. Samples contained 227 mg/l - 4147 mg/l dissolved solids. The chloride content ranged between 12.3% and 45.9% of the dissolved solids. The chloride content averaged at 70.5 mg/l, which the authors suggested was evidence that the origin of the sedimentary rocks were basement rocks rich in mafic minerals. The silicon concentrations averaged 16.1 mg/l.

Drennan Maud and Partners (1995 a and b) grouped the Emakwezini Formation mudstone, the Pietermaritzburg Shale Formation and the Volkrust Shale Formation together. Water analysis showed that these shales and mudstones yielded from fresh water through slightly saline water to saline chloride water and highly mineralised chloride water. Samples contained 94 mg/l - 6731 mg/l dissolved solids, which averaged at 2440 mg/l. Piper diagrams indicated that the chloride content ranged form 8 mg/l to 3682 mg/l, which represented 8% - 54% or the total dissolved solids. Drennan Maud and Partners explained the variation as a result of the distribution of rainfall, the magnitude of recharge area and the range of permeabilities. The authors found that rocks with greater permeabilities tended to occur in the areas with the greatest mean annual rainfall, and thus the salts were leached much more quickly out of these rocks than the low permeability rocks in the low rainfall areas. The magnesium concentrations in the Ecca Group shales formation averaged at 93.9 mg/l, and is thought to be derived from mafic minerals from the original basement rock. High silicon concentrations, averaged at 15.4 mg/l, was thought to indicate an abundance of felsic rock minerals.

E. Martinelli and Associates (1995) also found a broad range of electrical conductivity values in the Pietermaritzburg shales (10 - 495 mS/m). The water was found to be slightly alkaline (pH 7.4 - 8.8). Moderate to poor water quality was found in the lowland, with better quality near rivers due to recharge. The Piper diagrams showed a wide range of scatter, with water falling in the recently recharged bicarbonate group and scatter toward the Na-Cl rich group. The authors noted a change in quality of Vryheid Formation water with location. The water quality was fair to good in the north and west of Mapping Unit 5, but in the south east, near Ulundi, the quality was relatively poor. Carbonaceous shale and coal beds were thought to adversely affect the quality, as reflected in a low pH and high EC. In general, however, The pH varied from neutral to alkaline (pH 7 - 9), while electrical conductivity varied from 6 to 241 mS/m with a median of 33 mS/m. Piper diagrams indicated that Vryheid formation water was of bicarbonate type in the north and west, but of Na-Cl type in the low-lying areas near Ulundi.

5.5 Karoo Dolerite

Davies Lynn and Partners (1995 a and b) described the quality of water obtained from dolerite in and near the Umkomazi study area. The cations were characterised by a central cluster, indicating no dominant pair, but with extensions toward the sodium-potassium sector. The anions clustered in the bicarbonate sector. The water was described as calcium bicarbonate.

Drennan Maud and Partners (1995 a and b) looked at samples from Karoo dolerite sills and dykes in Mapping Unit 10, near Umkomazi and in Mapping Unit 3, near Umfolozi. The results from the southern area showed that the dolerite yielded fresh water though slightly saline water. The boreholes contained 28 - 518 mg/l of dissolved solids, while the springs showed 28 - 168 mg/l of dissolved solids. The chloride content varied from 1.5 to 12.4% of TDS. In the northern area the dolerite yielded fresh water thorough slightly saline chloride water to saline water. It contained 77 to 2430 mg/l of dissolved solids. The chloride content varied from 15% to 38% of the dissolved solids. Drennan Maud and Partners noted the variation in mean annual rainfall. Also there was uncertainty with regards to the location of the borehole intake zones, some of which were in the main body of the dolerite intrusion, while others were in the contact zone with the surrounding host rock. It was further pointed out that the composition of the host rock itself varied from argillaceous to arenaceous.

E. Martinelli and Associates (1995) examined samples from the Karoo dolerite near the Umfolozi area and found the quality to be variable with TDS values between 45 and 1219 mg/l, and with pH values from 6.6 to 8.5. Relative concentrations also varied as was shown by plotting the data on a Piper diagram. As with the other hydrogeological units examined by E. Martinelli and Associates, the north and west parts of Mapping Unit 5 produced water of recently recharged bicarbonate type, while in the southern and eastern parts, including Ulundi, the groundwater was a brackish Na-Cl type.

Table 5.1 Summary of Previous Hydrochemical Studies

Host Rock	Bond (1946)	Van Wyk (1963)	E. Martinelli and Associates (1995)	Davies Lynn and Partners (1995 a, b)	Drennan Maud and Partners (1995 a, b)
Basement Rocks	TDS=360mg/l Cl = 31%TDS low sulphate Fe<5mg/l Slightly Saline Group		TDS up to 1000 mg/l, with low rainfall. pH = 6.3 - 8.5 Sodium Bicarbonate to Sodium Chloride	Sodium Bicarbonate Sodium Chloride transition Fe from granites, gneisses	TDS=126mg/l to 905mg/l Cl=2.5-5.5% Mg=22.1mg/l Si=24.4 mg/l
Natal Group	TDS=114mg/l Cl=32%TDS Si=10%TDS SO_4=2%TDS Very Pure Water		EC>100mSm pH=7.8.7 Sodium Bicarbonate to Sodium Chloride	Sodium Chloride, some Calcium Bicarbonate "natural water"	TDS=78mg/l to 3181 mg/l Cl=11 to 45% of TDS Mg=22.8mg/l Si=24.4mg/l Fresh to Saline Chloride
Dwyka Formation	TDS=440mg/l SO_4=1.5% of TDS	Mineralised Chloride to Temporary Hard water	EC, Na, Cl, NO3 and F frequently > SABS guideline	Sodium Bicarbonate "dynamic"	TDS=75 to 846mg/ Cl=17.3 to 56.3% Mg=17.9mg.l Si=13.5 mg/l Fresh to Slightly Saline water
Ecca Group	Similar to Dwyka all water types except Extremely Saline	Mineralised Chloride, Slightly Saline Chloride and Temporary Hard water.	Bicarbonate, some sodium Chloride <u>Sandstones</u> EC=6 to 241 mS/m <u>Shales</u> EC=10-495 mS/m	Calcium Bicarbonate, some Sodium Chloride Fresh and newly recharged	<u>Sandstones</u> TDS=58mg/l to 564 mg/l Cl=2.2% to 25.2% TDS <u>Shales</u> TDS=94mg/l to 6731mg/l Cl=8%-54%TDS Mg=93.9mg/l Si=15.4mg/l
Karoo Dolerite			TDS=45mg/l to 1219mg/l pH=6.6-8.5 Bicarbonate to Sodium Chloride	Calcium Bicarbonate	TDS=28mg/l to 2430mg/l Cl=1.5 to 38%TDS

6. INFLUENCE OF LITHOLOGY ON GROUNDWATER QUALITY

In general, boreholes and springs provide water of better quality than surface water sources because they tend to have less biological and turbidity pollution. However, groundwater sources may cause health and aesthetic problems due to chemical constituents dissolved out of the host rock (Edmunds, 1994 a). The types and abundance of chemicals present in groundwater are related to the geological history and mineralogy of the host rock. The water quality is the net effect of a series of chemical reactions that have dissolved material from another phase, have altered previously dissolved components, or eliminated them from solution by precipitation.

Figure 6.1 shows Class 2 and Class 3 concentrations of chemical constituents and associated lithologies (see DWAF Classification, Table 4.1). In addition, the type of source has an effect on groundwater composition. In Figure 6.1 boreholes are represented by circles, springs are represented by triangles and reticulated systems are represented by boxes. The laboratory results are given in Appendix 3.

6.1 Comparison of Borehole and Spring Water

Springs in the both the Umkomazi and Umfolozi study areas are generally shallow, with water frequently emanating from the boundary surface between the soil cover and the underlying bedrock. Less frequently, deep springs occur in association with dolerite intrusions. Thus springs tend to provide recently recharged water with low chemical concentrations. In contrast, water derived from boreholes may have experienced relatively long flow paths which would have allowed the water greater opportunity to leach chemicals from the host rock. Because the soil cover was produced from decomposition and weathering of the bed rock it was anticipated that spring samples would show similar chemical trends to boreholes, but at lower concentrations. As discussed below, this linear relationship was found for major ions in Umkomazi samples, while graphs of trace metals and Umfolozi samples produced apparently anomalous results.

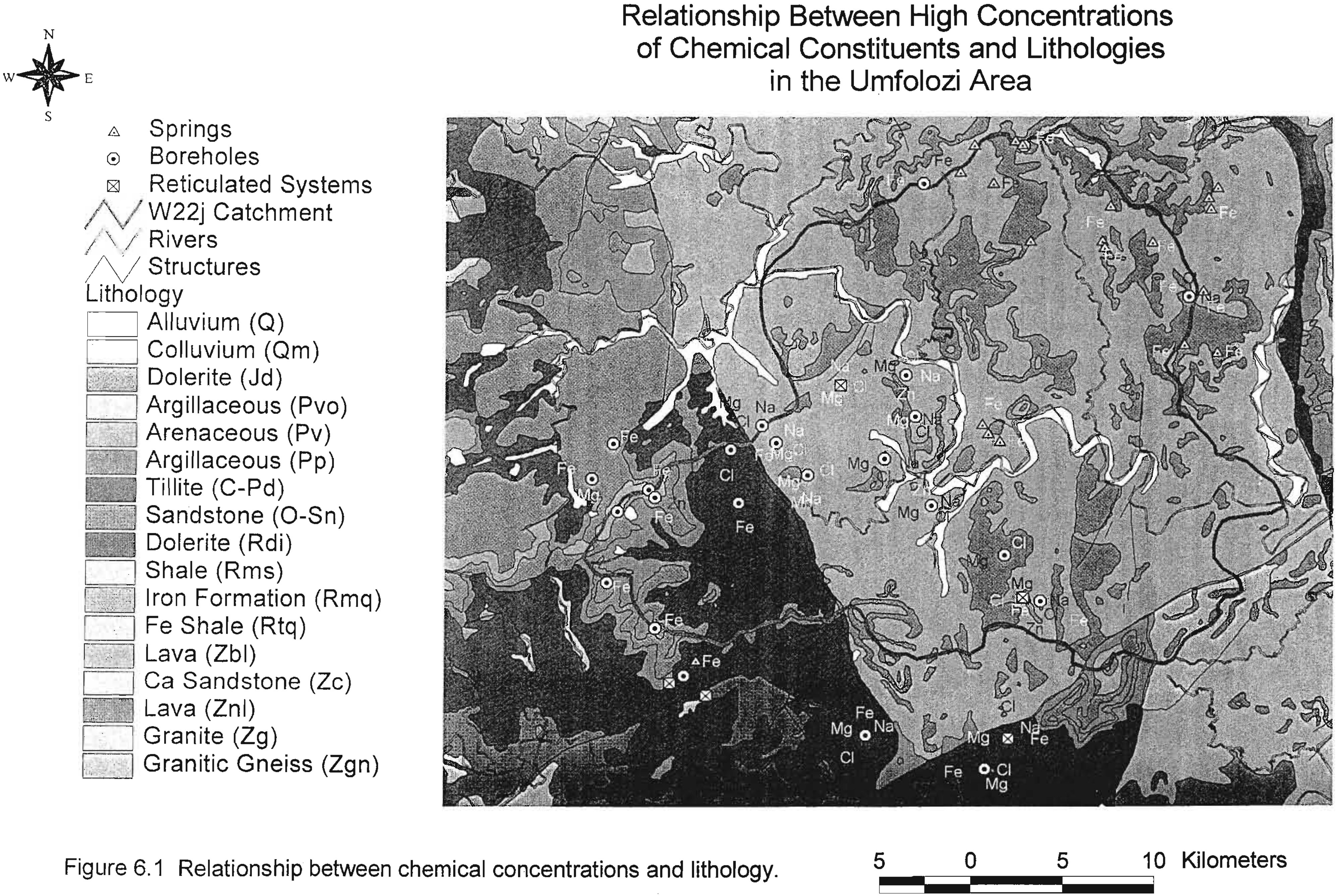


Figure 6.1 Relationship between chemical concentrations and lithology.

6.1.1 Umkomazi Area

The lithologies in the Umkomazi area from which both spring and borehole samples were collected and the number of samples are: basement rocks (springs =24, boreholes = 27), Natal Group Sandstone (springs =3, boreholes = 6), Dwyka Tillite (spring =1, boreholes =2) and Karoo dolerite (springs = 1, boreholes = 2). The number of spring and borehole samples are indicated respectively in brackets in the figure keys. Excluding anthropogenic pollutants and trace metals, Dwyka Tillite samples tend to produce the highest median concentrations of constituents, while Karoo dolerite produces the lowest median concentrations. Basement samples and Natal Group Sandstone produce similar middle values. Median borehole concentrations are greater than spring concentrations by a factor of approximately 1.85.

The linear relationship between median borehole and spring concentrations of the indicator variables, electrical conductivity (EC) and total dissolved salts (TDS), and the major ions, sodium (Na), calcium (Ca), magnesium (Mg), sulphate (SO_4), chloride (Cl) and bicarbonate and carbonate, and silica (Si) is displayed in Figure 6.2.

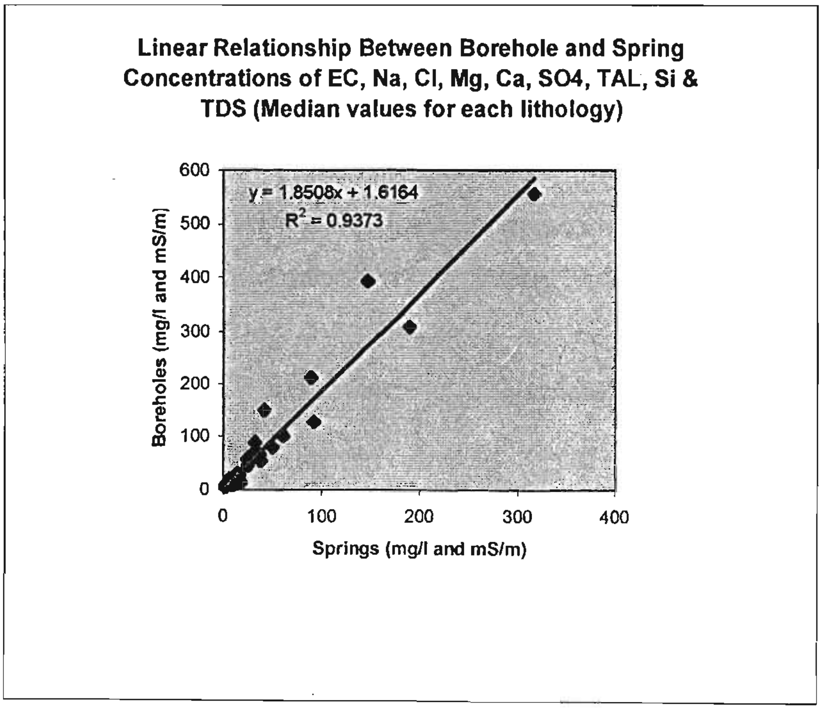


Figure 6.2 Median borehole concentrations are greater than median spring concentrations by a factor of approximately 1.85.

Median fluoride concentrations do not show a linear relationship because three of the four springs have median values of 0.2 mg/l. However, average (mean) values show a clear linear relationship. Boreholes produce approximately 10 times greater fluoride concentrations than springs (Figure 6.3).

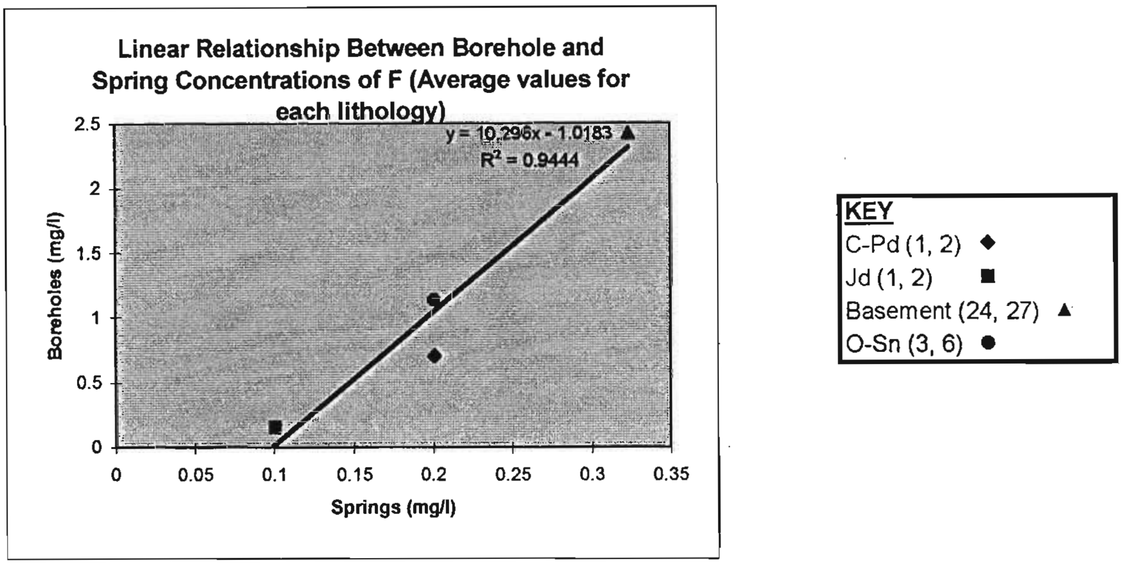


Figure 6.3 Average fluoride concentrations are approximately 10 times higher in boreholes than in springs.

Nitrate (NO_3), phosphate (PO_4), and ammonium (NH_4^+) arise from anthropogenic sources e.g. sewage effluent and agricultural run-off from nitrogen based fertilisers. Because the concentrations of these constituents are not directly linked to lithology there is no apparent relationship between median borehole and spring concentrations. Also, the trace metals (iron, manganese and zinc) do not show a recognisable relationship, possibly due to various conditions effecting the oxidation of these elements in the soil (Figure 6.4). Cadmium and arsenic are not included because concentrations were at or below detection levels.

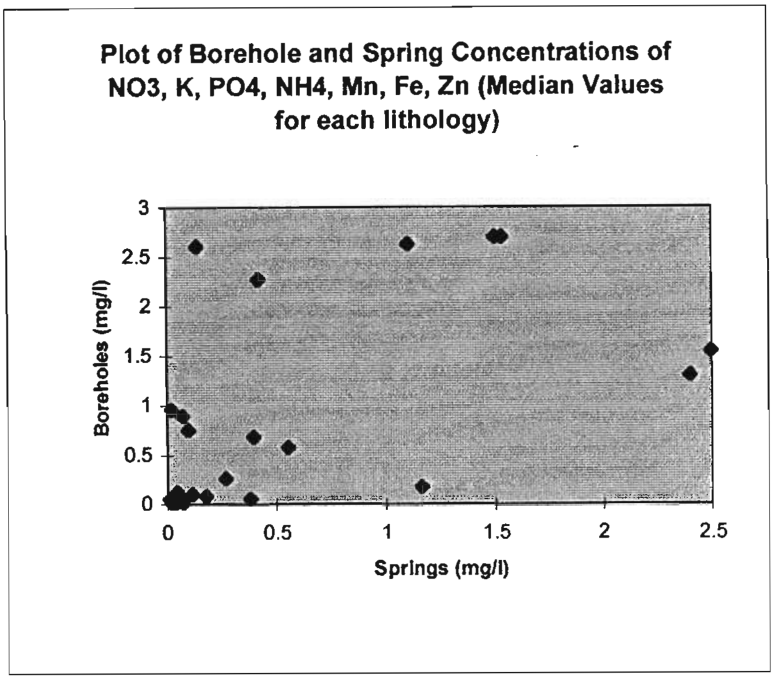


Figure 6.4 Median borehole and spring concentrations are apparently unrelated for anthropogenic pollutants and trace metals.

6.1.2 Umfolozi Area

The lithologies in the Umfolozi area from which both spring and borehole samples were collected and the number of samples are: Dwyka Tillite (springs=1, boreholes=5), Vryheid Formation (springs=11, borehole=11) and Karoo Dolerite (springs=8, boreholes=7). Unlike the Umkomazi samples, the Umfolozi samples do not show a linear relationship between median chemical concentrations in borehole and spring samples. The general trend is for dolerite boreholes and springs to have the lowest chemical concentrations, while Vryheid Formation boreholes have the highest borehole concentrations and Dwyka Tillite springs have the highest spring concentrations. This trend is well represented by electrical conductivity in Figure 6.5 .

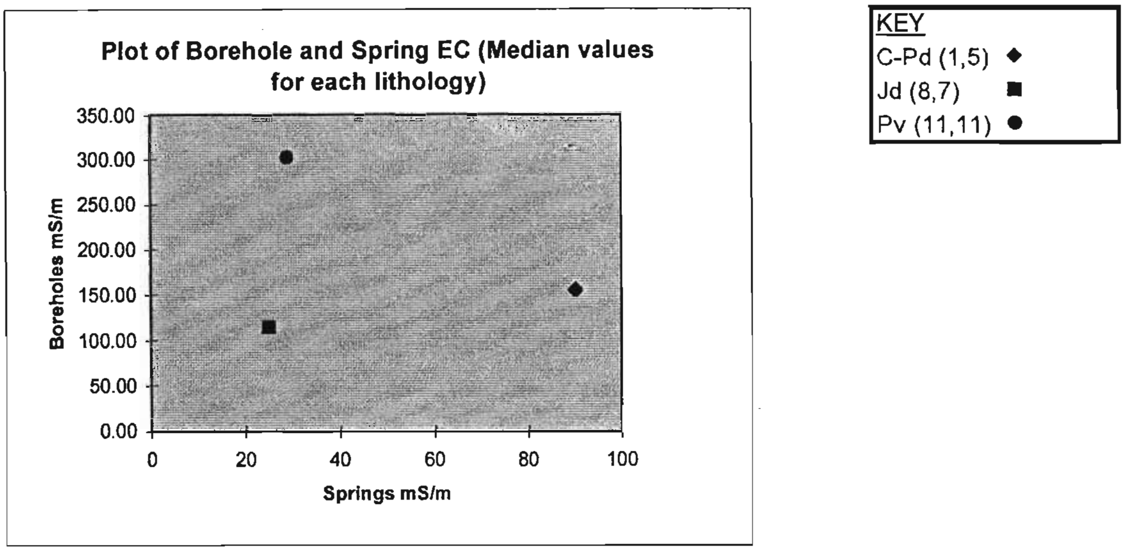


Figure 6.5 Plot of Umfolozi borehole and spring electrical conductivity (EC).

This raises the question of why the highest concentrations are found in borehole samples from the Vryheid Formation, while the highest spring concentrations are found in Dwyka Tillite samples. It may appear that the x co-ordinate of the Dwyka data point (represented by a green diamond) should be discarded as it is only based on one sample. However, when this point is moved laterally in line with the other two points the slope of the best fit line becomes extremely steep, suggesting a much higher borehole/spring ratio than found in the Umkomazi area. The other possibility, of discarding the Vryheid data point (the purple circle) on the basis that Vryheid was not considered in the Umkomazi area, whereas dolerite and Dwyka were, results in a best fit line with a slope less than one. A possible explanation is that the Vryheid Formation is primarily sandstone, and although it has high salinity at depth it weathers to a sandy loam with high permeability and infiltration capacity, while the Dwyka weathers to a clayey loam with lower permeability. Thus the sandy Vryheid soil produces springs with low chemical concentrations, while the clayey Dwyka soil produces springs with high chemical concentration.

6.2 Major Ions

Major ion analysis is routinely carried out on water quality samples. Various graphical methods have been developed for showing trends and patterns of ion concentrations. The Piper diagram, which shows relative abundance of major ions, is one of the most frequently used graphical methods. Stiff diagram reveals characteristic patterns. The Piper and Stiff diagrams given below were plotted with Rockware® software. Additionally, simple scatter graphs are used to illustrate trends between major ions and lithology.

6.2.1 Piper Diagrams: Relative Abundance

Piper (1944) developed a trilinear diagram as a graphical aid in the geochemical interpretation of water-analyses. The Piper diagram is commonly used for determining the source of dissolved constituents in groundwater and the related changes in chemical characteristics which occur as the water passes through different geological units. In order to plot points on the Piper diagram groundwater is considered to have three cation constituents (Mg, Na, and Ca) and three anion constituents (Cl, SO_4, and HCO_3). The concentration of less abundant ions are added to the major ion with which they are most closely associated, e.g. K with Na, NO_3 with Cl and CO_3 with HCO_3. Concentrations given in milligrams per litre are converted to milliequivalents per litre by the following conversion factors: Na: 0.0435; K: 0.02558; Ca: 0.0499; Mg: 0.08229; Cl: 0.02821; CO3: 0.03333; HCO3: 0.01639; SO4: 0.02082. Because the laboratory only provided results for total alkalinity (TAL) and not the separate components of bicarbonate and carbonate, the conversion factor for bicarbonate is used for all carbonate as well as bicarbonate species. In order to plot relative concentrations the milliequivalents per litre are converted to percent milliequivalents per litre. The major cations are plotted on the lower-left triangle, with 100% magnesium at the top vertex, 100% calcium at the lower-left corner and the sum of sodium and potassium at the lower-right corner. The anions are plotted on the lower-right triangle with sulphate at the top, chloride at the lower-right corner and bicarbonate and carbonate at the lower-left corner. Each sample has a point in each of the lower triangles. Lines are extended from the two lower points into the upper diamond field. The intersection of the lines positions the third point. The diameter of circles drawn around the points in the upper diamond field indicates the absolute concentrations of major ions as represented by total dissolved solids.

In general, water samples taken from the same lithology plot in clusters in each of the three fields. Tightly clustered groups indicate chemically uniform groundwater, whereas well spread clusters indicate a dynamic groundwater system. Geological formations in both areas show fairly well spread clusters, largely because of the secondary nature of the aquifers. Due to the fact that groundwater is confined to poorly connected discontinuities it is not chemically uniform through out the geological formation. Other influential factors include the type, abundance and solubility of minerals, rock temperature, the rock-water contact area, fluid pressure and flow velocity. To clearly locate a cluster and evaluate its "hydrochemical finger print" it is desirable to have 10 to 20 samples points of which more than 50% fall within a definable area (Davies Lynn and Partners, 1995 a). Unfortunately numerous groundwater samples were not analysed for several necessary ions, which limits the statistical significance of the Piper diagram analysis. With this in mind, assessment of the Piper diagrams for each lithology is given below.

Basement rocks occur only in the Umkomazi area (Figure 6.6). Sodium is the dominant cation while anion enrichment falls between bicarbonate and chloride. Relative sulphate concentrations are low, particularly for boreholes. Springs show an unexpected increase in sodium and chloride as compared to boreholes, possibly due to the proximity of the Indian Ocean (refer to Section 7).

Natal Group Sandstone samples with ion analysis occur only in the Umkomazi area (Figure 6.7). Similar to the underlying basement rocks, the Natal Group Sandstone shows sodium to be the dominant cation, while anion enrichment is divided between bicarbonate and chloride. Boreholes also show especially low sulphate, perhaps suggesting the Natal Group

Sandstone is hydraulically connected with the underlying basement rocks. Again, springs show greater relative sodium than boreholes.

Dwyka Tillite water samples were taken from boreholes in both areas and from springs in the Umkomazi area (Figure 6.8). Umfolozi samples show a marked increased in total dissolved solids as compared to Umkomazi samples, which is partially explained by a lower mean annual rainfall (refer to Section 7). As usual, springs have lower TDS than boreholes. The samples generally have no cation-anion pair exceeding 50%. In the cation triangle there is a slight trend toward the sodium sector, particularly seen in the Umkomazi samples. The anions show extremely low sulphate, especially among the Umfolozi samples.

Vryheid Formation Sandstone occurred in the Umfolozi area and is represented by both boreholes and springs (Figure 6.9). Of note is the very high TDS values. Cation enrichment tends towards the sodium sector with several samples falling in the no dominant cation region. Anion enrichment is spread between bicarbonate and chloride, with a trend toward the later. Once again, sulphates are particularly low for borehole samples.

Karoo Dolerite intrusions occur in both study areas and provide both borehole and spring water sources (Figure 6.10). Due to the variety of location and sources the clusters are fairly wide spread. The Umkomazi samples and the Umfolozi springs tend towards sodium enrichment, while the Umfolozi boreholes have relatively more magnesium, grouping them in the no-dominant sector. Anion enrichment is spread between the chloride and bicarbonate sectors, with Umfolozi samples having especially low sulphate concentrations.

In conclusion, due to the interconnected nature of the aquifers and the dynamic characteristics of the chemical concentrations it is difficult to identify the lithology of a sample based on its position on a Piper diagram. However, there are distinguishable differences between the position of Umkomazi samples and Umfolozi samples on Piper diagrams. The Umkomazi area shows a relatively tight cation cluster in the sodium sector, as compared to the well spread cluster in the Umfolozi area, which stretches up to the magnesium sector. The anions from both areas show spread between bicarbonate and chloride enrichment, however, the Umfolozi samples have notably low sulphate concentrations. Further, as indicated by the circles, the Umfolozi samples have higher TDS (Figures 6.11 and 6.12).

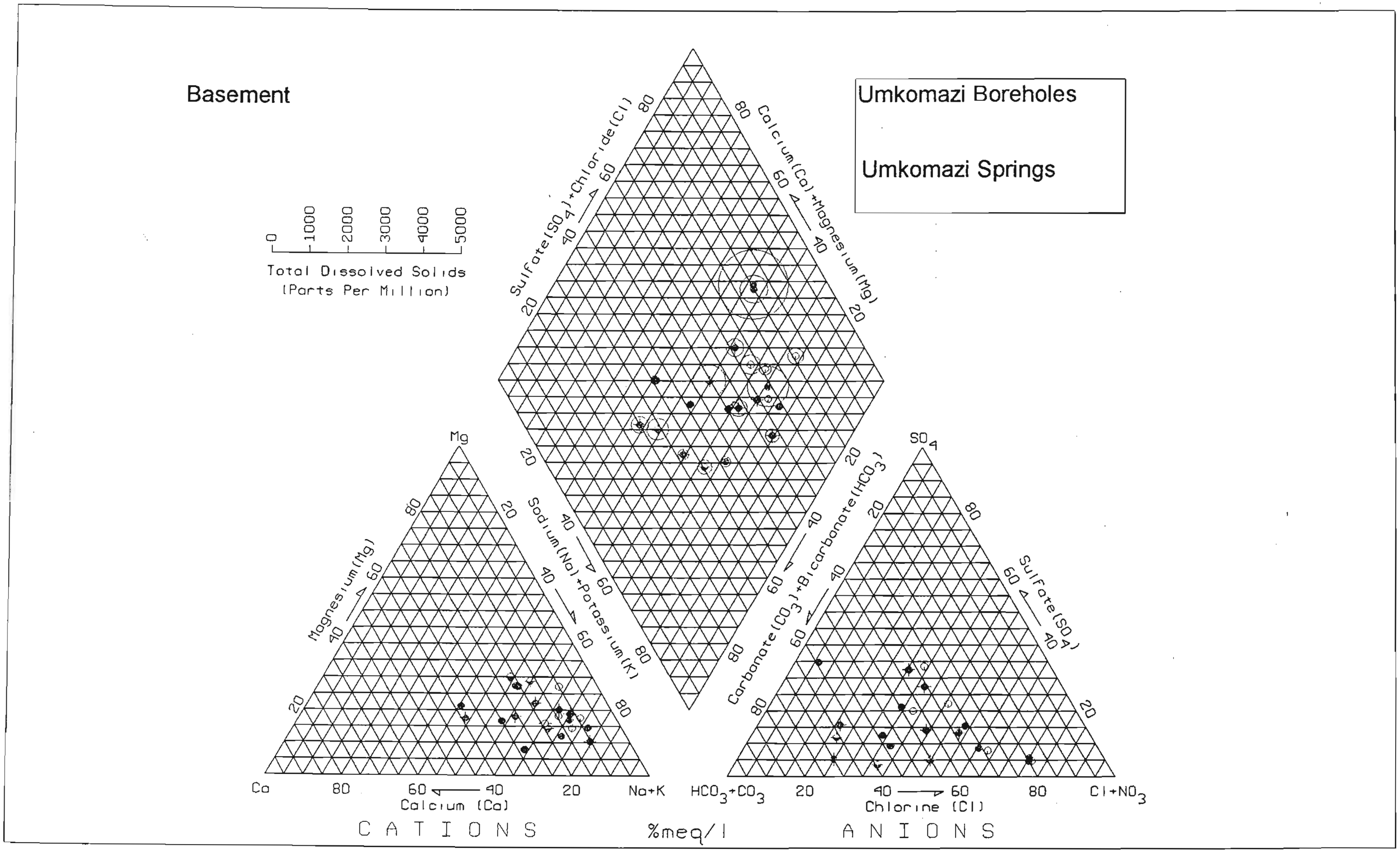


Figure 6.6 Piper Diagram, Basement Rocks

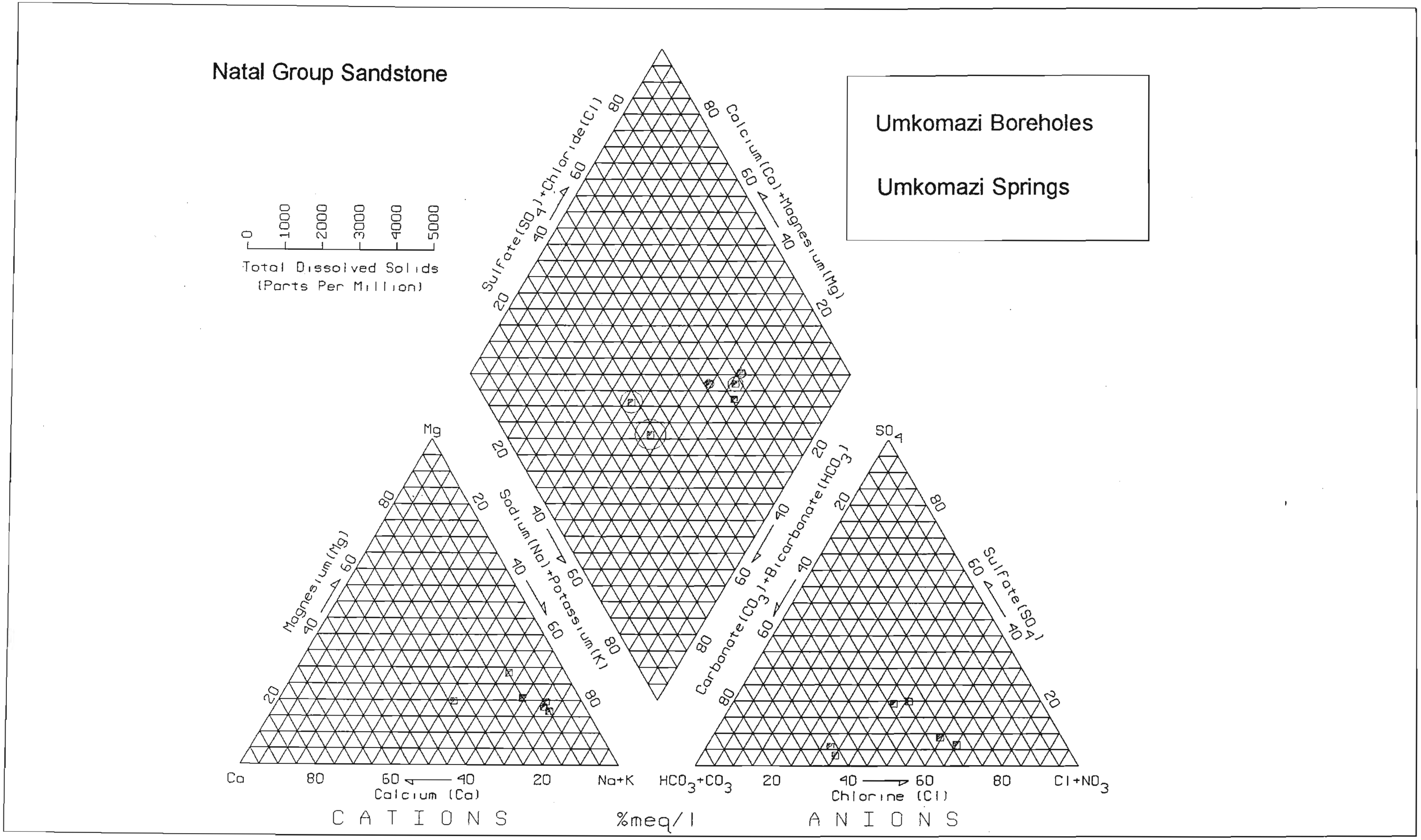


Figure 6.7 Piper Diagram, Natal Group Sandstone.

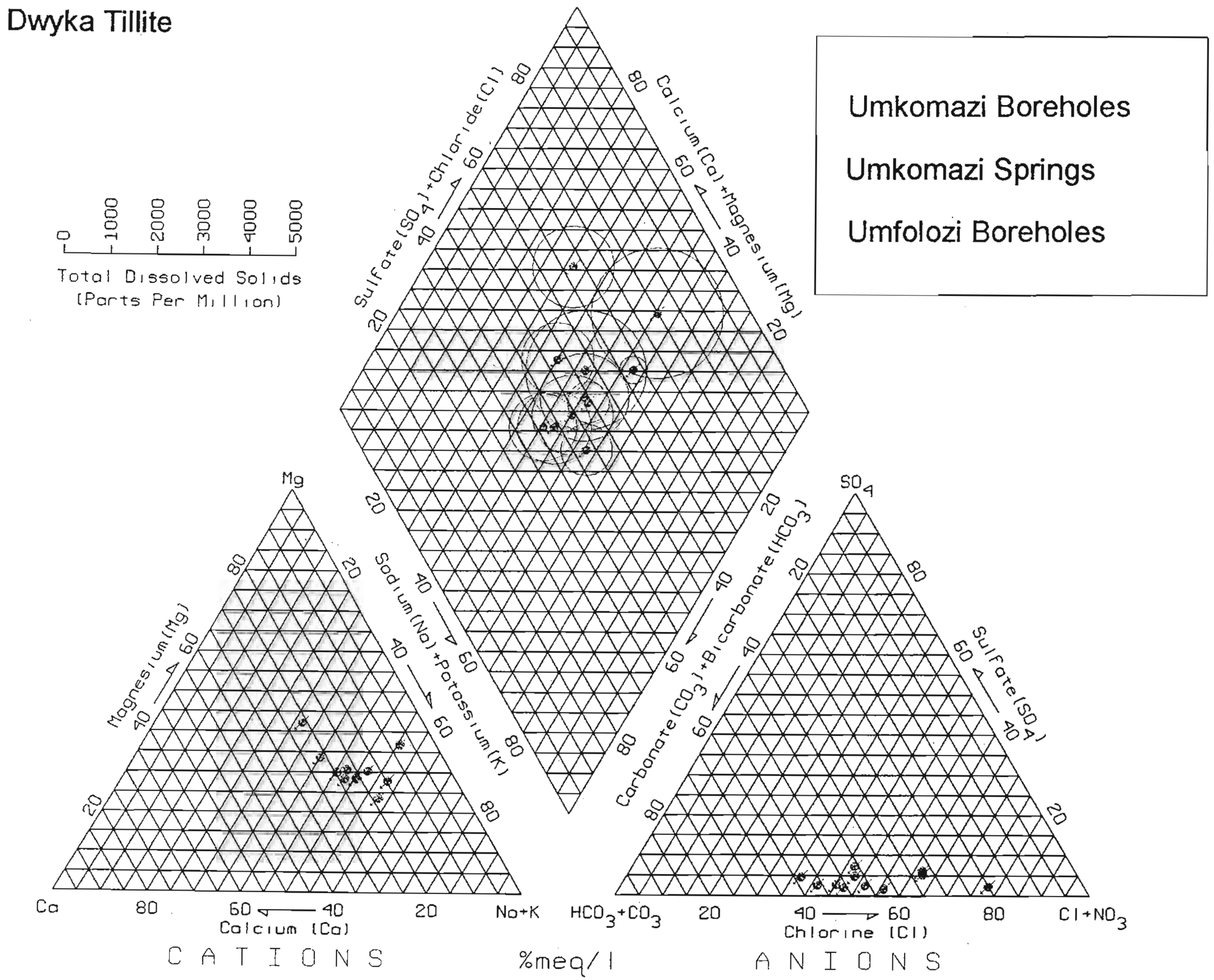


Figure 6.8 Piper Diagram, Dwyka Tillite.

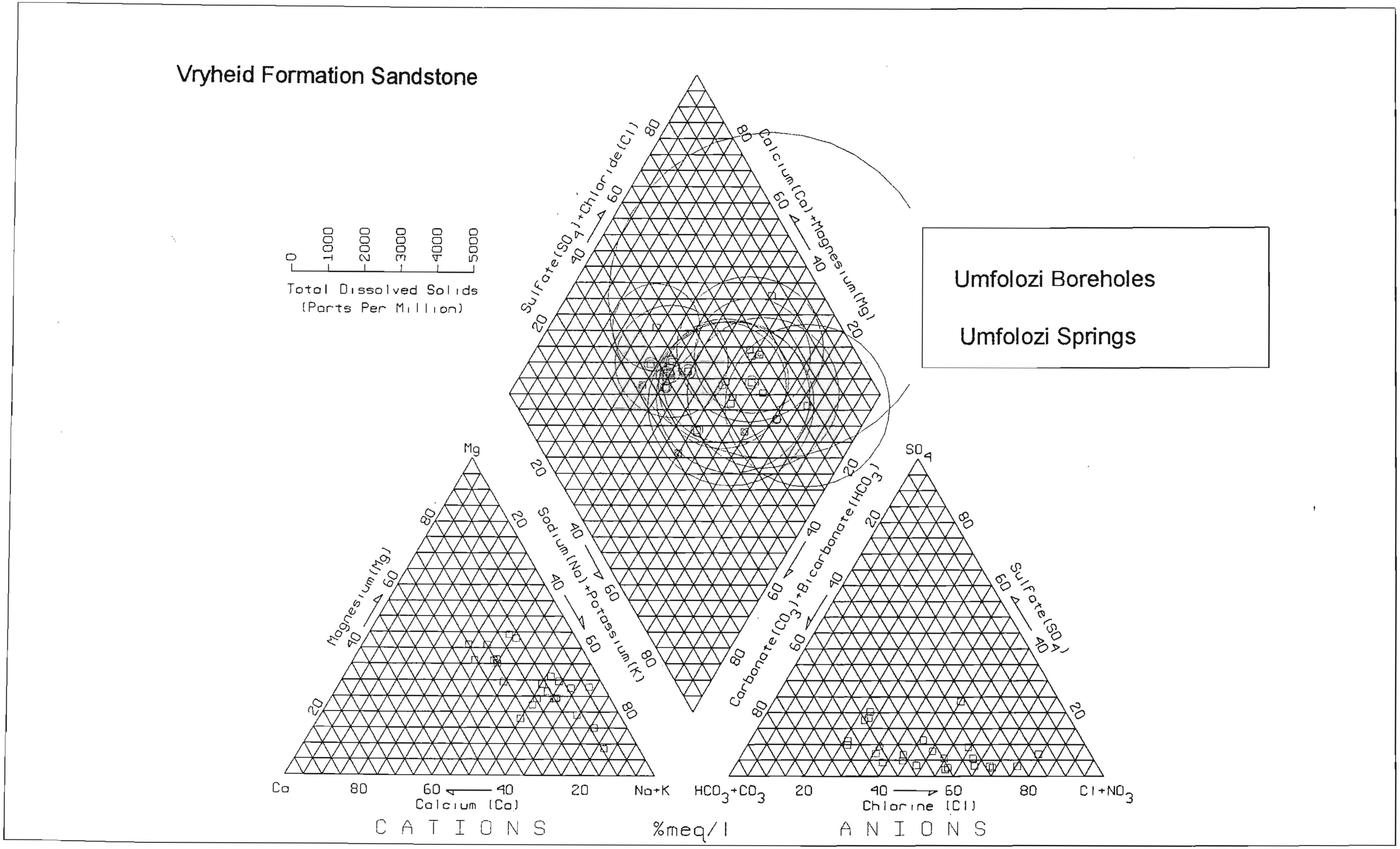


Figure 6.9 Piper Diagram, Vryheid Formation Sandstone.

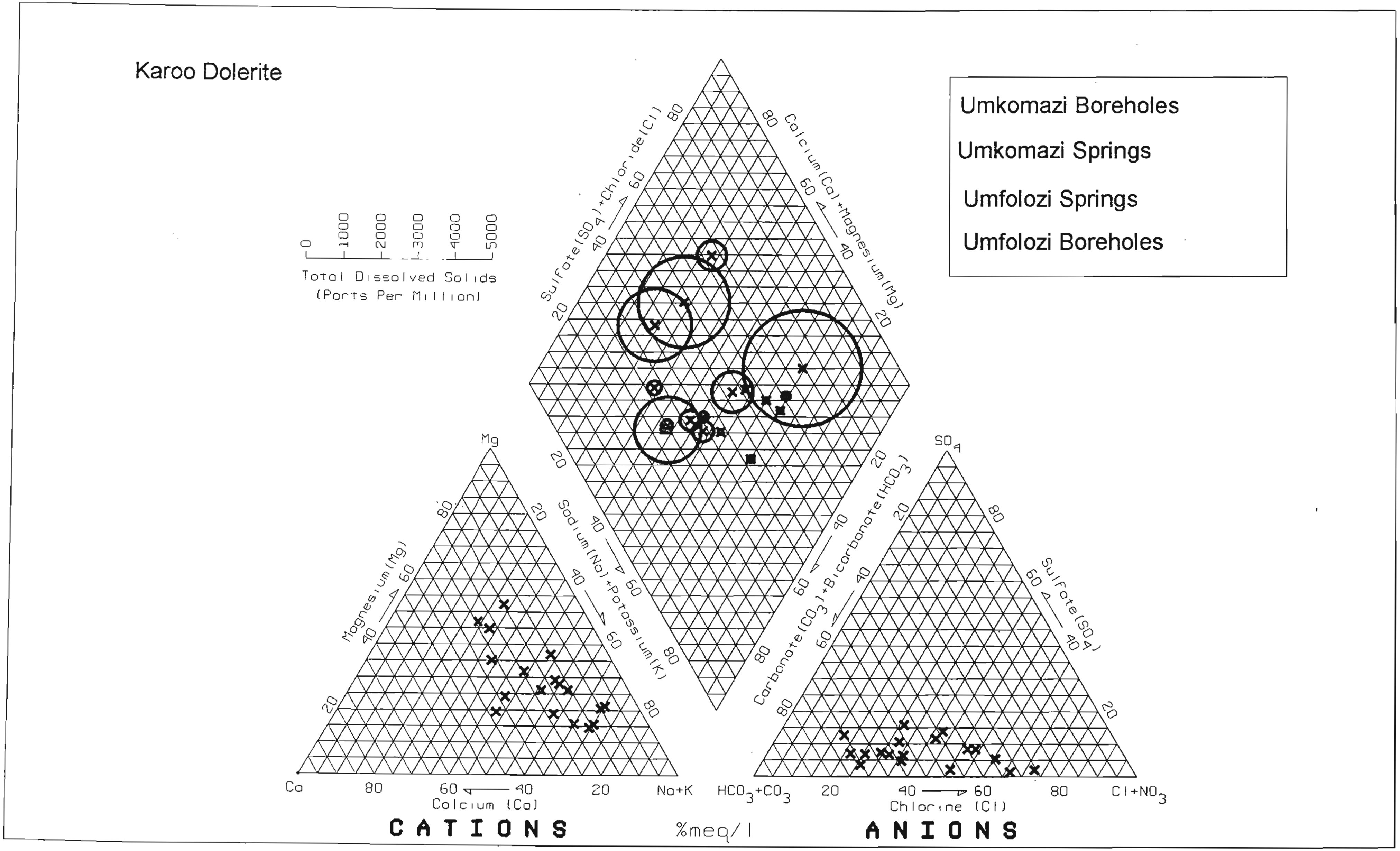


Figure 6.10 Piper Diagram, Karoo Dolerite.

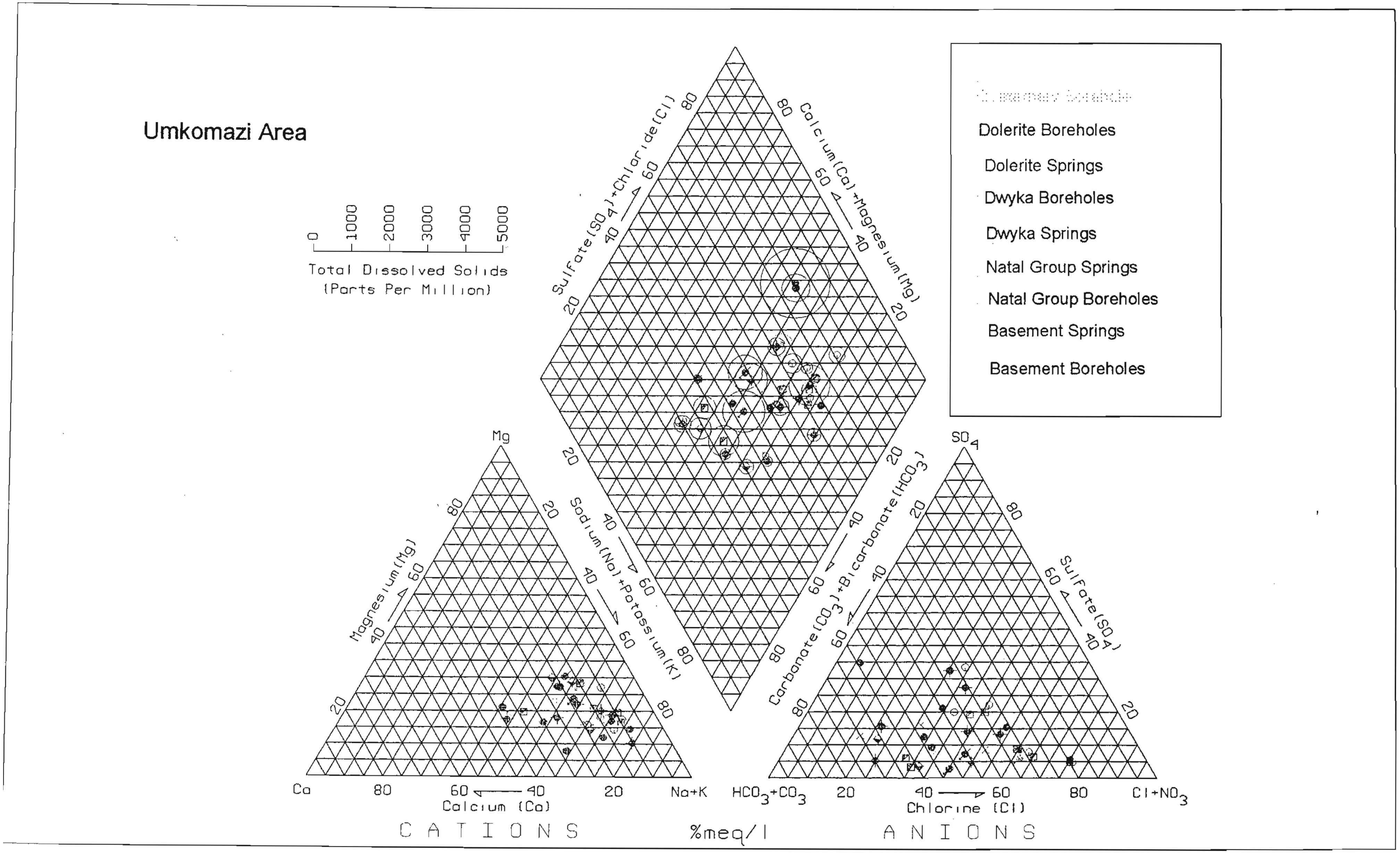


Figure 6.11 Piper Diagram, Umkomazi Area.

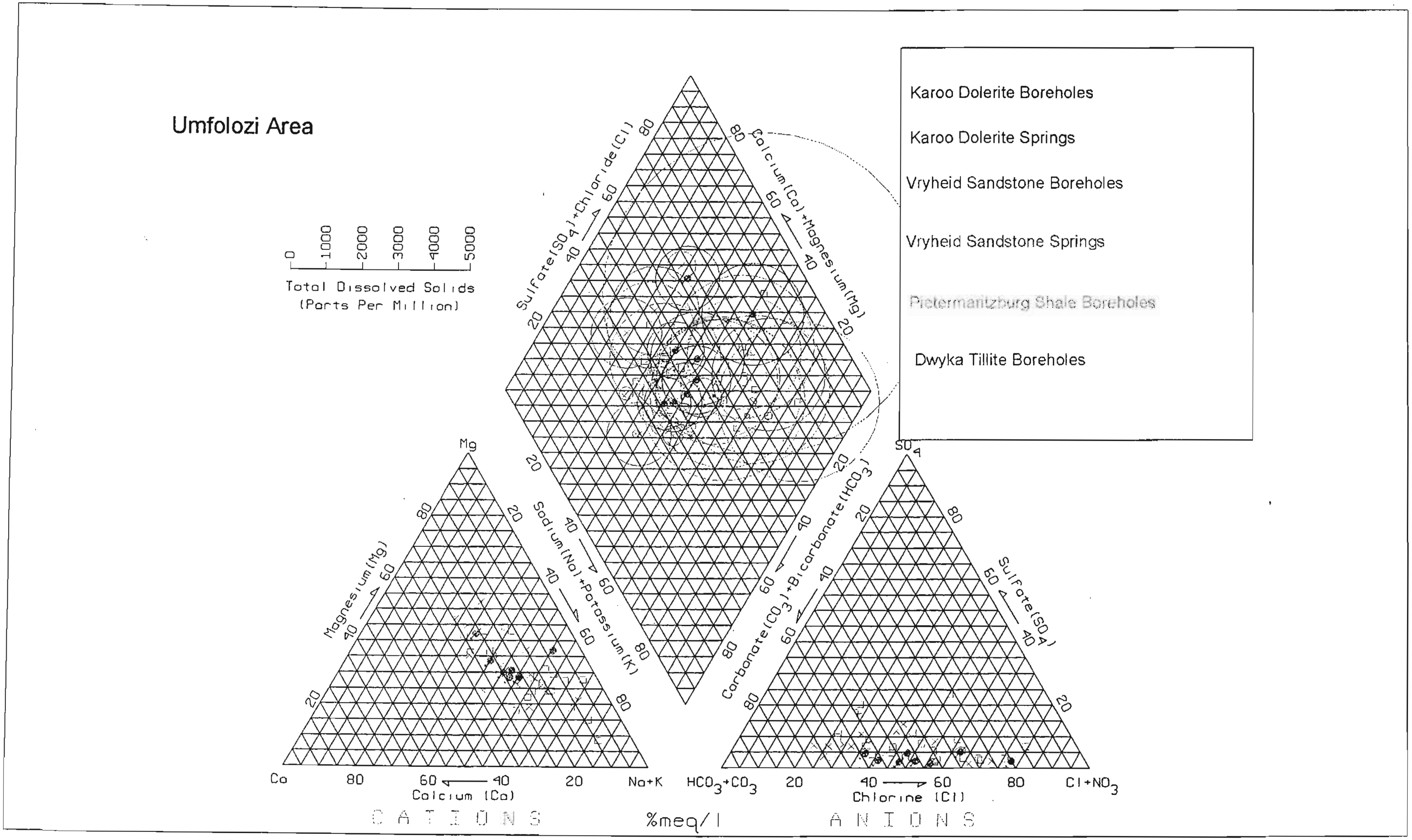


Figure 6.12 Piper Diagram, Umfolozi Area.

6.2.2 Stiff Diagrams: Characteristic Patterns

Stiff (1953) developed a means of interpreting chemical water analysis through use of characteristic patterns. Like the Piper diagram, the Stiff diagram groups the major ions into cations and anions and further subdivides the cations into sodium (Na+) plus Potassium (K^+), calcium (Ca^{++}), and magnesium (Mg^{++}), while the anions are divided into bicarbonate (HCO_3^-) plus carbonate (CO_3^-), sulphate (SO_4^-), and chloride (Cl^-). Each sample is represented by a polygon constructed of six points jointed together by lines. The three cation points lie to the left of the middle line, while the three anion points lie to the right of the middle line. Theoretically, each geological unit will produce a polygon of a characteristic shape which can be recognised at a glance. Also, theoretically, the effects of dilution and concentration should have minimal effect on the shapes of the polygons, though they are reflected in the relative size of the polygons. In practice, there is a fair amount of shape variation among samples from the same lithology for similar reasons that the Piper diagrams show variation. A Stiff diagram is presented for each sample with major ion results. Samples are separated by study area, lithology and source type.

In the **Umkomazi Area** Stiff diagrams of **Basement** samples from boreholes show that at low TDS levels relative concentrations of major ions are fairly well balanced (except for sulphates which are consistently very low), representing recently recharged water, while at higher concentrations, e.g. sample ZQCZMKH3B, the sodium and chloride points create dominant spikes indicating more stagnant groundwater (Figure 6.13). Spring samples show very low TDS and few spikes. An exception is spring sample ZQCZBHEIF, which shows relatively high concentrations and the development of sodium and chloride peaks. This illustrates the difficulties of establishing groundwater finger prints and suggests that Stiff patterns do change with dilution and concentration.

Natal Group Sandstone is represented by a variety of shapes, both in borehole and spring samples (Figure 6.14). The samples with the lowest concentrations create vertical polygons, whereas those with higher concentrations tend toward horizontal polygons with sodium dominating the cation side and while either chloride or bicarbonate dominate the anion side.

The two borehole samples and single spring sample from **Dwyka Tillite** are all horizontal polygons (Figure 6.15). Sulphate is consistently low. Anions are enriched in approximately equal amounts of chloride and bicarbonate. On the cation side, samples show the least amount of calcium, followed by a small peak of magnesium and a slightly longer spike of sodium.

The three **Karoo Dolerite** samples (two boreholes and a spring) show vertical to round polygons as expected from their low TDS values. The single **Quaternary** sample shows a dominance of bicarbonate and sodium. It is likely that this borehole penetrated into the bedrock below the Quaternary aquifer.

The **Dwyka Tillite** samples from the **Umfolozi area** show similar Stiff patterns to the Dwyka samples from the Umkomazi area. However, the Umfolozi samples contain higher TDS and thus show greater horizontal elongation. The greater TDS is probably due to a low mean annual rain fall in the Umfolozi area. On the anion side sulphates are extremely low while chloride provides a slightly greater peak than bicarbonate. On the cation side sodium is generally slightly greater than magnesium, while calcium is lowest causing an indent in the polygon pattern. The samples taken from reticulated systems, as expected, show similar major ion trends as the boreholes. Though sample ZQCZNCE1S does show relatively high TDS and likewise elongation (Figure 6.16).

Vryheid Formation boreholes show greatly elongated sodium and chloride spikes, with a shorter, secondary magnesium spike (Figure 6.17). These samples provide the most uniform patterns and likewise the clearest finger print. Even sample ZQCZLOM1B, which has much greater TDS than the other samples shows the same pattern. However sample with low TDS e.g. ZQCZBHE1B and ZQCZMAT1B, show round to vertical polygons, suggesting recent recharge water. These boreholes likely intercept a high permeability discontinuity such as a fracture or fault. Stiff patterns of Vryheid springs show a striking contrast to the Vryheid boreholes (Figure 6.18).

Spring samples have low TDS and vertical to round polygon shapes, suggesting recently recharged water. Bicarbonate is frequently the dominant anion. Reticulated samples show similar trends to boreholes (Figure 6.19).

Dolerite boreholes generally have higher TDS than their Umkomazi counterparts, once again probably due to a lower mean annual rain fall, and thus show a fair amount of horizontal elongation (Figure 6.20). Sodium and chloride form the dominant peaks for sample ZQCZNDL1B, which has the highest TDS. Magnesium and bicarbonate are relatively high for other samples, suggesting more recent recharge. Umfolozi springs show Stiff polygons that are generally vertical to round and have lower TDS than corresponding boreholes (Figure 6.21). Exceptions occur for samples with higher TDS.

The two borehole samples from **Pietermaritzburg Formation** show very similar patterns, though they are characteristic of most samples with low TDS Sulphates are extremely low, while bicarbonate dominates the anions. On the cation side sodium is slightly higher than magnesium, followed by calcium.

In conclusion, it was found that samples with higher TDS values tend to develop horizontally elongated sodium and chloride spikes, while more recently recharged samples, such as springs or those intercepting major discontinuities, show vertical to round polygons. Sulphates were notably low in all samples, while sodium and bicarbonate dominated the anions. Cations were most frequently dominated by sodium, followed by magnesium and then calcium. With the exception of Vryheid Formation boreholes it was difficult to assign a single finger print to a particular geological unit. This is due to the heterogeneous nature of the secondary aquifers in the study areas.

Umkomazi Boreholes and Springs (Basement)

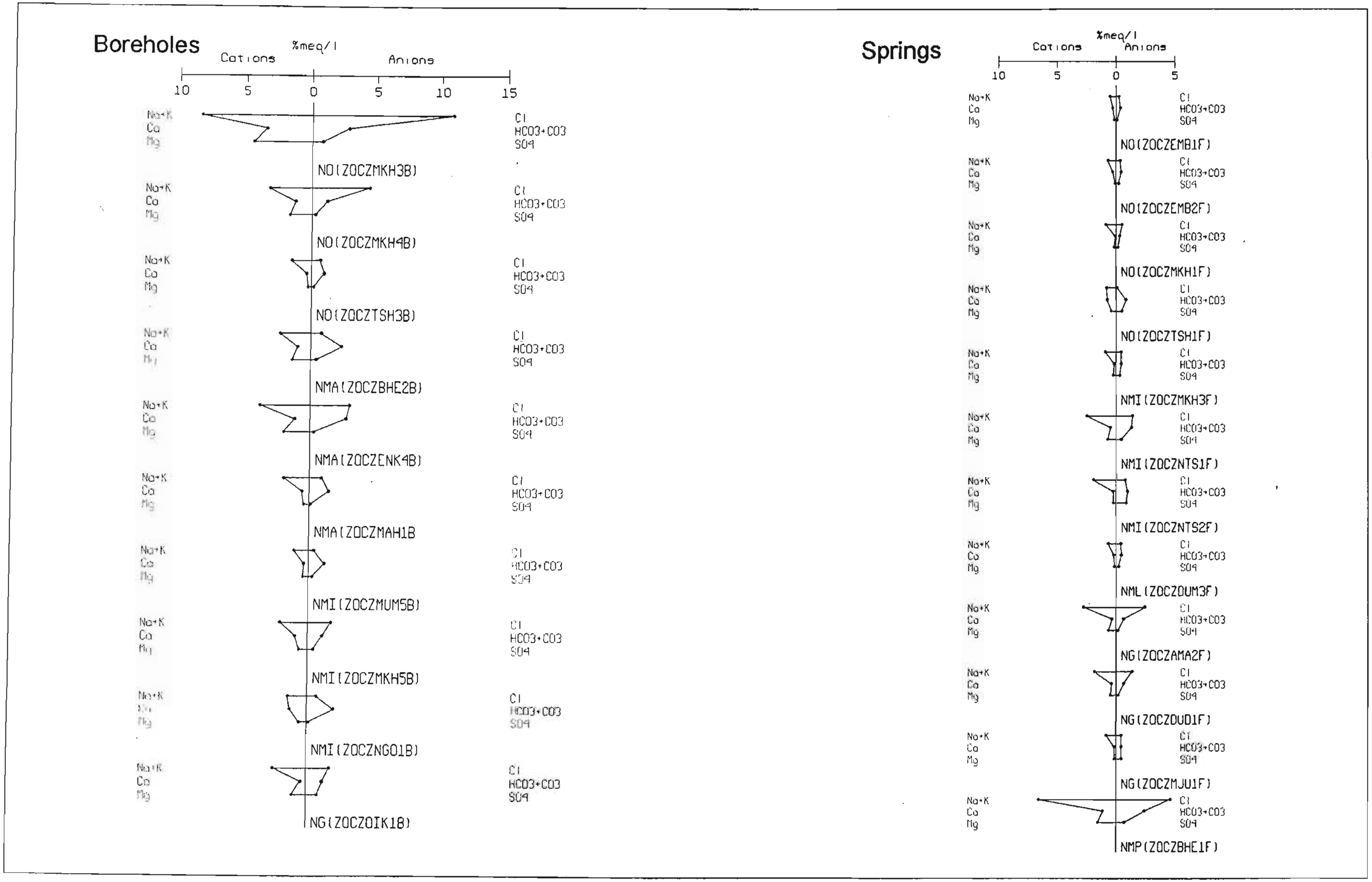
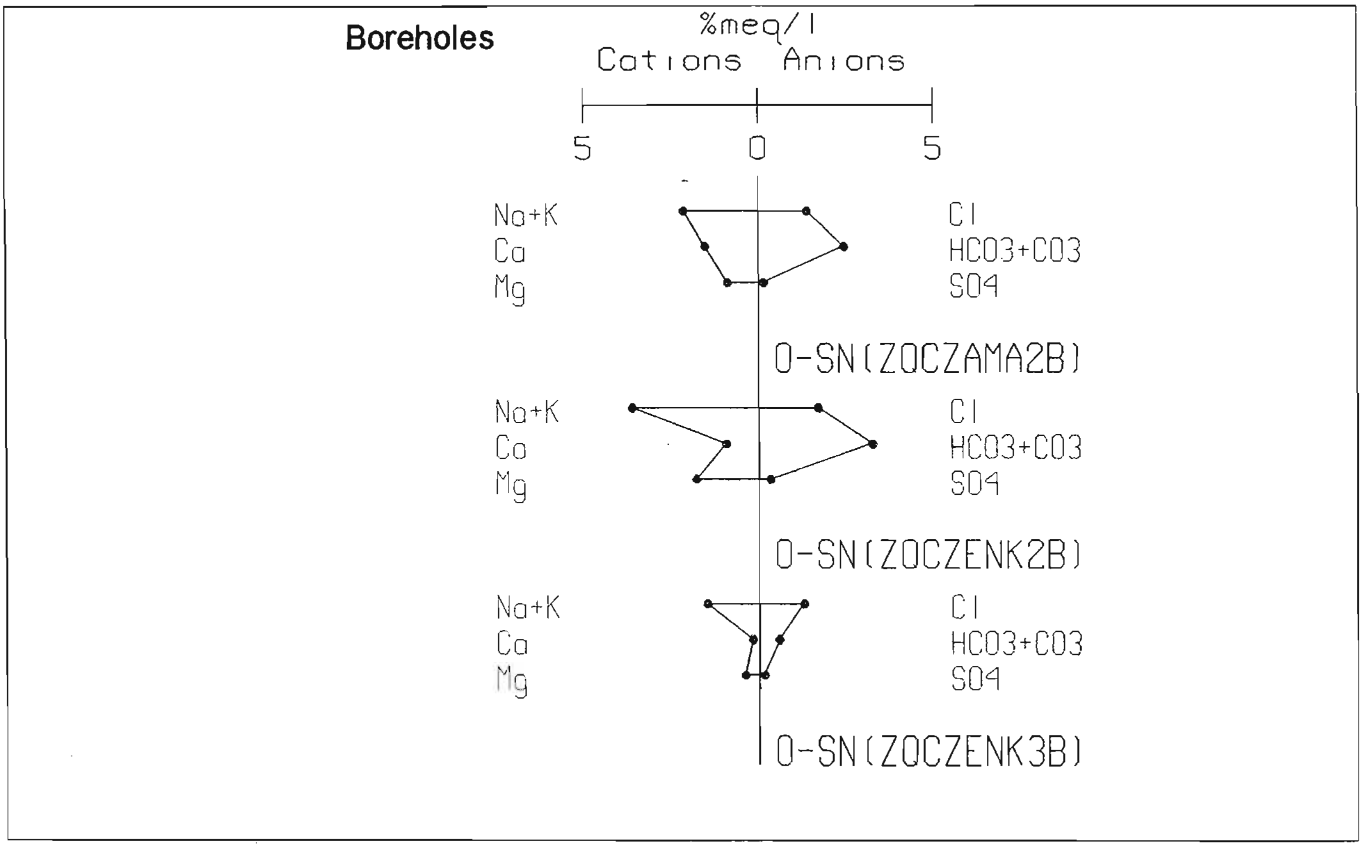


Figure 6.13 Stiff Diagram, Umkomazi Boreholes and Springs (Basement).

Umkomazi Boreholes and Springs (Natal Group)



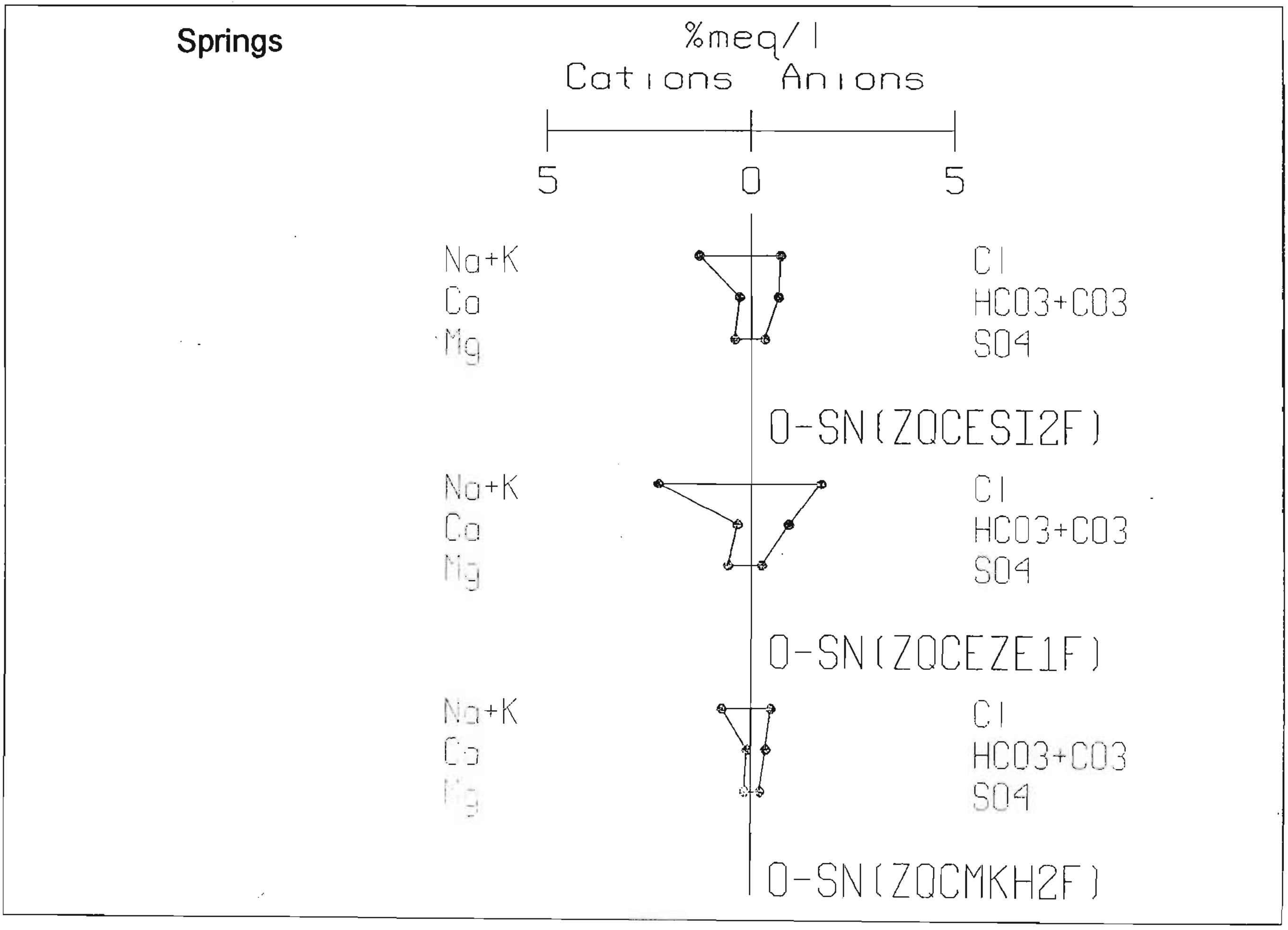
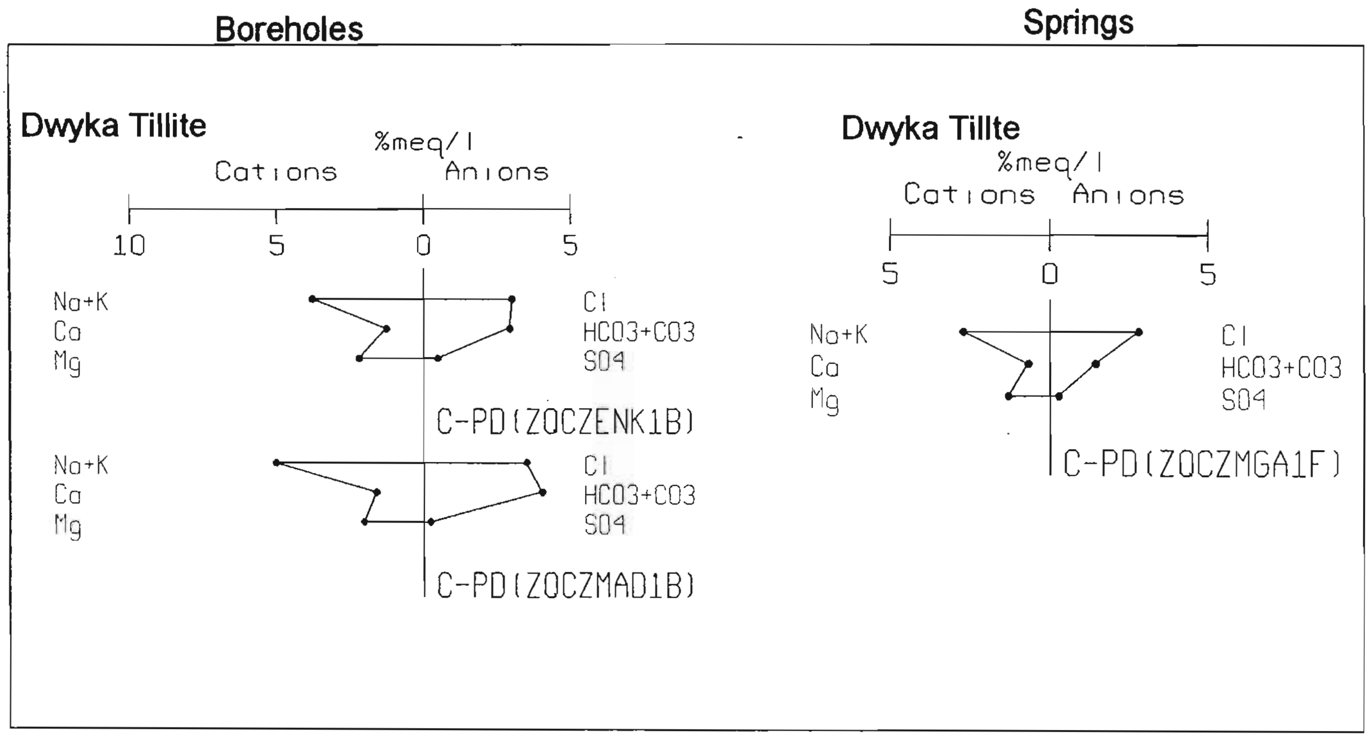
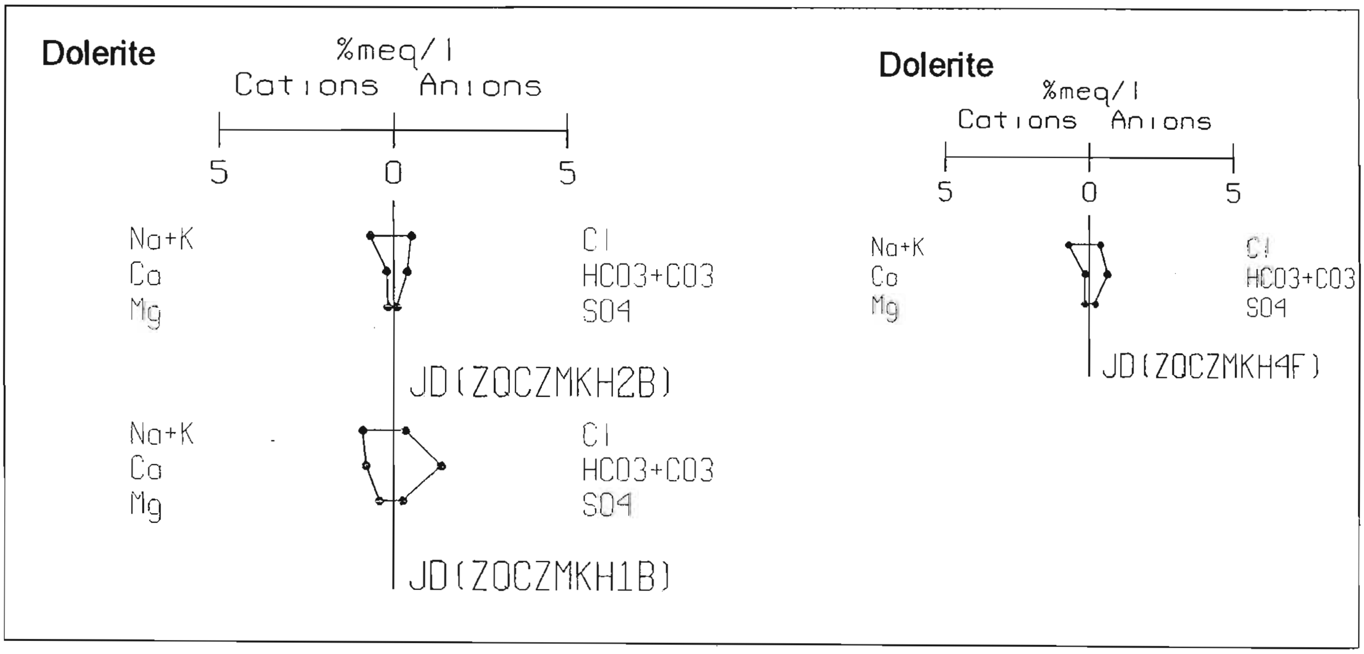


Figure 6.14 Stiff Diagram, Umkomazi Boreholes and Springs (Natal Group).

Umkomazi Boreholes and Springs (Dwyka, Dolerite, Quaternary)





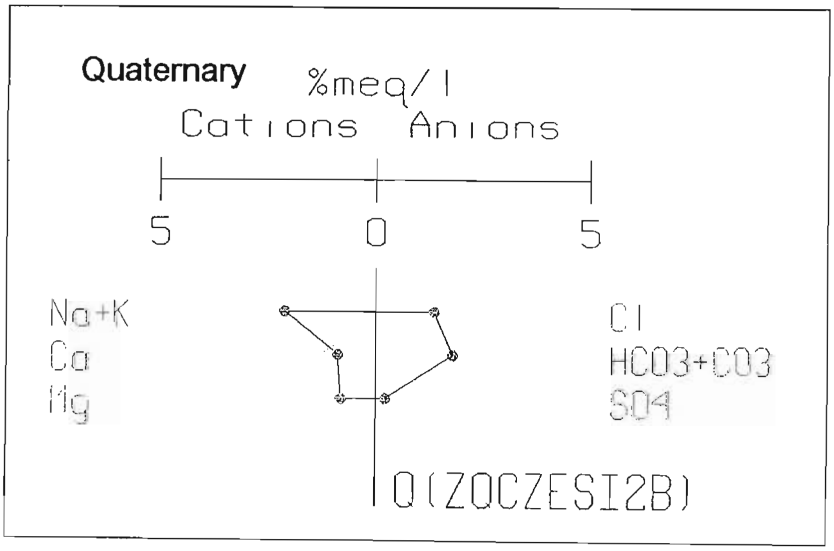


Figure 6.15 Stiff Diagram, Umkomazi Boreholes and Springs (Dwyka, dolerite, Quaternary).

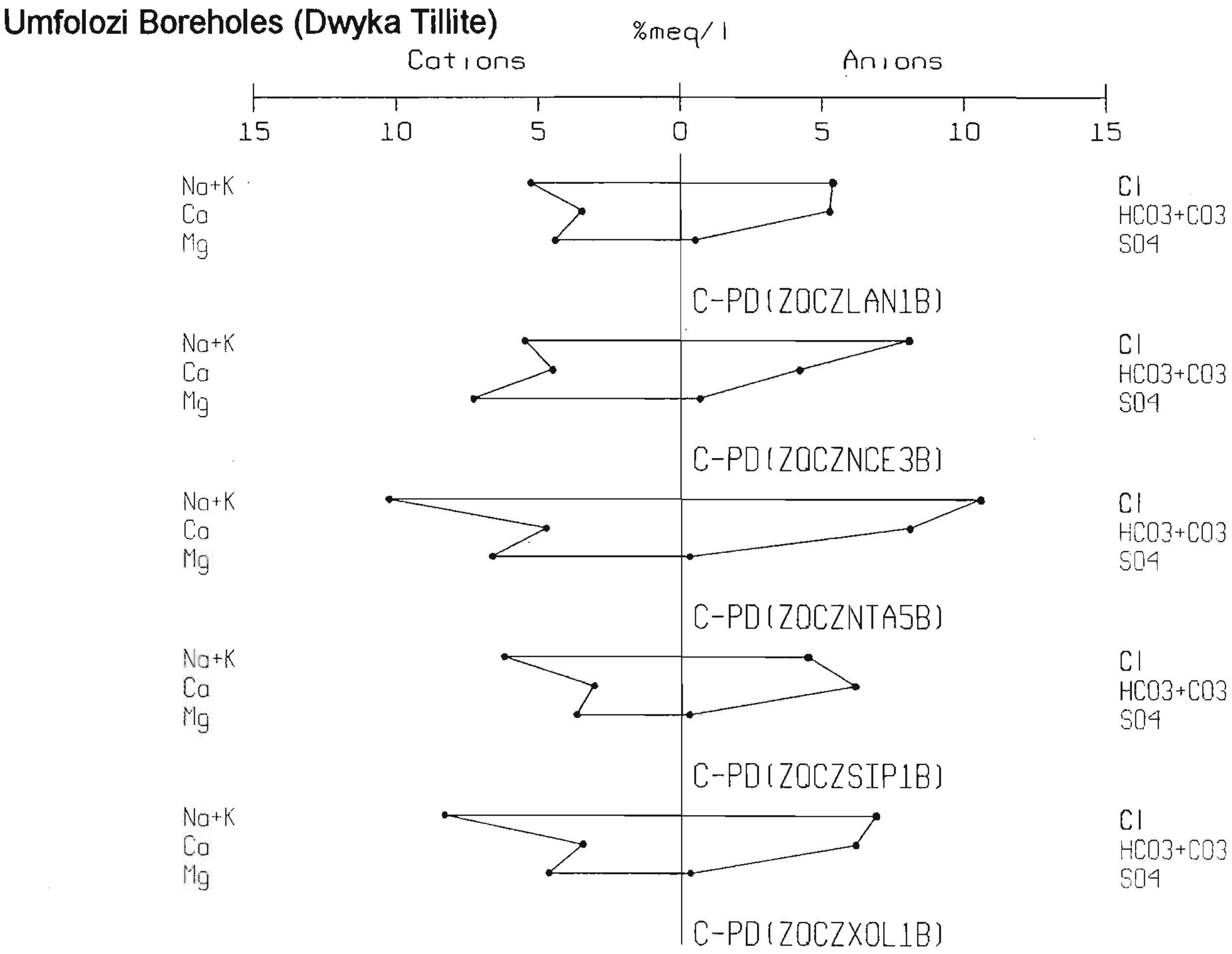


Figure 6.16 Stiff Diagram, Umfolozi Boreholes (Dwyka Tillite).

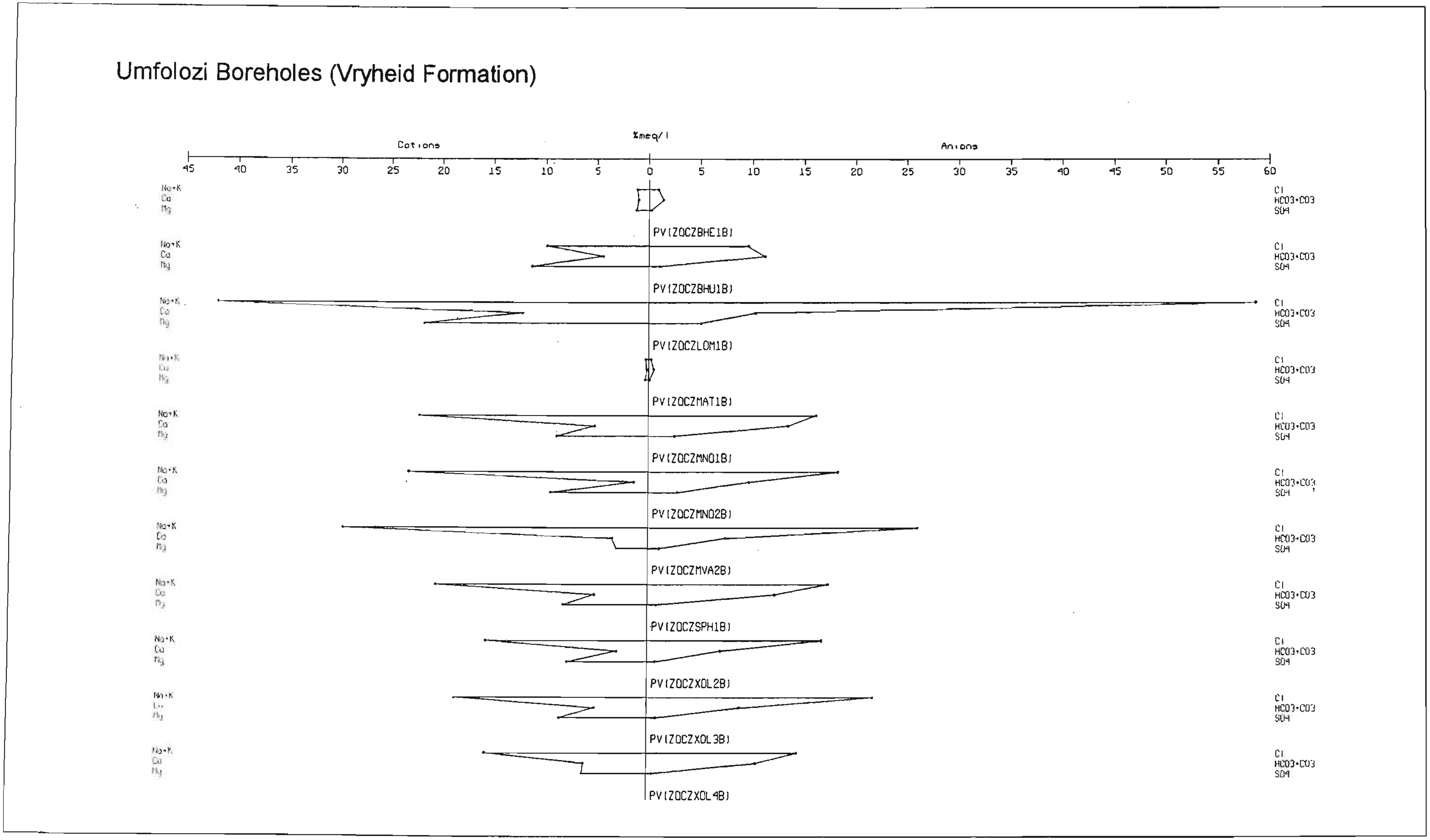


Figure 6.17 Stiff Diagram, Umfolozi Boreholes (Vryheid Formation).

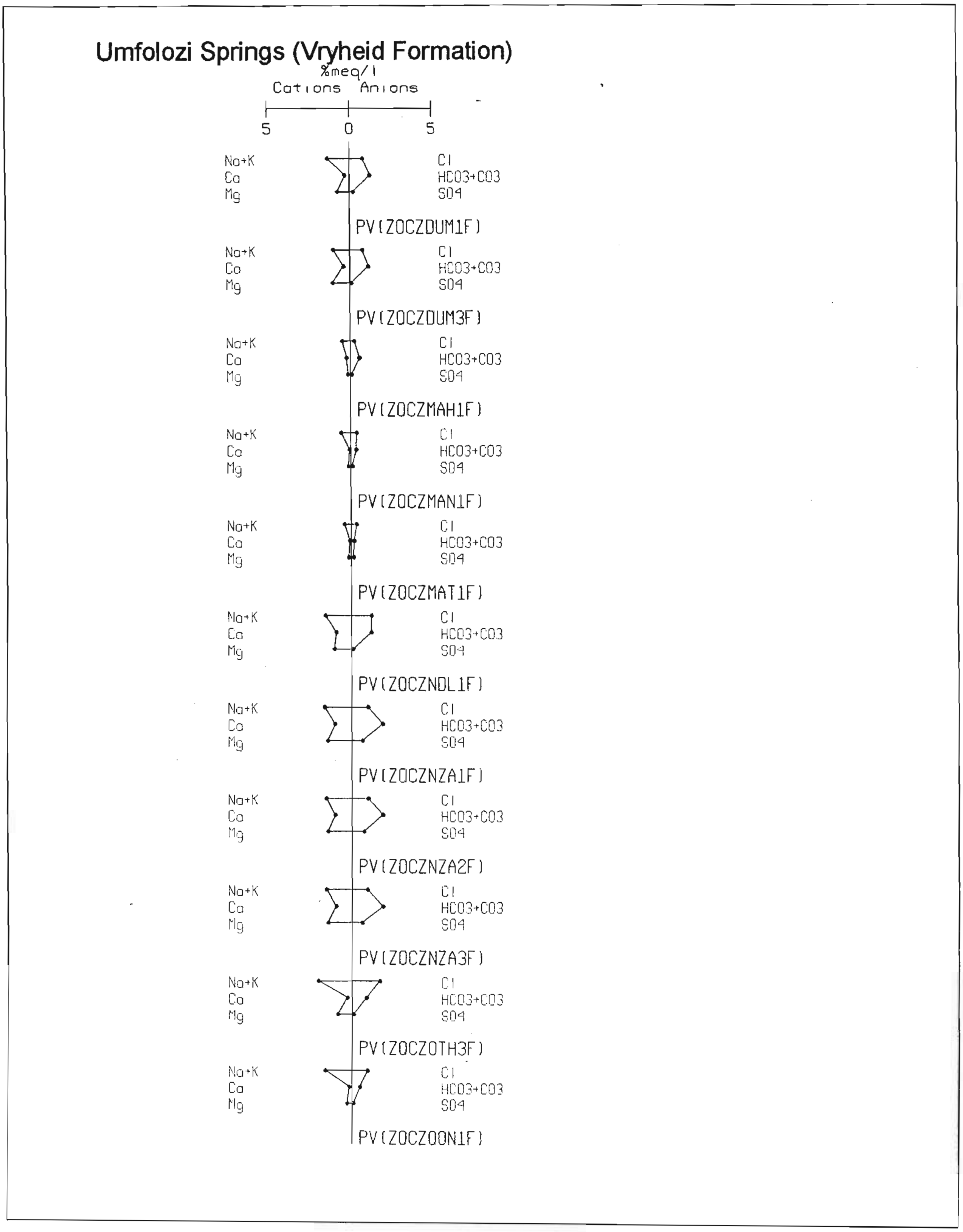


Figure 6.18 Stiff Diagram, Umfolozi Springs (Vryheid Formation).

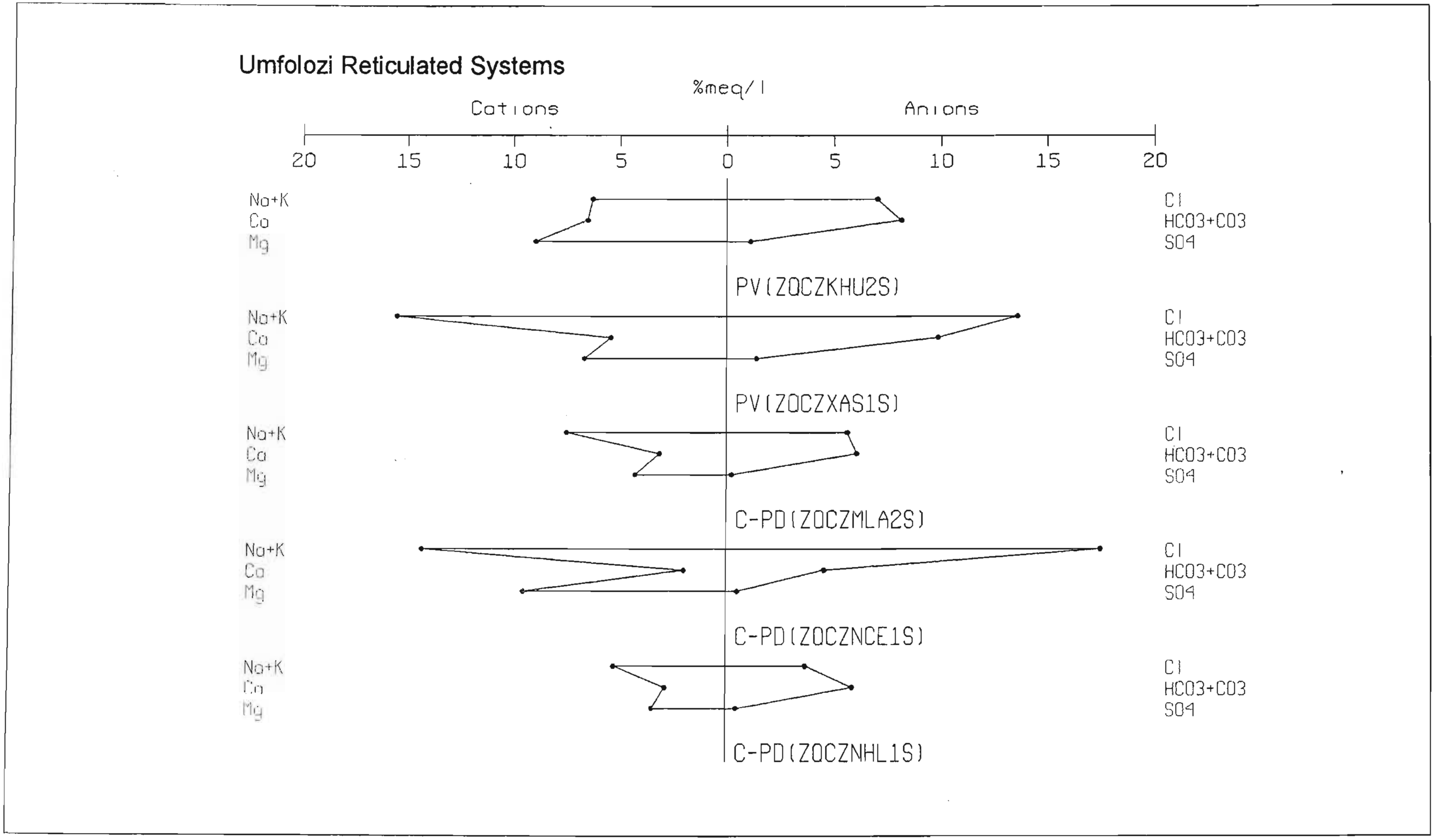


Figure 6.19 Stiff Diagram, Umfolozi Reticulated Systems (Vryheid Formation, Dwyka Formation).

Umfolozi Boreholes (Dolerite)

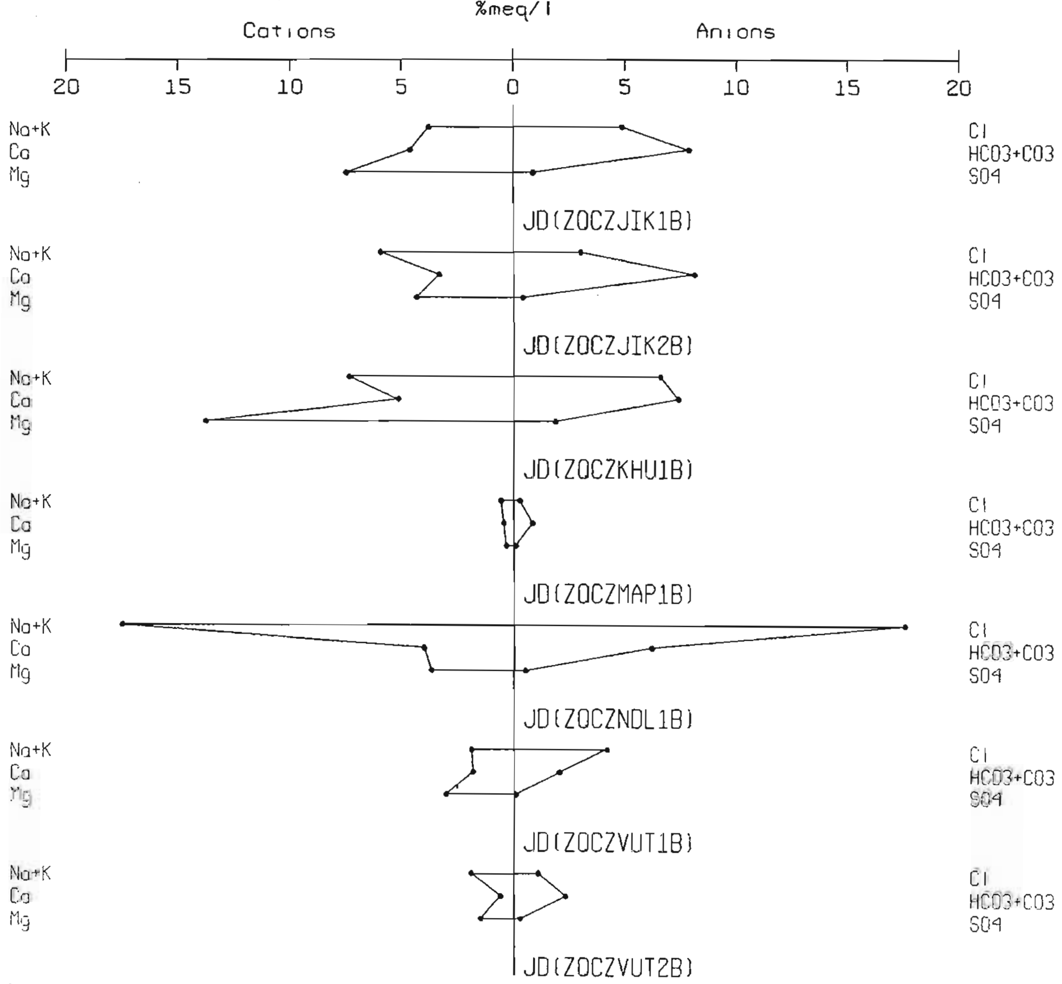


Figure 6.20 Stiff Diagram, Umfolozi Boreholes (Dolerite).

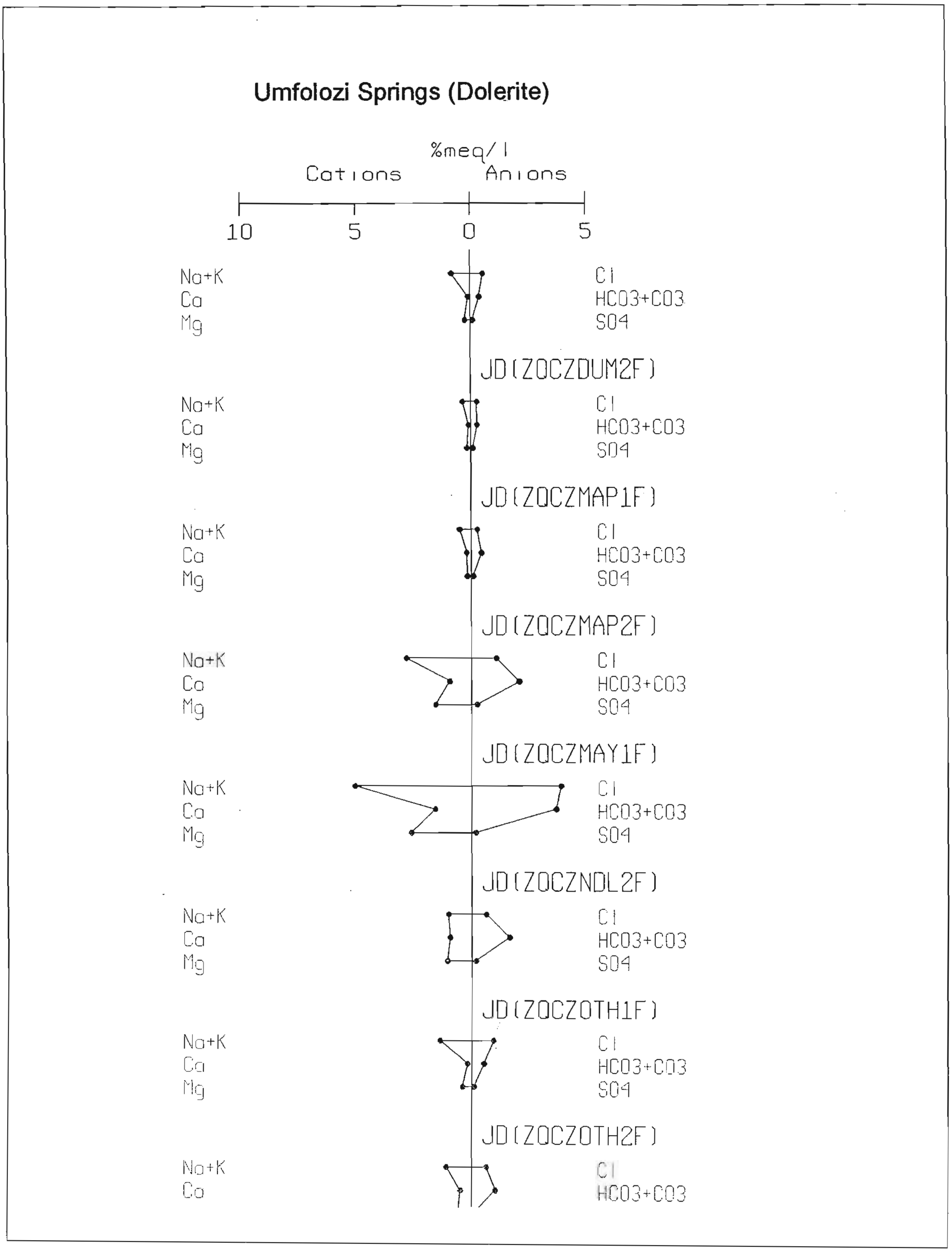

Umfolozi Springs (Dolerite)

Figure 6.21 Stiff Diagram, Umfolozi Springs (Dolerite)

6.2.3 Milliequivalent Scatter Diagrams: Trend Analysis

Significant trends which were visible on the Piper and Stiff diagrams were further analysed in absolute terms by plotting the samples as milliequivalents per litre on X-Y scatter diagrams. Although samples plot with wide scatter, as indicated by very low R^2 values, best fit lines show the general relationship between variables. R^2 is the accepted value for expressing best fit lines in statistics and is calculated automatically by Excel® software following a programmed equation. If the reader is interested in R values these can be calculated by taking the square root of R^2.

As seen from the Piper and Stiff diagrams, sulphates were very low among the anions, while enrichment was divided between bicarbonate and chloride. Figure 6.22 shows bicarbonate species (as total alkalinity) versus chloride for springs in both study areas. The general trend is for total alkalinity (TAL) to increase with chloride. Umkomazi springs have a lower TAL to chloride ratio than Umfolozi springs. This is possibly due to the salt laden winds off the nearby Indian Ocean which may result in relatively high soil salinity in the Umkomazi area.

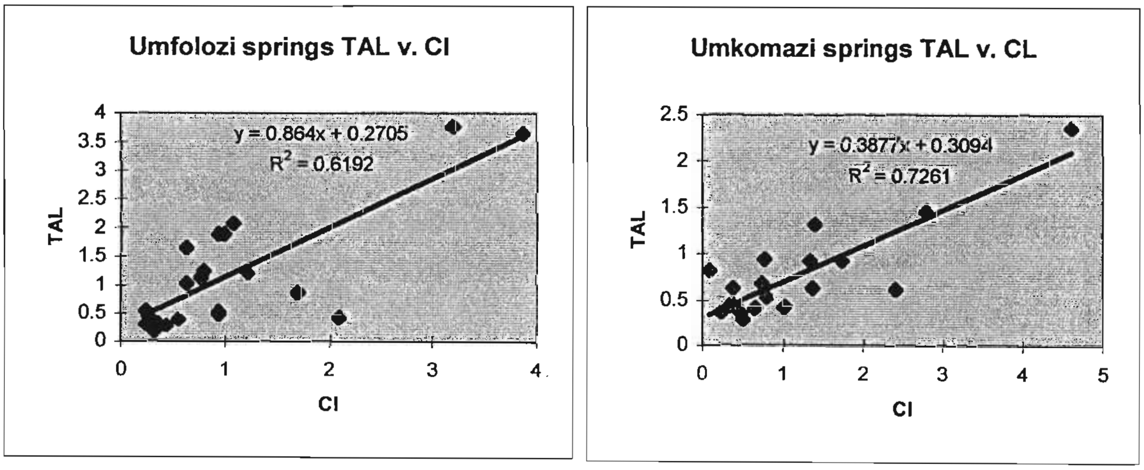


Figure 6.22 Bicarbonate species versus chloride. Umkomazi springs have a lower TAL to chloride ratio.

One of the more interesting trends among the cations is the enrichment of sodium plus potassium compared to the enrichment of magnesium plus calcium (Figure 6.23). In the Umfolozi area springs have a higher Ca+Mg to

Na+K ratio than corresponding boreholes. This suggests that as groundwater flows through the soil it picks up calcium and magnesium ions from the clays. Once the water enters the bed rock it becomes primarily enriched in sodium and potassium ions through dissolution of the host rock. The groundwater continues to dissolve calcium and magnesium, though at a relatively slower rate than in the soil. The scenario is reversed in the Umkomazi area where boreholes show a relative increase in calcium and magnesium as compared to sodium and potassium. Once again, this may be a result of increased soil salinity near the Indian Ocean.

As discussed in Section 5, relatively high sodium and chloride concentrations have been attributed to salt laden winds by Bond (1946), Van Wyk (1963) and Drennan Maud and Partners (1995 a). Further, Kienzle (1993) examined the role of atmospheric salt input in South African river catchments near the ocean. Kienzle concluded that catchments situated relatively close to the coast (50 - 70 km) and with high precipitation have a mean annual salt input of between 150 and 250 kg per ha, while inland catchments with low precipitation have a salt input of only 40 to 80 kg per ha.

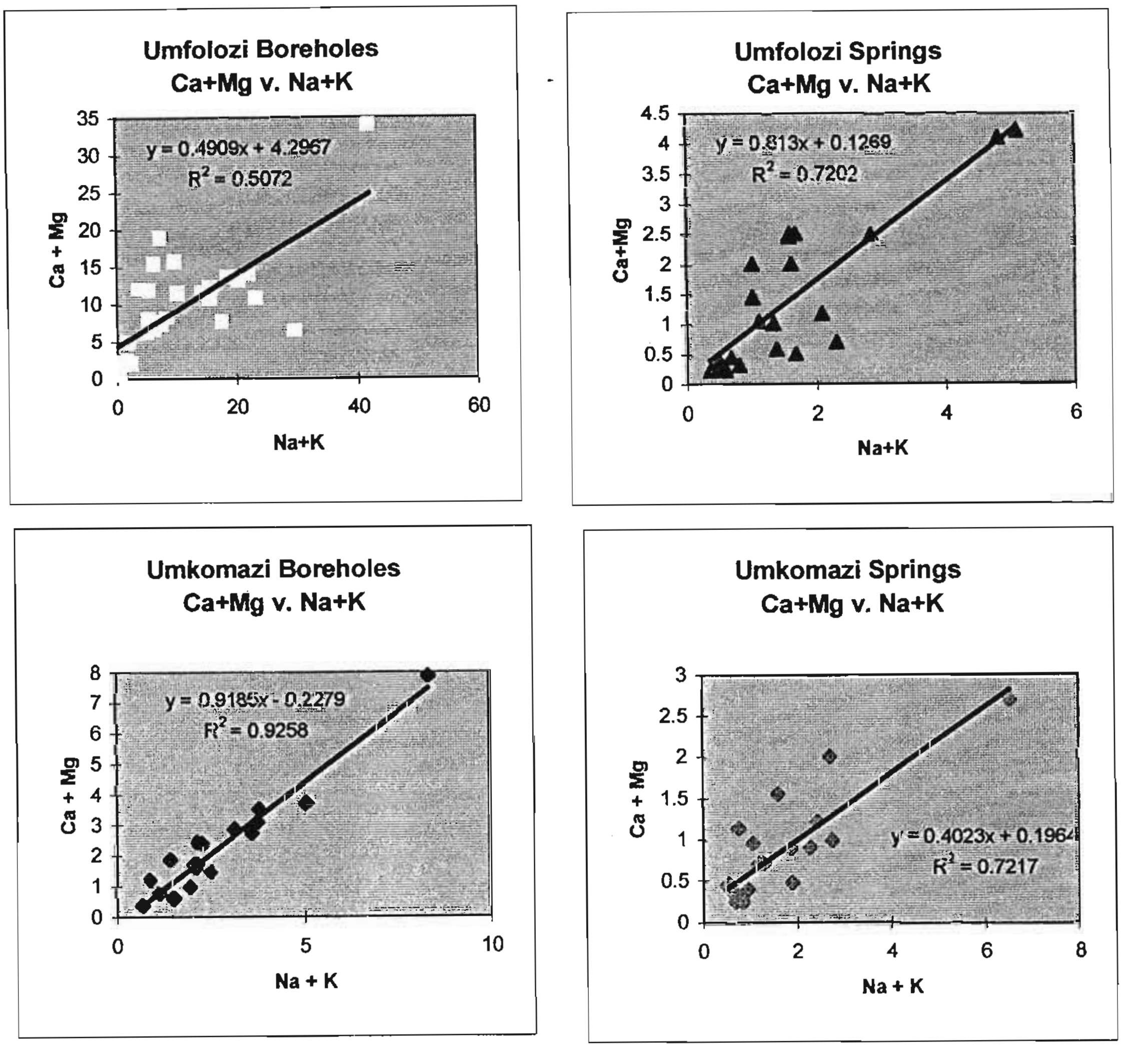


Figure 6.23 The enrichment of sodium plus potassium compared to the enrichment of magnesium plus calcium.

6.2.4 Statistical Analysis

Various statistical methods were used to analyse the relationship between major ion concentrations and the geological unit from which the samples were derived. Two methods for representing middle tendencies, the mean and the median, were used. The mean is the arithmetic average of sample concentrations, while the median is the middle data entry and is not significantly effected by anomalous samples. Standard deviation is included as an indication of the reliability of the middle values. Because representation of middle tendencies masks extreme values, these are included separately as maximum and minimum values. Statistics for Umkomazi boreholes and springs are given in Table 6.1 and Table 6.2, respectively.

Table 6.1 Major Ion Statistics for Umkomazi Boreholes (Grouped by Lithology).

lithology	Na mg/l	Cl mg/l	Mg mg/l	K mg/l	Ca mg/l	SO4 mg/l	TAL
AVERAGES							
C-Pd(2)	101	114.5	26	1.3	30	61	211
Jd(2)	16.5	15	3.5	2.7	10	8	54
Basement(27)	174	135.9	14.7	2.82	21	35	105
O-Sn(6)	77.7	88.4	13.5	2.65	18	12	127
Q(1)	47	48	10	3.2	18	10	109
MEDIANS							
C-Pd(2)	101	114.5	26	1.3	29.5	16	211
Jd(2)	16.5	15	3.5	2.7	10	8	54
Basement(27)	66	62	12	2.7	20	13	89
O-Sn(6)	66.00	56.75	13.50	2.63	19.00	9.50	149.00
Q(1)	47.00	48.00	10.00	3.20	18.00	10.00	109.00
STDEV							
C-Pd(2)	19.799	12.02082	1.414214	0.282843	4.94975	8.48528	46.669
Jd(2)	3.53553	4.242641	2.12132	0.282843	8.48528	5.65685	42.4264
Basement(27)	379.127	165.1899	11.41101	1.56869	17.3572	81.6885	41.4812
O-Sn(6)	48.4229	58.43322	6.560896	1.569939	13.5277	11.1551	84.1843
Q(1)							
MAX							
C-Pd(2)	115	123	27	1.5	33	22	244
Jd(2)	19	18	5	2.9	16	12	84
Basement(27)	1983	634	54	7.4	69	420	172
O-Sn(6)	159.00	183.00	22.00	4.41	31.00	32.00	198.00
Q(1)	47.00	48.00	10.00	3.20	18.00	10.00	109.00
MIN							
C-Pd(2)	87	106	25	1.1	26	10	178
Jd(2)	14	12	2	2.5	4	4	24
Basement(27)	25	14	1	0.5	7	0.16	59
O-Sn(6)	32.00	45.00	5.00	1.00	4.00	0.16	34.00
Q(1)	47.00	48.00	10.00	3.20	18.00	10.00	109.00

Table 6.2 Major Ion Statistics for Umkomazi Springs (Grouped by Lithology).

lithology	Na mg/l	Cl mg/l	Mg mg/l	K mg/l	Ca mg/l	SO_4 mg/l	TAL
AVERAGES							
C-Pd(1)	61	99	16	2.4	14	13	89
Jd(1)	16	13	2	1.5	3	9	38
basement(24)	45	55	7.82	1.7	8	21.9	45
O-Sn(3)	32	35	4.7	1	5	12.7	40
MEDIANS							
C-Pd(1)	61	99	16	2.4	14	13	89
Jd(1)	16	13	2	1.5	3	9	38
basement(24)	36	36.7	5.3	1.53	6	17.5	32
O-Sn(3)	29	26	5	1.1	6	12	41
STDEV							
C-Pd(1)							
Jd(1)							
basement(24)	35.78365	51.51116	6.836964	1.086816	5.767949	17.65374	34.37818
O-Sn(3)	18.23001	23.24507	2.516611	0.264575	2.645751	3.05505	17.03917
MAX							
C-Pd(1)	61	99	16	2.4	14	13	89
Jd(1)	16	13	2	1.5	3	9	38
basement(24)	150	177	24	5.3	23	70	144
O-Sn(3)	52	61	7	1.2	7	16	56
MIN							
C-Pd(1)	61	99	16	2.4	14	13	89
Jd(1)	16	13	2	1.5	3	9	38
basement(24)	11	3	1	0.5	2	3.55	18
O-Sn(3)	16	17	2	0.7	2	10	22

Medians were chosen to graphically represent middle tendencies because, unlike the mean, they were not influenced by extreme maximum and minimum values. Figure 6.24 shows a fairly consistent relationship between median concentrations of major ions and lithology in the Umkomazi area. Dwyka Tillite has the highest concentrations while dolerite has the lowest. Natal Group and basement samples plot close together in the middle. Exceptions are a high sulphate concentration in basement springs and a high alkalinity value in dolerite springs. Potassium shows an anomalous inverse relationship between borehole and spring concentrations (Figure 6.25).

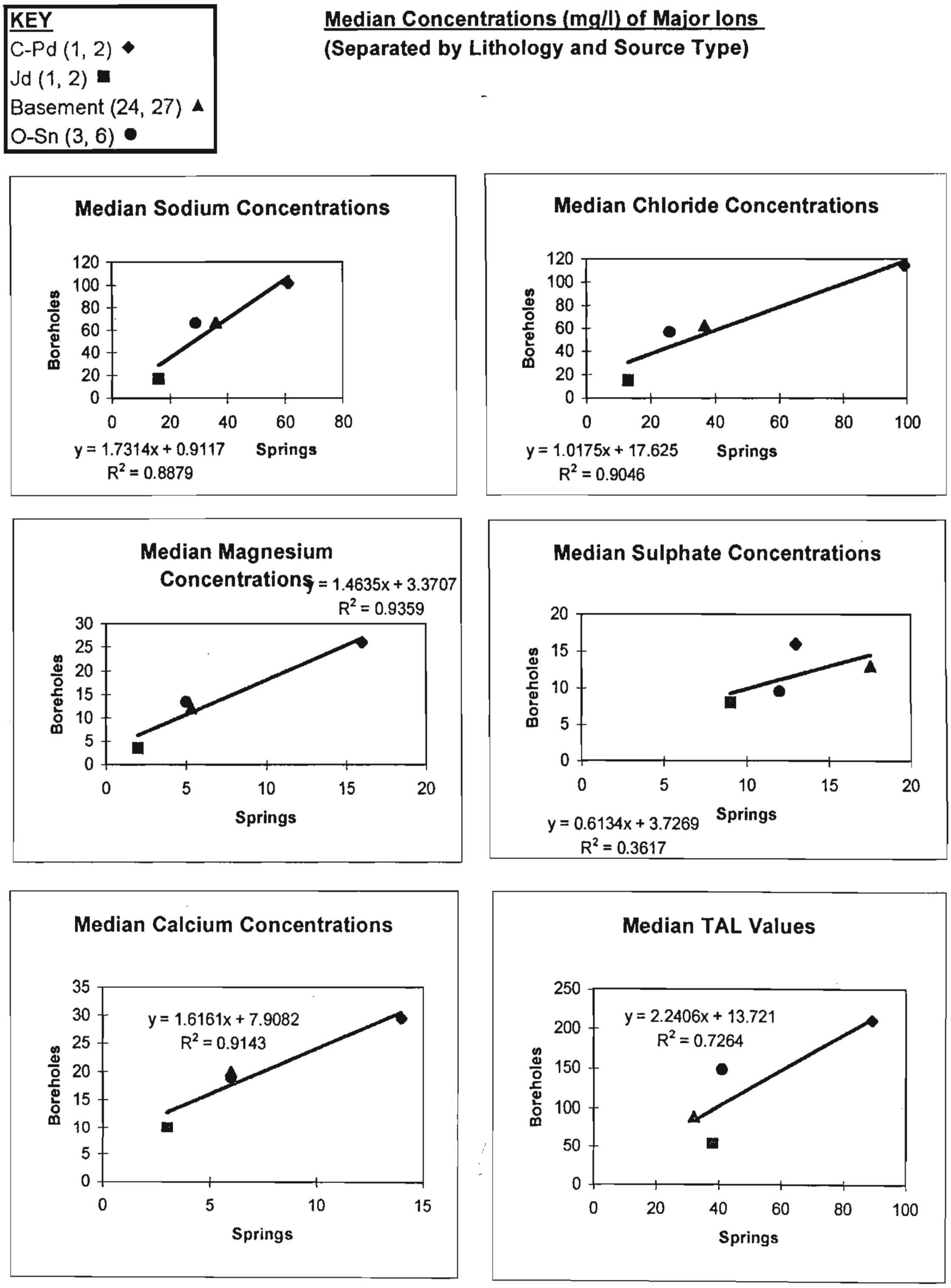


Figure 6.24 Relationship between median concentrations of major ions and lithology in the Umkomazi area.

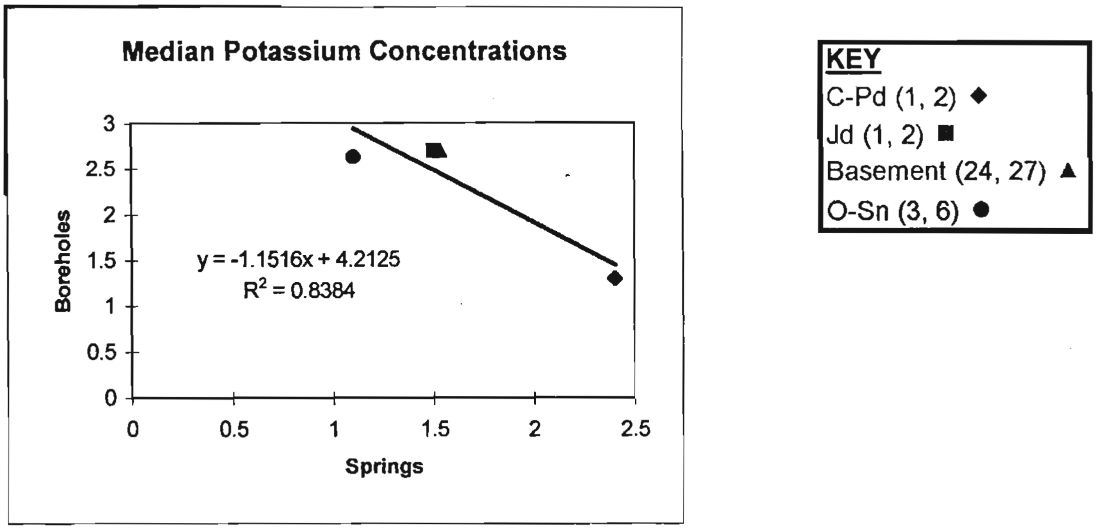


Figure 6.25 Inverse linear relationship between borehole and spring concentrations of potassium.

Statistics for the Umfolozi borehole and spring samples are given in Table 6.3 and Table 6.4, respectively.

Table 6.3 Major Ion Statistics for Umfolozi Boreholes (Grouped by Lithology).

Lithology	Na mg/l	Cl mg/l	Mg mg/l	K mg/l	Ca mg/l	SO_4 mg/l	TAL
AVERAGES							
C-Pd(5)	162.6	250	65	2.54	78	20	362
Jd(7)	127.7	189	59	1.14	58	28	302
Pp(2)	47	41	17	0.7	21	4	134
Pv(11)	412	643	96	4.5	86	68	512
MEDIANS							
C-Pd(5)	141.00	242.00	57.00	2.90	70.00	15.00	372
Jd(7)	87.00	147.00	45.00	1.00	67.00	20.00	377
Pp(2)	47	40.5	16.5	0.7	20.5	4	134
Pv(11)	422	592	99	4.5	89	40	590
STDEV							
C-Pd(5)	48.80881	84.37535	18.8202	1.470714	14.8054	8.348653	86.33945
Jd(7)	132.9207	205.2242	55.26559	0.930694	38.53075	29.90779	190.3343
Pp(2)	7.071068	13.43503	2.12132	0.565685	2.12132	0	9.899495
Pv(11)	274.3162	551.7459	70.59616	2.725436	65.41101	70.91467	252.8584
MAX							
C-Pd(5)	235	374	89	4.4	96	32	490
Jd(7)	402	621	168	2.8	104	89	494
Pp(2)	52	50	18	1.1	22	4	141
Pv(11)	960	2076	265	8.9	245	242	818
MIN							
C-Pd(5)	121	159	45	0.9	62	13	255
Jd(7)	13	9	4	0.2	9	4	51
Pp(2)	42	31	15	0.3	19	4	127
Pv(11)	6	7	4	0.3	4	4	29

Table 6.4 Major Ion Statistics for Umfolozi Springs (Grouped by Lithology).

Lithology	Na mg/l	Cl mg/l	Mg mg/l	K mg/L	Ca	SO_4 mg/l	TAL
AVERAGES							
C-Pd(1)	110	113	33	1.4	28	20	230
Jd(8)	37	36	10	0.9	12	6	76
Pv(11)	29	30	10	1.3	10	12	64
MEDIANS							
C-Pd(1)	110	113	33	1.4	28	20	230
Jd(8)	24	22	6	0.85	7	4	47
Pv(11)	36	33	11	1	6	4	68
STDEV							
C-Pd(1)	0	0	0	0	0	0	0
Jd(8)	36.71804	42.00829	10.58216	0.369362	10.87592	2.748376	71.34111
Pv(11)	12.83036	15.2208	6.63325	0.811508	8.040805	12.61168	39.09941
MAX							
C-Pd(1)	110	113	33	1.4	28	20	230
Jd(8)	117	137	32	1.5	32	11	223
Pv(11)	47	60	18	3	21	35	115
MIN							
C-Pd(1)	110	113	33	1.4	28	20	230
Jd(8)	8	9	2	0.5	2	4	16
Pv(11)	9	8	2	0.3	2	4	10

Medians were again selected to graphically show the relationship between major ion concentrations and lithology. Although Umfolozi samples do not show a linear relationship between borehole and spring concentrations, there is a clear relationship between major ion concentrations and lithology (Figure 6.26). Generally, dolerite samples have the lowest medians concentrations for both boreholes and springs, while Vryheid Formation samples have the highest borehole concentrations and Dwyka Tillite samples have the highest spring concentrations. Minor exceptions are the relatively high sulphate concentrations in dolerite boreholes as compared to Dwyka boreholes, and relatively high calcium concentration in dolerite springs as compared to Dwyka springs. Potassium shows the same trend as the other more common ions.

The high concentrations of major ions from the Dwyka and Vryheid aquifers is likely due to the marine influence during their deposition (Lloyd, 1994). In contrast, the igneous and metamorphic basement and dolerite aquifers show low concentrations, as does the Natal Group, which was deposited in a fluvial environment (Figures 6.27 and 6.28).

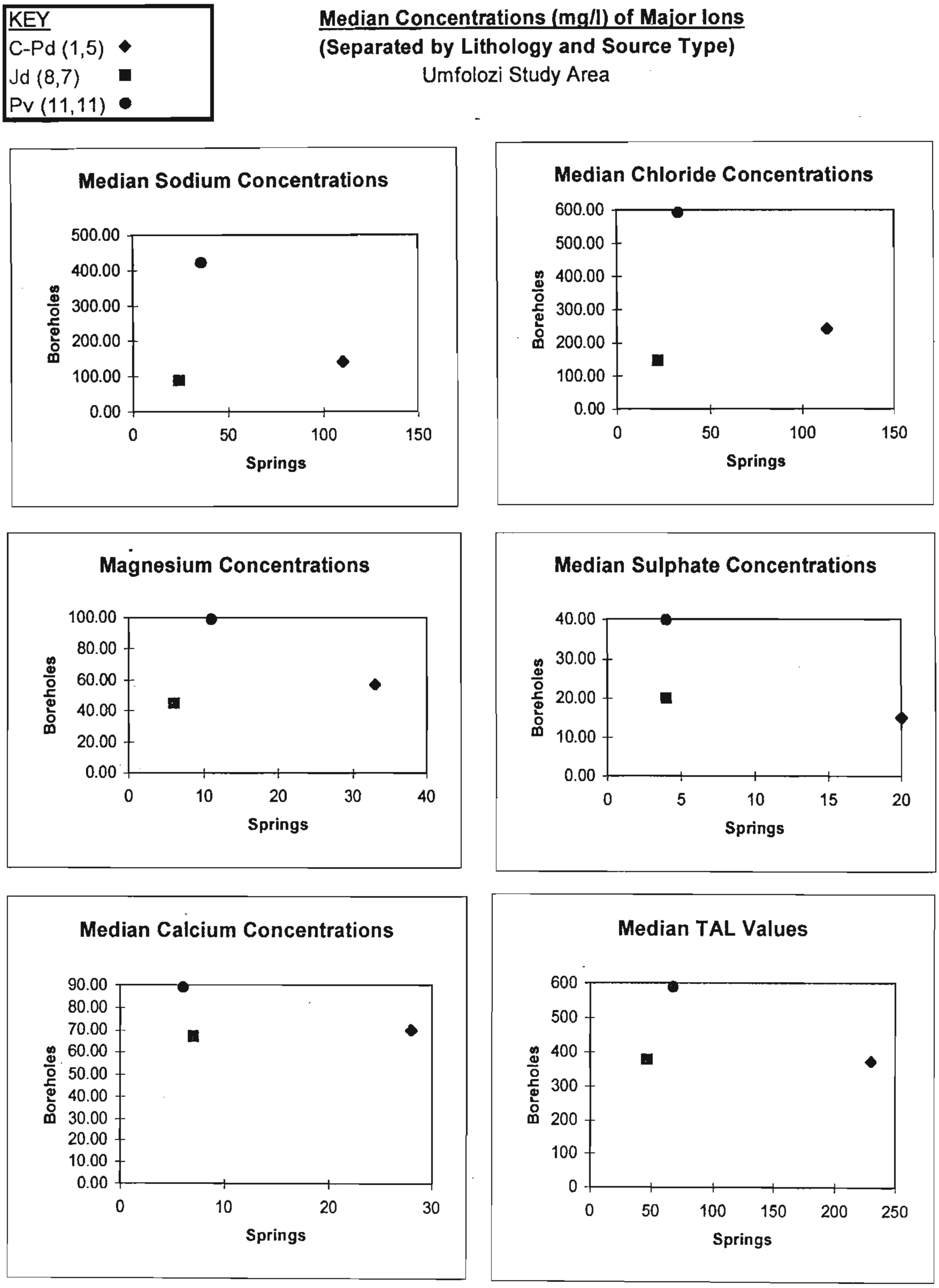
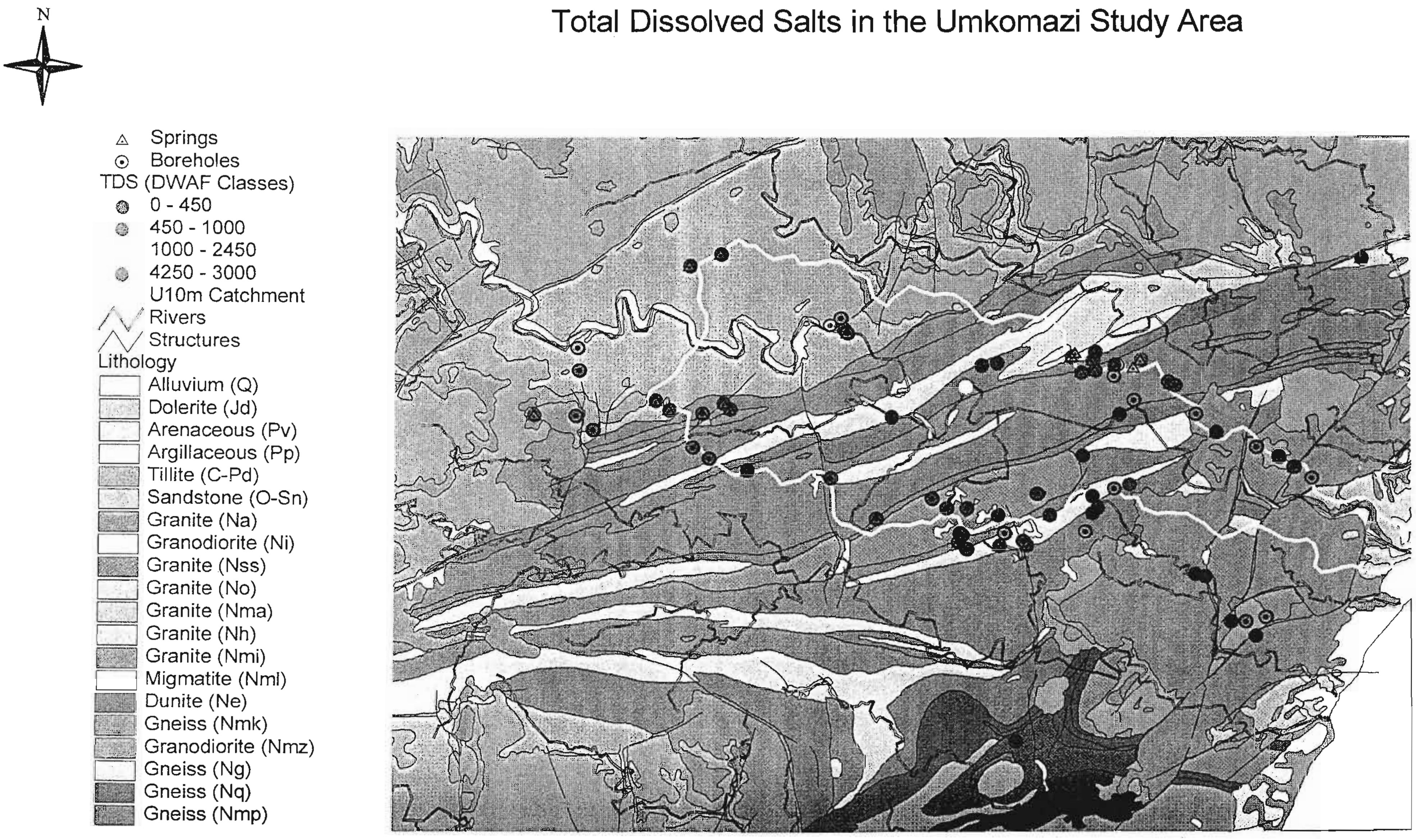


Figure 6.26 Relationship between median concentrations of major ions and lithology in the Umfolozi area.



Total Dissolved Salts in the Umkomazi Study Area

Figure 6.27 TDS concentrations overlain on the Umkomazi geology map.

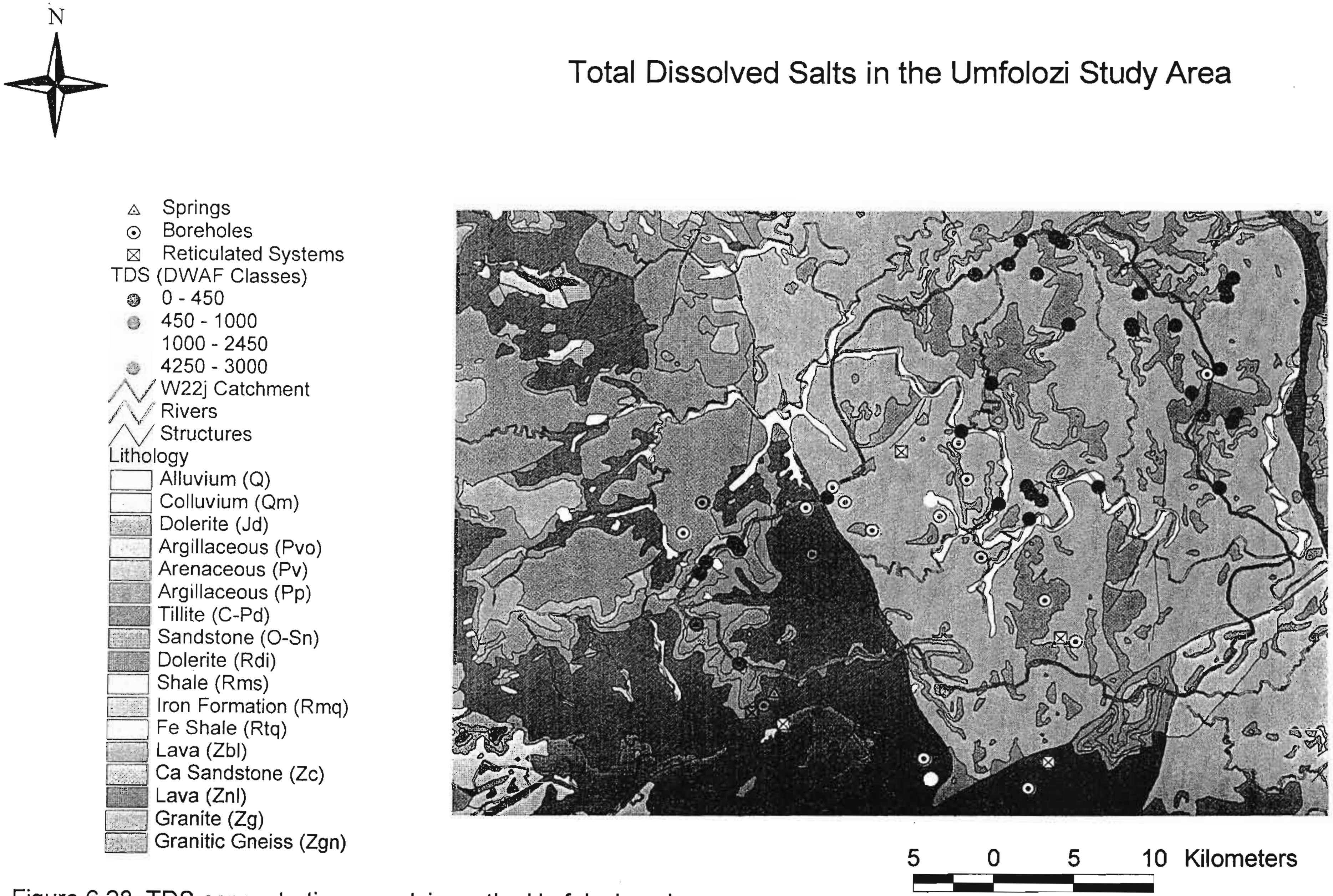


Figure 6.28 TDS concentrations overlain on the Umfolozi geology map.

6.3 Minor Ions

Minor ion analysis reveals the basic geochemical reactions taking place and can be used to give information on recharge history (Edmunds, 1994 b). Statistical analysis of constituents excluding major ions and trace metals is presented in Tables 6.5 - 6.8 at the end of this section. Of these constituents nitrate, ammonium and potassium are linked to landuse activities and will be discussed in Section 8. Other constituents e.g. silica were not considered to have negative health or aesthetic effects in drinking water. Thus fluoride is the only constituent thoroughly examined in this section.

As discussed in Section 4.3.2, the **fluoride** ion is isomorphous with the hydroxyl ion in several silicate and phosphate minerals and also replaces hydroxylapatite with fluorapatite in mammalian systems. Fluoride is found mainly in silicate minerals and is concentrated in late stage crystallisation of magmas and in residual material and vapours and thus is associated with highly siliceous igneous rocks, alkalic rocks and hydrothermal solutions. The relationship between fluoride concentration and lithology in the Umkomazi area is clearly seen in Figure 6.29.

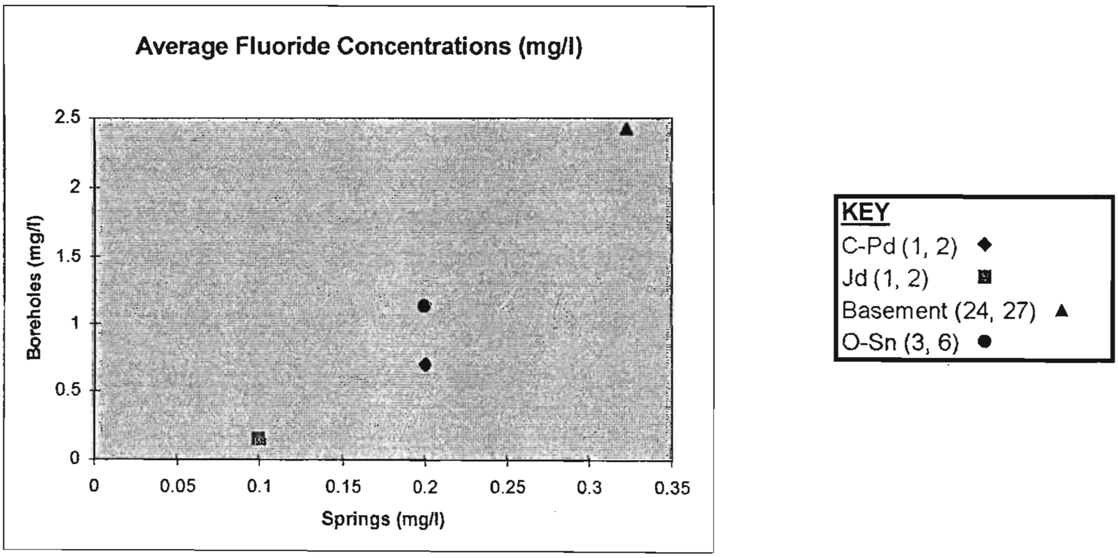


Figure 6.29 Umkomazi fluoride concentrations grouped by lithology.

The highest average fluoride concentration occurs in the basement rocks of the Natal Metamorphic Province. As discussed in Section 3.2.1, these rocks consist of the older supracrustal gneisses and the younger Mapumulo Metamorphic Suite, which are mainly granitic in composition, and thus relatively siliceous with a high ratio of alkali feldspar to total feldspar. The lowest fluoride concentrations are found in the Karoo Dolerite, which consists primarily of labradorite and pyroxene. Fluoride found in the Natal Group may be due to hydraulic continuity between the sandstone and the underlying basement. Fluoride in the Dwyka Formation may be due to the fact that the Tillite contains clasts of basement material. In the Umfolozi area where the basement rocks of the Archaean Kaapvaal Province are covered by younger sedimentary rocks the highest median fluoride concentration is from Dwyka Tillite (Figure 6.30).

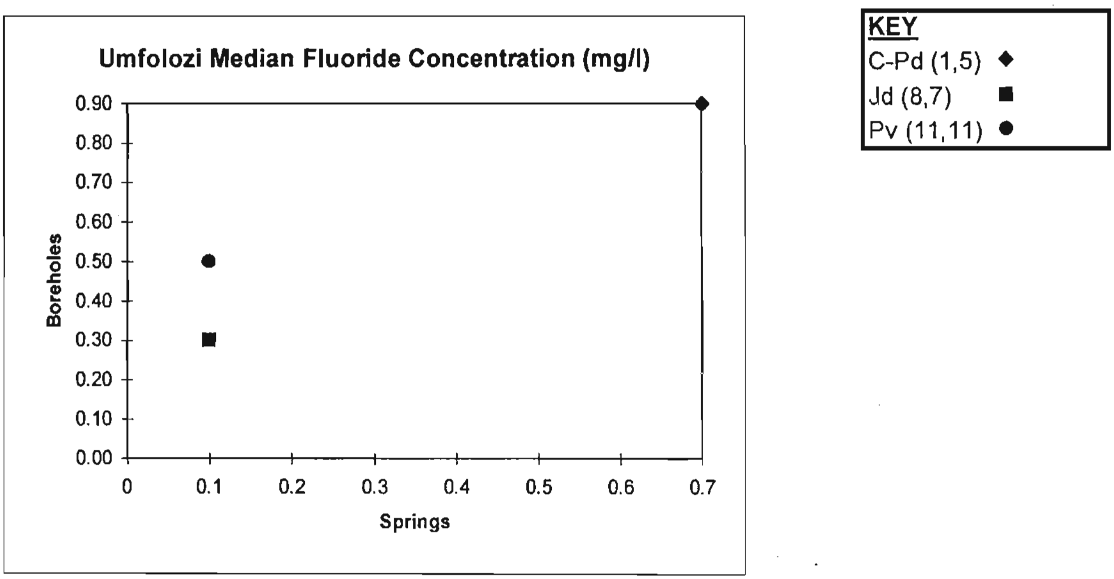


Figure 6.30 Umfolozi fluoride concentrations grouped by lithology.

As in the Umkomazi area, the fluoride present in the Dwyka Tillite may be due to the existence of basement clasts in the tillite. Once again, the dolerite shows low concentrations, while the Vryheid sandstone has an intermediate borehole concentration.

Ashley and Burley (1994) linked the solubility of fluoride to the solubility of its compound calcium fluoride (CaF_2). The theoretical solubility limit of calcium fluoride is expressed by the equation:

$$\log[Ca] = -2 \log[F] - 10.57$$

This equation is represented by the solubility curve in Figure 6.31. Samples that plot above the solubility curve are over-saturated with respect to calcium fluoride, while those that plot below the solubility curve are under-saturated (Edmunds and Smedley, 1996). In general, borehole samples are over-saturated with calcium fluoride, while spring samples are under-saturated. The solubility curve suggests that an *increase* in dissolved calcium in the groundwater results in a *decrease* in fluoride, through the precipitation of calcium fluoride.

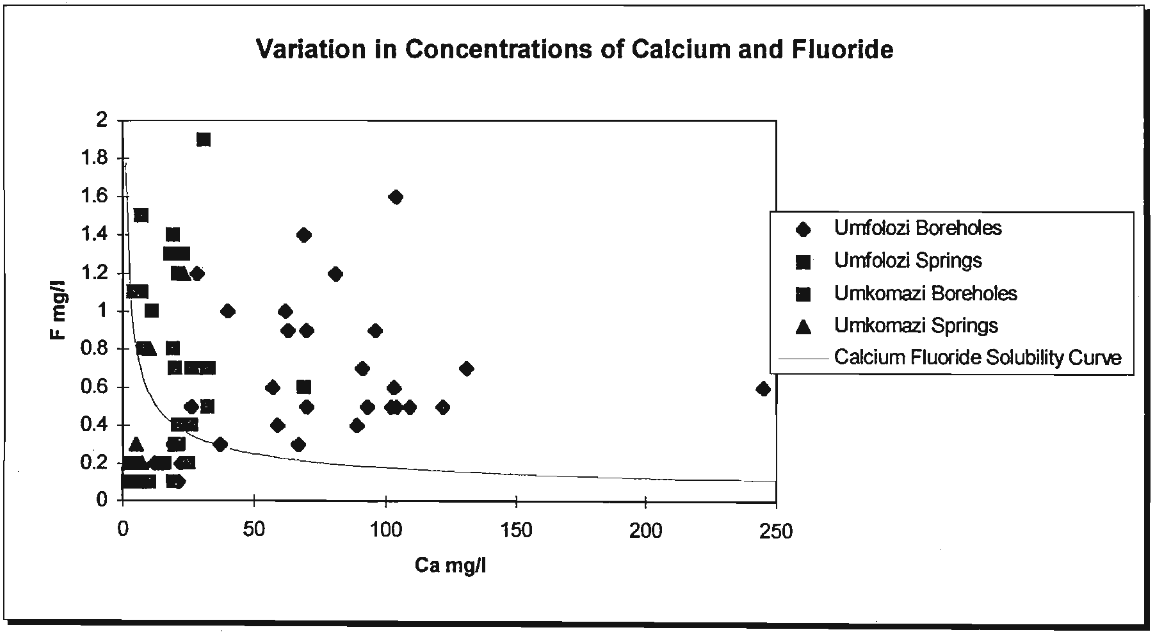


Figure 6.31 **Variation in concentrations of calcium and fluoride.**

In conclusion, the highest fluoride concentrations were found in the basement rocks of the Natal Metamorphic Province, while the lowest concentrations were found in the Karoo dolerite. Intermediate values were associated with the sedimentary rocks. Further, fluoride concentrations were found to be related to the amount of dissolved calcium in the groundwater.

Table 6.5 Minor Ion Statistics for Umkomazi Boreholes (Grouped by Lithology).

lithology	F mg/l	NO3 mg/l	PO4-P	NH4	Si
AVERAGES					
C-Pd(2)	0.7	2.28	0.02	0.03	13.6
Jd(2)	0.15	0.9	0.01	0.04	17.8
Basement(27)	2.42	4.04	0.02	0.12	19.7
O-Sn(6)	1.13	0.72	0.02	0.1	15.7
Q(1)	1.3	0.22	0.01	0.02	22.1
MEDIANS					
C-Pd(2)	0.7	2.275	0.015	0.03	13.6
Jd(2)	0.15	0.895	0.01	0.04	17.75
Basement(27)	1.22	1.55	0.02	0.1	19.7
O-Sn(6)	0.95	0.06	0.02	0.07	15.40
Q(1)	1.30	0.22	0.01	0.02	22.10
STDEV					
C-Pd(2)	0	3.0759145	0.007071068	0	0.8485281
Jd(2)	0.070710678	1.18086832	0.014142136	0.0282843	11.525841
Basement(27)	3.858400684	7.29451886	0.017372915	0.1712192	6.4536811
O-Sn(6)	0.695288909	1.26414266	0.005773503	0.1072847	1.1372481
Q(1)					
MAX					
C-Pd(2)	0.7	4.45	0.02	0.03	14.2
Jd(2)	0.2	1.73	0.02	0.06	25.9
Basement(27)	20.3	36	0.07	0.8	30.5
O-Sn(6)	2.02	3.20	0.02	0.30	17.00
Q(1)	1.30	0.22	0.01	0.02	22.10
MIN					
C-Pd(2)	0.7	0.1	0.01	0.03	13
Jd(2)	0.1	0.06	0	0.02	9.6
Basement(27)	0.2	0.04	0.01	0	8.3
O-Sn(6)	0.31	0.04	0.01	0.02	14.80
Q(1)	1.30	0.22	0.01	0.02	22.10

Table 6.6 Minor Ion Statistics for Umkomazi Springs (Grouped by Lithology).

lithology	F mg/l	NO3 mg/l	PO4-P	NH4	Si
AVERAGES					
C-Pd(1)	0.2	0.42	0.02	0.05	10.2
Jd(1)	0.1	0.07	0.07	0.06	13.3
basement(24)	0.32	3.48	0.11	0.05	15.7
O-Sn(3)	0.2	1.02	0.04	0.03	16.2
MEDIANS					
C-Pd(1)	0.2	0.42	0.02	0.05	10.2
Jd(1)	0.1	0.07	0.07	0.06	13.3
basement(24)	0.2	2.495	0.03	0.04	14.3
O-Sn(3)	0.2	0.38	0.04	0.025	15.1
STDEV					
C-Pd(1)					
Jd(1)					
basement(24)	0.301	3.74	0.27	0.04	5.25
O-Sn(3)	0	1.31	0.02	0.01	4.11
MAX					
C-Pd(1)	0.2	0.42	0.02	0.05	10.2
Jd(1)	0.1	0.07	0.07	0.06	13.3
basement(24)	1.2	16.69	1.02	0.1	24.8
O-Sn(3)	0.2	2.53	0.06	0.03	20.7
MIN					
C-Pd(1)	0.2	0.42	0.02	0.05	10.2
Jd(1)	0.1	0.07	0.07	0.06	13.3
basement(24)	0.07	0.08	0.01	0	7.5
O-Sn(3)	0.2	0.16	0.02	0.02	12.7

Table 6.7 Minor Ion Statistics for Umfolozi Boreholes (Grouped by Lithology).

Lith	NO_3 mg/l	PO4-P	NH4	Si	F mg/l
AVERAGES					
C-Pd(5)	15.98	0.01	0.09	14.6	0.8
Jd(7)	16.16	0.01	0.08	19.2	0.44
Pp(2)	4.55	0.02	0.05	25.5	0.25
Pv(11)	3.79	0.01	0.15	12.9	0.67
MEDIANS					
C-Pd(5)	8.84	0.01	0.1	14.4	0.90
Jd(7)	0.48	0.01	0.04	15.3	0.30
Pp(2)	4.545	0.015	0.05	25.45	0.25
Pv(11)	0.16	0.01	0.03	10.4	0.5
STDEV					
C-Pd(5)	13.69959379	0.00547723	0.05585696	0.856154192	0.2
Jd(7)	41.03769034	0.00786796	0.09797959	11.00809226	0.364495738
Pp(2)	6.286179285	0.00707107	0.028284271	9.687362902	0.070710678
Pv(11)	5.339880148	0.0053936	0.417165762	6.668324036	0.504164475
MAX					
C-Pd(5)	38.87	0.02	0.15	16	1
Jd(7)	109.21	0.03	0.3	42.1	1.2
Pp(2)	8.99	0.02	0.07	32.3	0.3
Pv(11)	13.03	0.02	1.42	29.7	1.6
MIN					
C-Pd(5)	6.73	0.01	0.03	13.9	0.5
Jd(7)	0.1	0.01	0.03	8.6	0.1
Pp(2)	0.1	0.01	0.03	18.6	0.2
Pv(11)	0.1	0	0.01	7.1	0.1

Table 6.8 Minor Ion Statistics for Umfolozi Springs (Grouped by Lithology).

Lith	NO_3 mg/l	PO4-P	NH4	SI	F mg/l
AVERAGES					
C-Pd(1)	7.16	0.04	0.05	14.1	0.7
Jd(8)	4.26	0.02	0.04	16.2	0.15
Pv(11)	2.67	0.03	0.04	11.8	0.16
MEDIANS					
C-Pd(1)	7.16	0.04	0.05	14.1	0.7
Jd(8)	2.18	0.02	0.035	18.15	0.1
Pv(11)	1.1	0.02	0.04	9.7	0.1
STDEV					
C-Pd(1)	0	0	0	0	0
Jd(8)	5.97016257	0.007071068	0.025071327	7.955725701	0.141421356
Pv(11)	3.68627824	0.040271804	0.031651512	6.922637437	0.112006493
MAX					
C-Pd(1)	7.16	0.04	0.05	14.1	0.7
Jd(8)	17.57	0.03	0.09	28.9	0.5
Pv(11)	11.2	0.15	0.12	26.7	0.4
MIN					

6.4 *Trace Metals*

Lab results indicated that the trace metals manganese, iron and zinc frequently caused deterioration of water quality in both catchment areas. These trace metals cause aesthetic effects such as staining of clothes and pots and unpleasant taste. Less commonly, trace metals may cause health effects, particularly in sensitive individuals. Trace metals are derived from the weathering of bedrock and possibly from the corrosion of metal pipes.

Unlike the major ions, trace metal concentrations are not reflected by TDS and EC results. Further, it was found that the trace metals do not show linear relationships between borehole and spring concentrations or clear trends between concentration and lithology. The trace metal statistics for the Umkomazi and Umfolozi study areas are presented in Table 6.9 and Table 6.10, respectively. Median concentrations of the trace metals were separated by lithology and source type (Figure 6.32 and 6.33).

Table 6.9 Trace Metal Statistics for Umkomazi Boreholes and Springs (Grouped by Lithology).

BOREHOLES (mg/l)

lithology	Mn	Fe	Zn
AVERAGES			
C-Pd(2)	0.035	0.268	0.756
Jd(2)	0.08	0.688	2.609
Basement(27)	0.127	1.91	9.96
O-Sn(6)	0.122	1.606	0.083
Q(1)	0.027	0.42	0.684
MEDIANS			
C-Pd(2)	0.0345	0.268	0.7555
Jd(2)	0.0795	0.6875	2.609
Basement(27)	0.05	0.58	0.96
O-Sn(6)	0.12	0.18	0.10
Q(1)	0.03	0.42	0.68
STDEV			
C-Pd(2)	0.046	0.038	0.424
Jd(2)	0.101	0.004	2.742
Basement(27)	0.183	3.693	2.565
O-Sn(6)	0.090	3.550	0.071
Q(1)			
MAX			
C-Pd(2)	0.067	0.295	1.055
Jd(2)	0.151	0.69	4.548
Basement(27)	0.73	18.5	8.66
O-Sn(6)	0.25	8.85	0.24
Q(1)	0.03	0.42	0.68
MIN			
C-Pd(2)	0.002	0.241	0.456
Jd(2)	0.008	0.685	0.67
Basement(27)	0.001	0.041	0.003
O-Sn(6)	0.01	0.07	0.06
Q(1)	0.03	0.42	0.68

SPRINGS (mg/l)

lithology	Mn	Fe	Zn
AVERAGES			
C-Pd(1)	0.042	0.268	0.096
Jd(1)	0.177	0.396	0.14
basement(24)	0.132	0.965	0.085
O-Sn(3)	0.035	2.038	0.123
MEDIANS			
C-Pd(1)	0.042	0.268	0.096
Jd(1)	0.177	0.396	0.14
basement(24)	0.0115	0.5535	0.02
O-Sn(3)	0.044	1.163	0.112
STDEV			
C-Pd(1)			
Jd(1)			
basement(24)	0.332	1.529	0.135
O-Sn(3)	0.031	1.994	0.058
MAX			
C-Pd(1)	0.042	0.268	0.096
Jd(1)	0.177	0.396	0.14
basement(24)	1.6	7.56	0.642
O-Sn(3)	0.06	4.32	0.186
MIN			
C-Pd(1)	0.042	0.268	0.096
Jd(1)	0.177	0.396	0.14
basement(24)	0.001	0.003	0.003
O-Sn(3)	0.001	0.631	0.072

Table 6.10 Trace Metal Statistics for Umfolozi Boreholes and Springs (Grouped by Lithology).

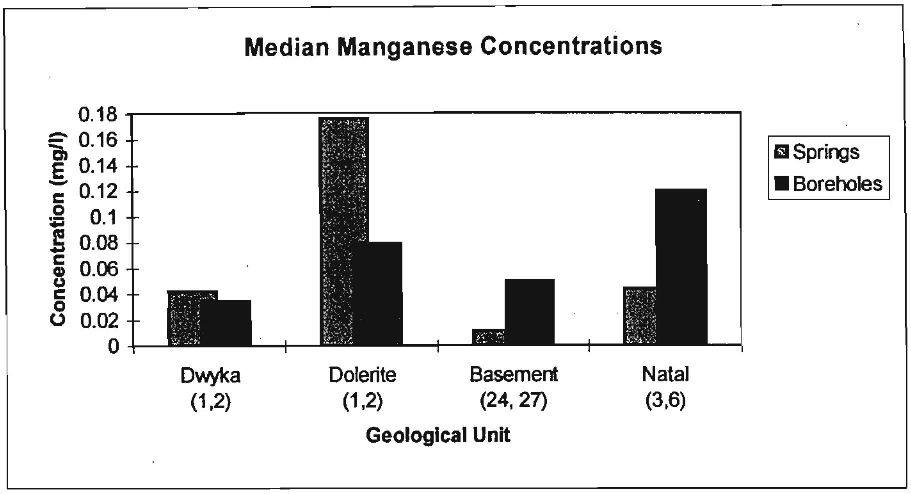
BOREHOLES (mg/l)

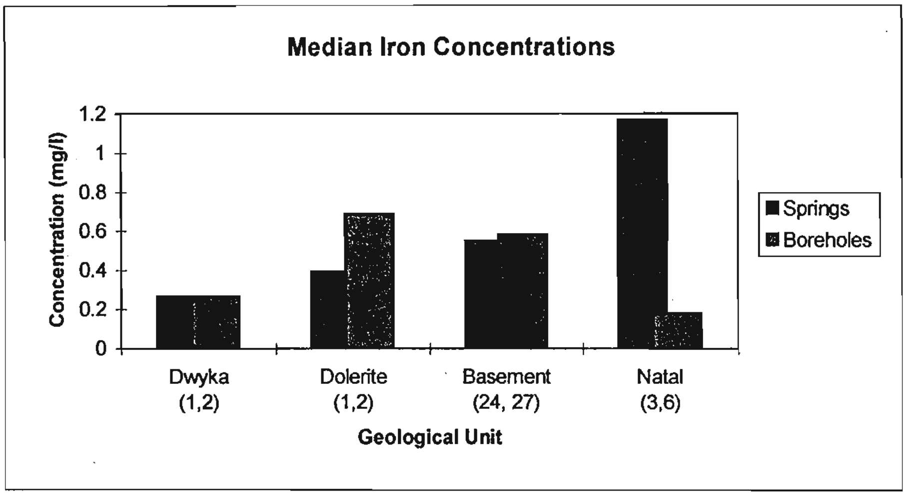
Lithology	Mn	Fe	Zn
AVERAGES			
C-Pd(5)	0.034	0.915	2.359
Jd(7)	0.038	0.918	3.88
Pp(2)	0.117	0.548	0.476
Pv(11)	0.178	1.516	3.158
MEDIANS			
C-Pd(5)	0.038	0.575	2.407
Jd(7)	0.009	0.780	2.247
Pp(2)	0.117	0.548	0.476
Pv(11)	0.092	0.41	1.307
STDEV			
C-Pd(5)	0.032	0.840	2.008
Jd(7)	0.065	0.498	5.799
Pp(2)	0.164	0.010	0.669
Pv(11)	0.315	3.577	3.940
MAX			
C-Pd(5)	0.07	2.249	5.415
Jd(7)	0.177	1.633	16.57
Pp(2)	0.233	0.555	0.949
Pv(11)	1.067	12.24	11.52
MIN			
C-Pd(5)	0.001	0.103	0.153
Jd(7)	0.001	0.311	0.143
Pp(2)	0.001	0.541	0.003
Pv(11)	0.001	0.003	0.094

SPRINGS (mg/l)

Lithology	Mn	Fe	Zn
AVERAGES			
C-Pd(1)	0.045	0.64	0.06
Jd(8)	0.032	0.973	0.375
Pv(11)	0.137	1.19	0.358
MEDIANS			
C-Pd(1)	0.045	0.64	0.06
Jd(8)	0.016	0.877	0.3575
Pv(11)	0.001	0.739	0.186
STDEV			
C-Pd(1)	0	0	0
Jd(8)	0.048	0.655	0.254
Pv(11)	0.429	1.160	0.498
MAX			
C-Pd(1)	0.045	0.64	0.06
Jd(8)	0.143	1.895	0.827
Pv(11)	1.429	4.07	1.611
MIN			
C-Pd(1)	0.045	0.64	0.06
Jd(8)	0.001	0.225	0.088
Pv(11)	0.001	0.292	0.003

<u>Umkomazi Trace Metal Concentrations</u>
Separated by Lithology and Source Type





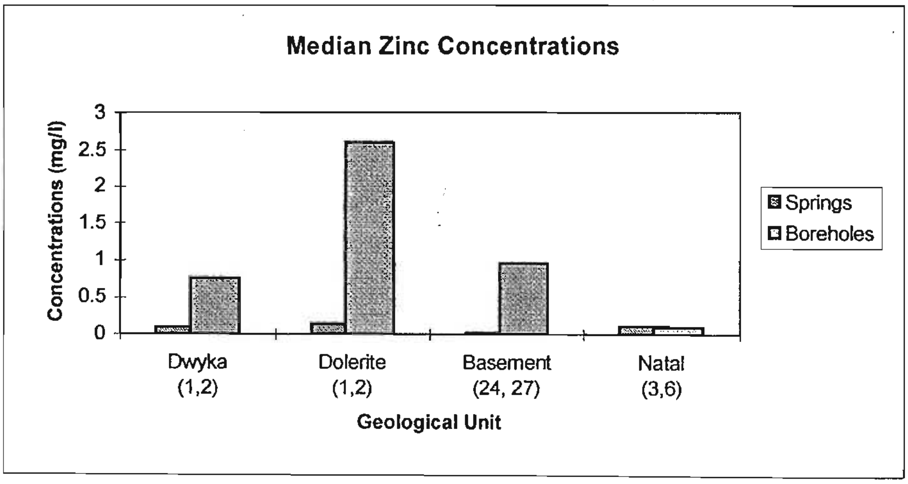


Figure 6.32 Umkomazi trace metal concentrations separated by lithology and source type.

Umfolozi Trace Metal concentrations
Separated by Lithology and Source Type

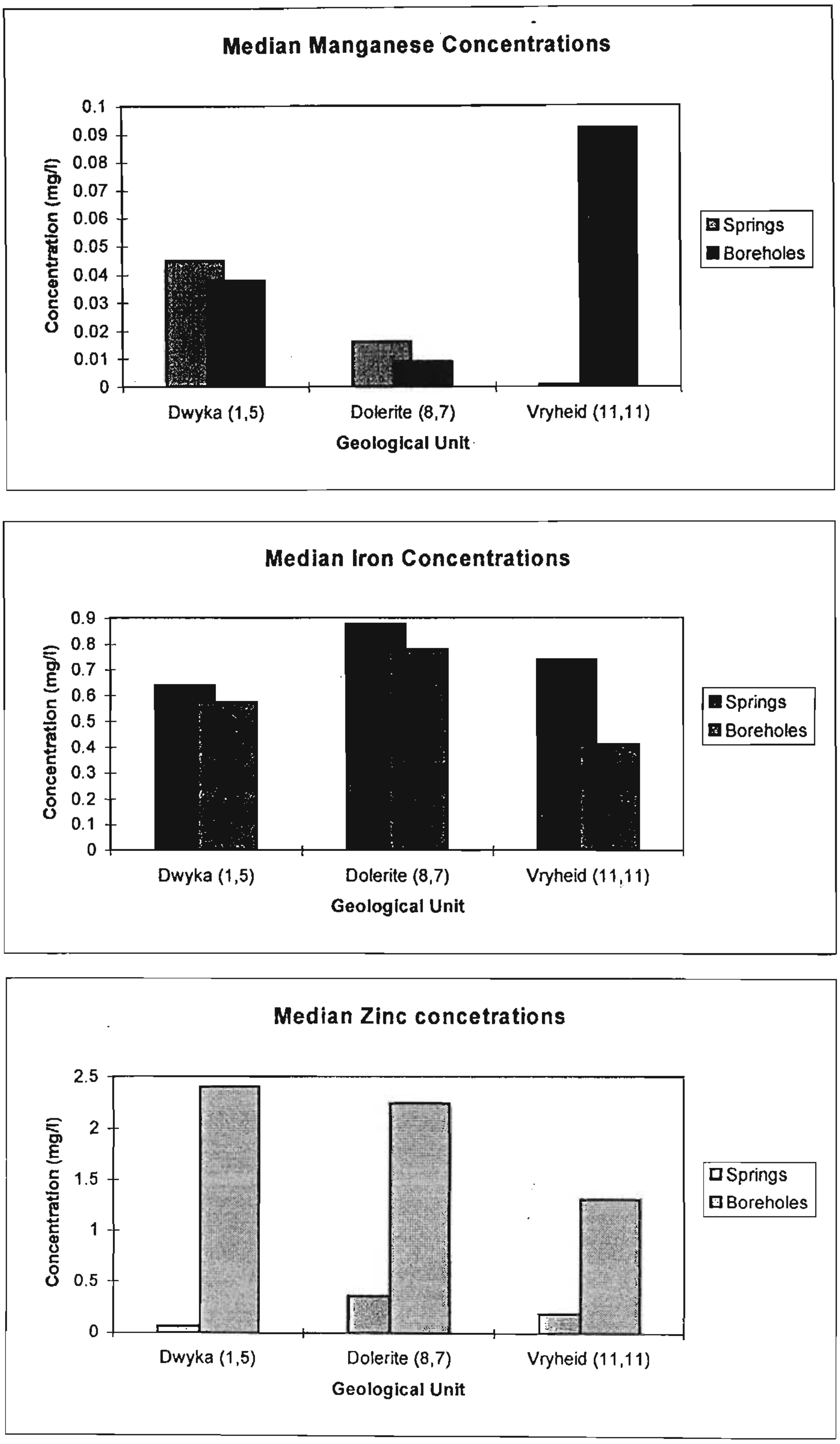


Figure 6.33 Umfolozi trace metal concentrations separated by lithology and source type.

Median **manganese** concentrations among the Umkomazi samples were highest in the Karoo Dolerite springs, followed by Natal Group boreholes and dolerite Springs (Figure 6.32 top). However, among the Umfolozi samples the dolerite showed the lowest manganese concentrations, while the Vryheid boreholes showed the highest (Figure 6.33 top).

Umkomazi **iron** concentrations were highest in water derived from Natal Group springs, but lowest in Natal Group boreholes (Figure 6.32 middle). In the Umkomazi area all other lithologies showed higher concentrations in boreholes samples than in corresponding spring samples. However, in the Umfolozi area all lithologies showed *lower* concentrations of iron in borehole samples than in spring samples, while the dolerite had the highest median value (Figure 6.33 middle). Iron is derived from the ferromagnesium minerals present in the host rocks, e.g. pyroxene in the dolerite and basement rocks, as given in Figure 6.34.

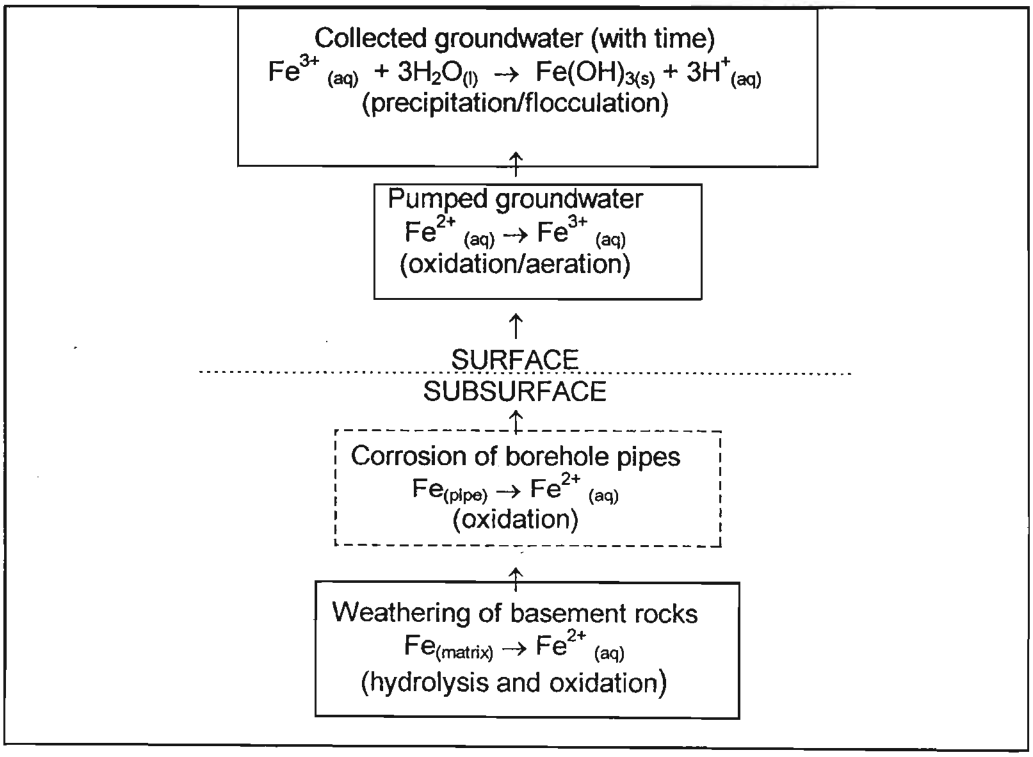


Figure 6.34 Processes by which iron enters drinking water (after Taylor and Howard, 1994).

Springs are generally shallow, with flow frequently occurring along the planar surface between the soil and the underlying bedrock. The weathered soil layer facilitates the accumulation of iron species in the groundwater through the mechanisms of hydrolysis and oxidation, which explains the high concentration of iron in springs as compared to boreholes. Surface water tends to have lower iron concentrations due to the precipitation and flocculation of iron with time, as well as dilution by rain water. Thus consumers may switch from the aesthetically displeasing groundwater to the biologically polluted surface waters, as biologically contamination is not readily apparent. Iron concentrations are related to lithology and source type in Figures 6.35 and 6.36.

Unlike manganese and iron, **zinc** concentrations were consistently higher in boreholes than in springs (Figures 6.32 and 6.33 bottom). In the Umkomazi area median concentrations were highest in the dolerite, while in the Umfolozi area Dwyka concentrations were marginally higher.

Galvanised steel pipes may provide a secondary source of trace metals. Steel pipes are galvanised with a zinc plating and the pipes themselves may contain manganese, aluminium and chromium (aluminium and chromium concentrations were not analysed in this study). During sampling an effort was made to purge boreholes of stagnant water, in order to give a representative sample of the geological unit. As consumers do not purge the stagnant water prior to collection they may drink water with higher trace metal concentrations than recorded in the samples. The trace metal concentrations in samples from reticulated systems was examined in comparison to samples from boreholes, though no consistent increase is seen in the former (Figure 6.37).

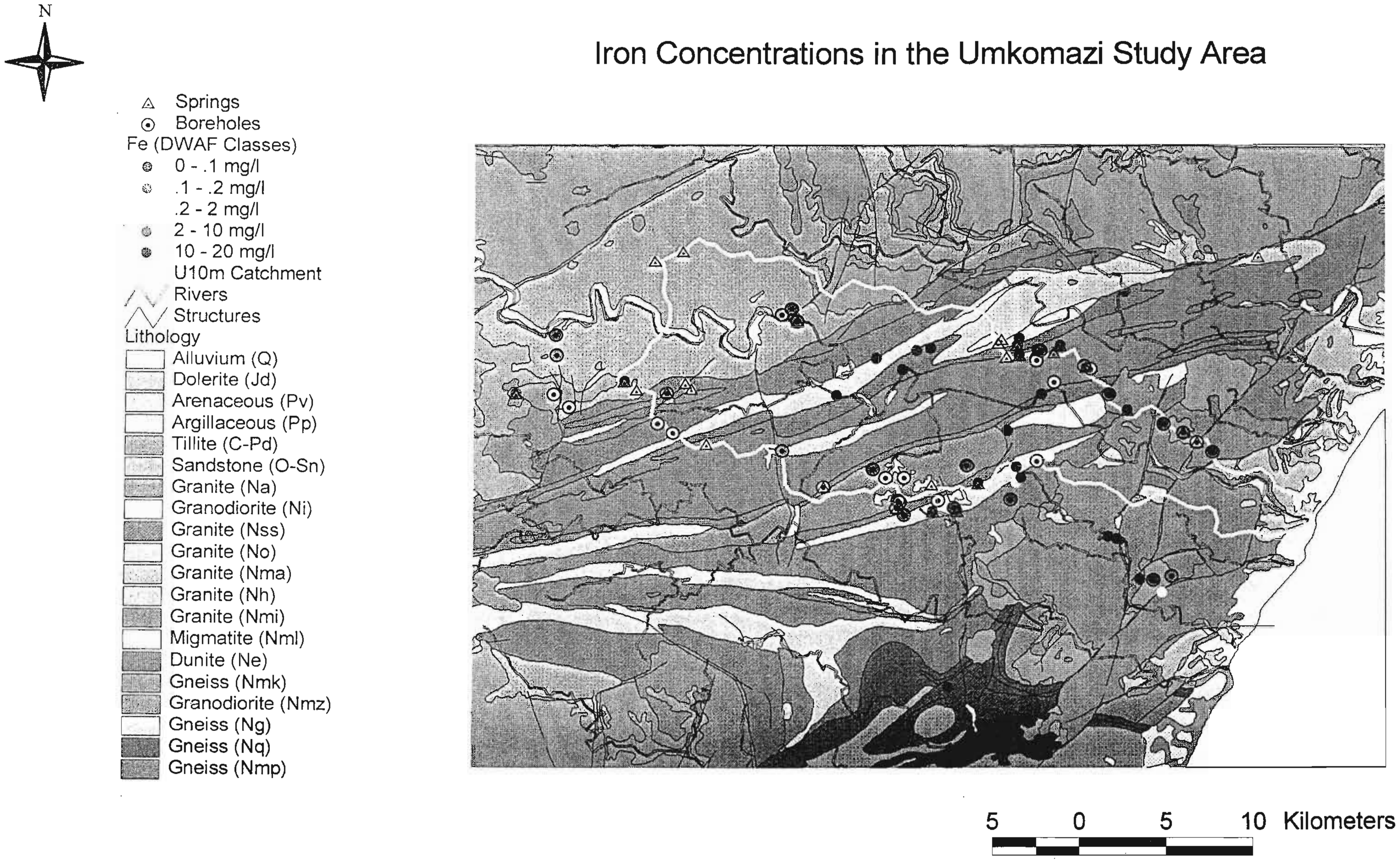


Figure 6.35 Iron concentrations overlain on the Umkomazi geology map.

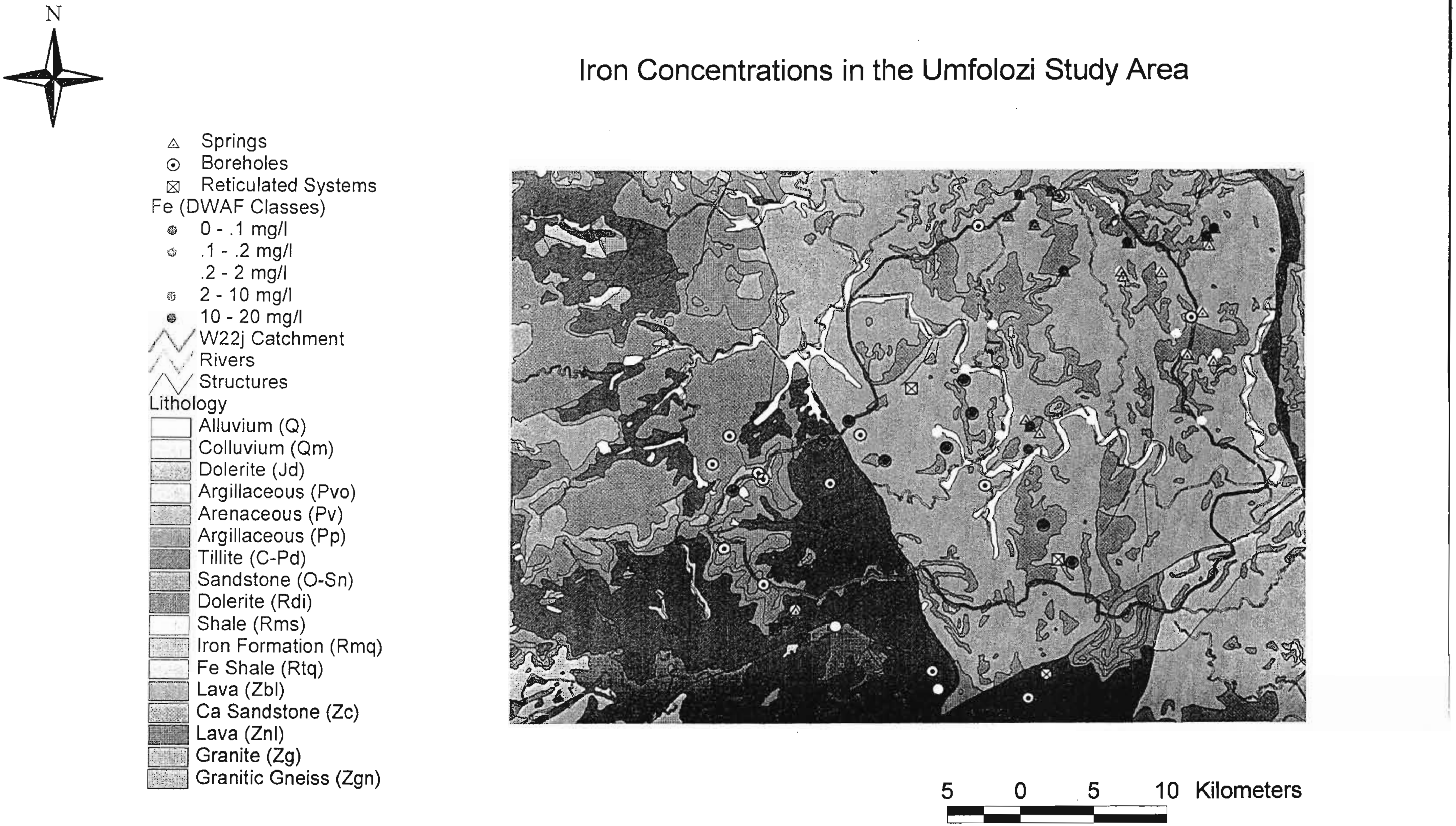


Figure 6.36 Iron concentrations overlain on the Umfolozi geology map.

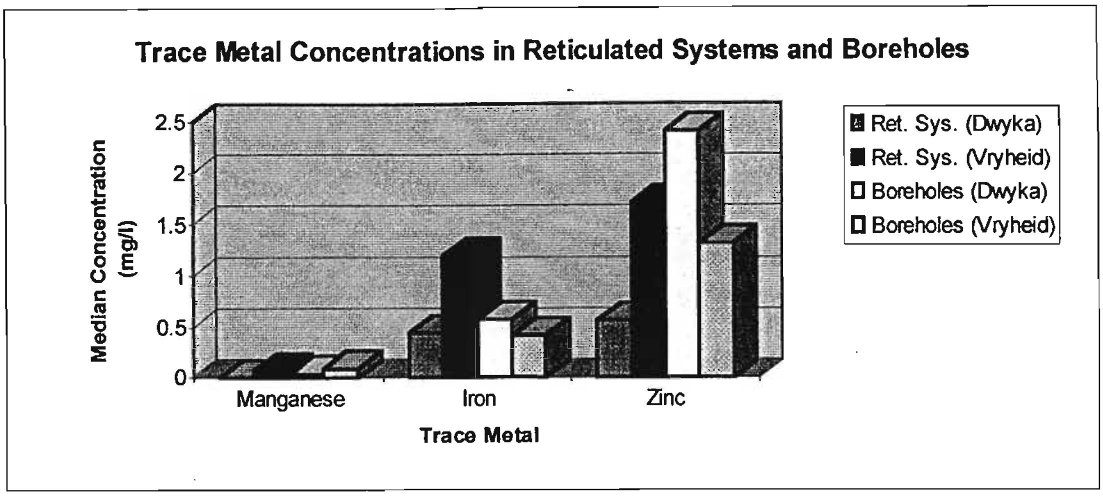


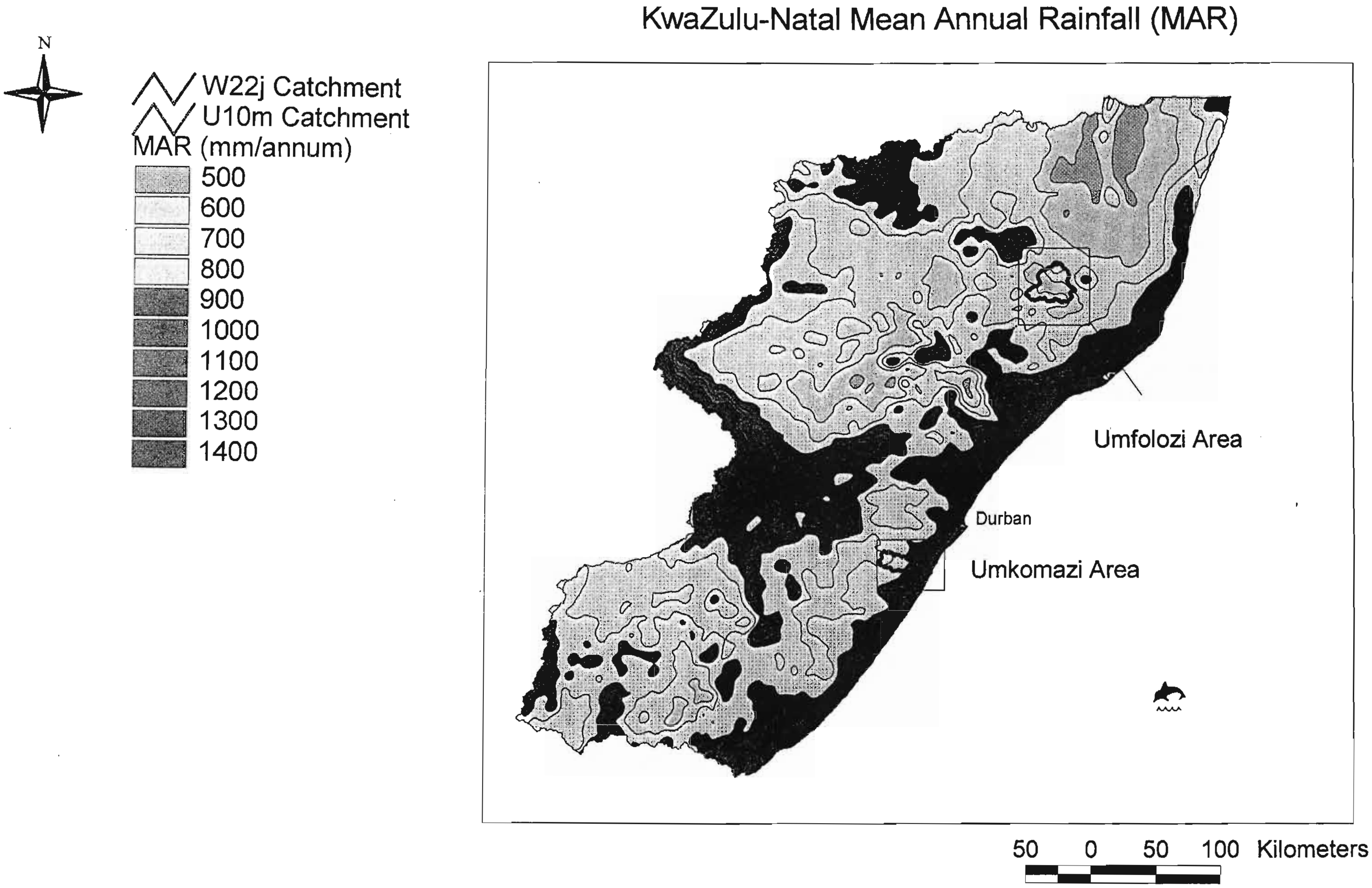
Figure 6.37 Reticulated systems and boreholes show similar trace metal concentrations.

In conclusion, the trace metals manganese, iron and zinc are primarily derived through the weathering of minerals in the bedrock, particularly ferromagnesium minerals such as pyroxene which occurs in dolerite (Bates and Jackson, 1984). Spring samples frequently show high concentrations of iron due to the hydrolysis and oxidation of iron species in the soil. Galvanised steel pipes may act as a secondary source of trace metals. Communities should be educated that the discoloration and staining caused by the trace metals does not, in general, mean the water is unfit for drinking, except possibly for sensitive individuals. Groundwater is usually safer for drinking than surface water, though the later may be more appropriate for laundry in areas where groundwater causes sever staining.

7. INFLUENCE OF RAINFALL ON GROUNDWATER QUALITY

Examination of the relationship between rainfall and electrical conductivity provides insight into trends in groundwater composition. Generally, there is an inverse relationship between rainfall and Total Dissolved Solids (TDS) / Electrical Conductivity (EC) because higher rainfall tends to flush out stagnant groundwater with more recently recharged water, which is lower in chemical constituents (Back and Letolle, 1982). This trend is clearly visible in the Umfolozi area. However, in the Umkomazi area the situation is complicated due to the proximity of the Indian Ocean. Mean Annual Rainfall (MAR) is highest on the coast, but airborne salinity also increases near the coast (Kienzle, 1993) resulting, locally, in a (positive) linear relationship between MAR and TDS/EC.

Comparison between the two catchment areas reveals that the Umfolozi area has lower MAR (600 - 800 mm/annum) than the Umkomazi area (700 - 1,000 mm/annum), and therefore generally higher EC values (Figures 7.1 - 7.3). This is largely because the Umfolozi area is located further from the coast. Away from the coast rainfall is controlled by elevation and topography. Higher altitudes receive greater precipitation, especially south-eastern facing slopes, as they intercept the main rain-bearing winds. Low areas, such as the Umfolozi Valley, receive relatively little rainfall. The following analysis is limited by the fact that available rainfall figures were given as annual means, while samples were only taken during September, which, especially in the Umfolozi area, represents a dry period (precipitation occurs mainly during the summer months, from November to March.)



KwaZulu-Natal Mean Annual Rainfall (MAR)

Figure 7.1 KwaZulu-Natal Mean Annual Rainfall (MAR).

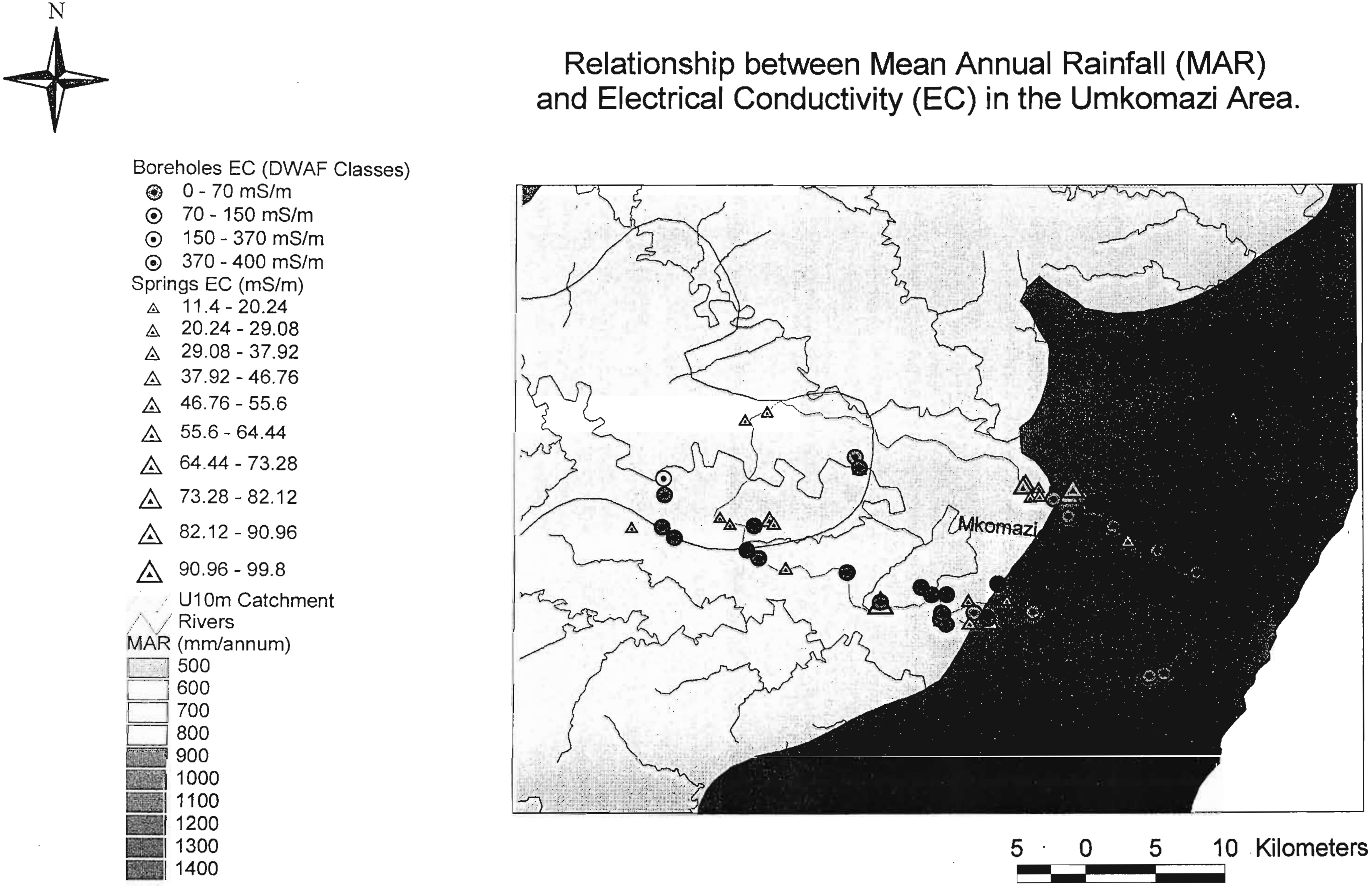


Figure 7.2 Relationship between MAR and EC in the Umkomazi area.

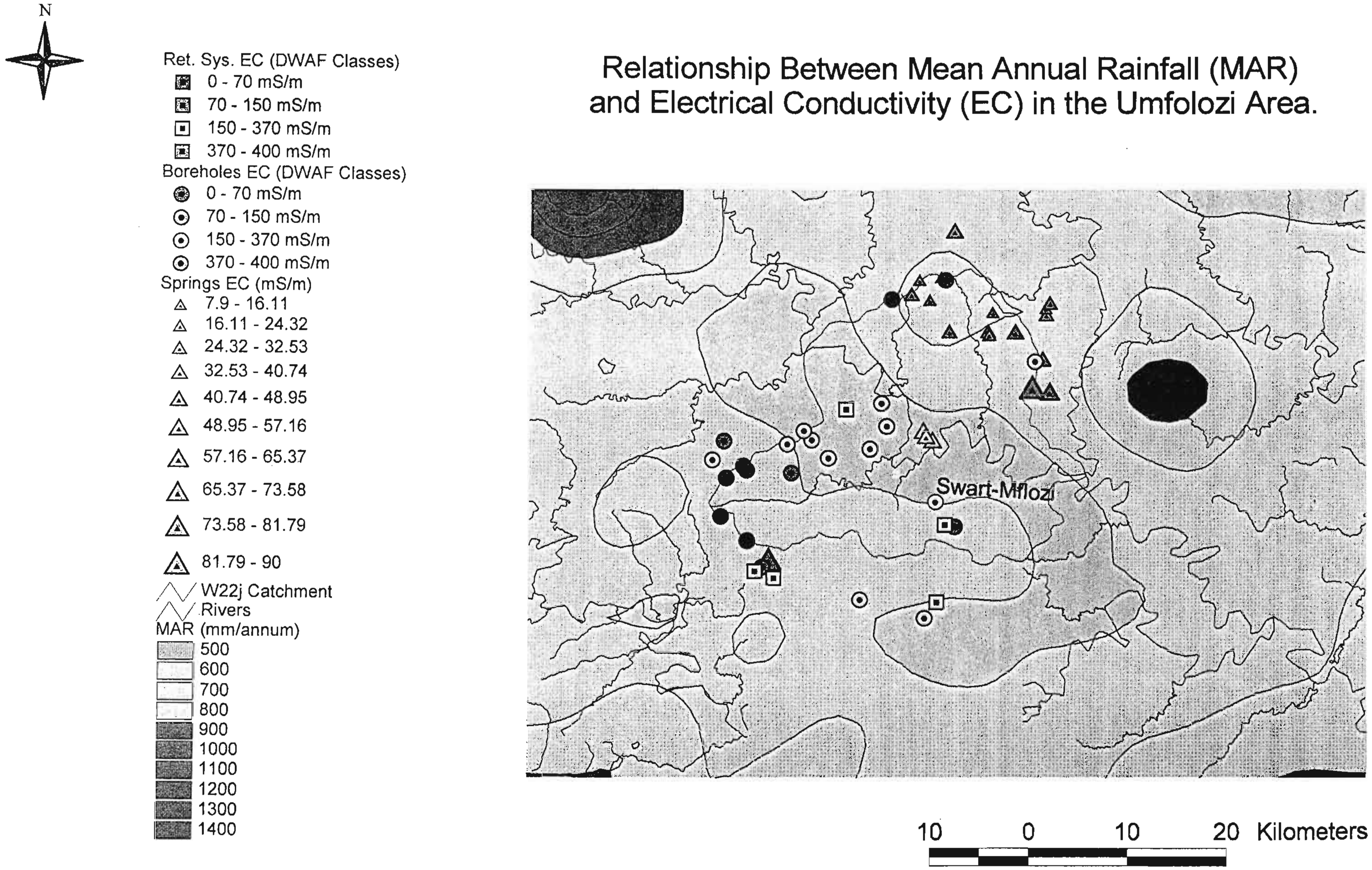


Figure 7.3 Relationship between MAR and EC in the Umfolozi area.

In the Umfolozi area boreholes frequently produce groundwater with unacceptable (Class 2 or Class 3) electrical conductivity (EC) values, e.g. greater than 150 mS/m (refer to Section 4.4 for DWAF Classification). Unacceptable samples are concentrated in the low rainfall area (MAR = 600 mm/annum) associated with the Umfolozi Valley. Springs provide more recently recharged water and thus have lower EC values than boreholes. However, even at lower concentrations, springs show a rainfall related trend; spring EC values are lowest in conjunction with the relatively high rainfall area (MAR = 800 mm/annum) located in the northern part of the study area (Figure 7.3). While electrical conductivity values are well spread for each rainfall level, median values indicate an inverse relationship between electrical conductivity and mean annual rainfall(Figure 7.4).

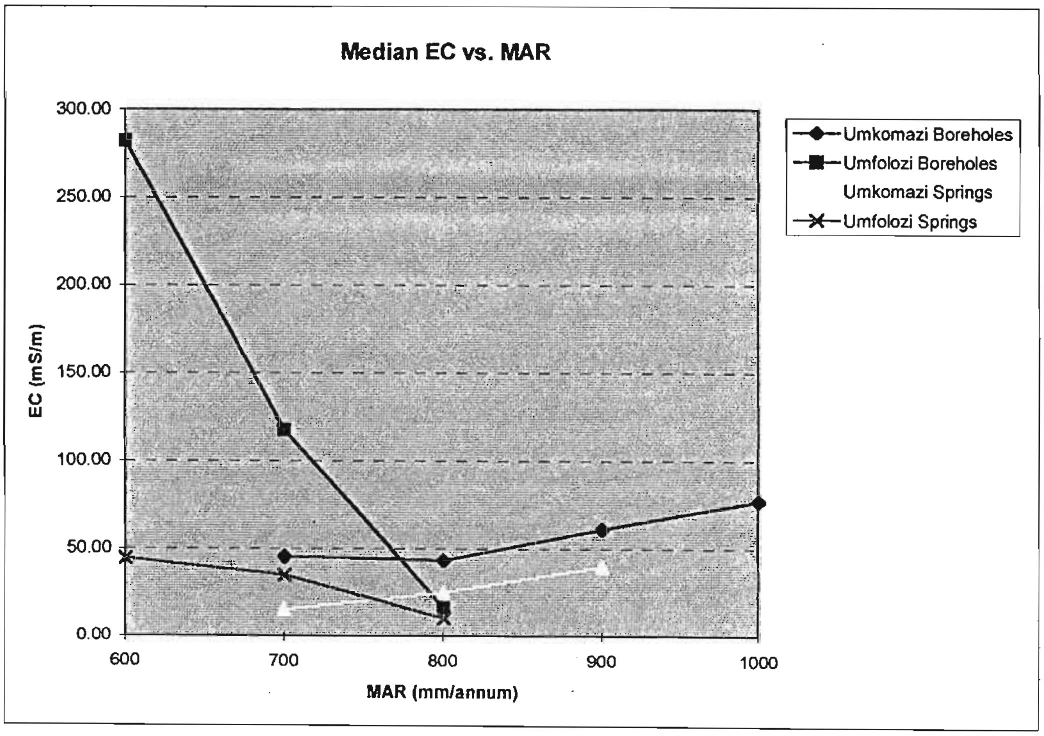


Figure 7.4 Umfolozi samples show an inverse relationship between EC and MAR, whereas Umkomazi samples show a positive linear relationship. Springs have lower EC than boreholes.

In contrast to the Umfolozi samples, the Umkomazi samples show acceptable EC (Figure 7.2). An exception, sample ZQCZMKH3B, had a lower end class 2 electrical conductivity value (165 mS/m), and was located in the relatively low MAR zone (MAR = 700 mm/annum). Also in contrast to the Umfolozi samples, the Umkomazi samples show an increase in median EC with an increase in rainfall (Figure 7.4). This apparent contradiction can be explained by examination of the rainfall map which shows an increase in rainfall near the coast. It is reasonable to expect that an increase in salt laden mists would also be experienced near the coast and that the salt deposited in the soil would be leached into the groundwater and that this would lead to an increase in EC. Further from the coast in the Umkomazi area, between MAR zones of 700 and 800 mm/annum there is a slight tendency, observable in boreholes, toward the inverse relationship seen in the Umfolozi area, this anomaly is likely due to a decrease in coastal influences (e.g. salinity) in this area.

Comparison of areas that experience a mean annual rainfall of 700 mm/annum indicates that Umfolozi boreholes have a higher median electrical conductivity than corresponding Umkomazi boreholes. However, at 800 mm/annum Umfolozi water sources have a *lower* median than corresponding Umkomazi water sources. It is probably that at a MAR of 700 mm/annum the Umfolozi boreholes have higher EC because of the predominance of relatively high salinity sedimentary rocks, compared to the basement rocks which dominate the Umkomazi area. However, at a MAR of 800 mm/annum the lithology type becomes less important compared to the increased coastal salinity in the Umkomazi area.

In conclusion, examination of rainfall provides useful insights into chemical trends in groundwater. In general there is an inverse relationship between mean annual rainfall (MAR) and electrical conductivity (EC). However, it has been shown that various factors e.g. coastal salinity, different lithologies, and different types of water sources, vastly complicate the analysis. Also, a more rigorous examination, including groundwater recharge and aquifer storativity would give more accurate results (Bredenkamp *et al*, 1995).

8. INFLUENCE OF LAND USE ACTIVITIES ON GROUNDWATER QUALITY

During sampling observations were recorded concerning land use practices e.g. mining, farming, the occurrence of animal dung and human excreta, distance to the nearest pit latrine and human activities such as clothes washing (Appendix 4). Nitrate and microbiological contamination were found to be a result of land use practices.

Except for the rare occurrence of nitrate minerals in the aquifer rocks, nitrate contamination in groundwater results from pit latrines, domestic animal wastes, human excreta, and natural soil nitrogen processes which are intensified during dryland cropping (Wagner and Sukrisno, 1994). High nitrate consumption leads to methaemoglobinaemia (blue baby) in infants and is linked to stomach cancer in adults. Similarly, microbiological contamination is caused by inappropriate land use activities and is largely dependant on source type. Springs are generally shallow, occurring at the contact between the soil cover and the underlying bed rock, and frequently yield high *E. coli* counts, whereas boreholes produce largely acceptable samples because fewer micro-organisms survive the infiltration process. Although E. coli and nitrate contamination both come from faecal sources examination of data shows a non-linear relationship between these constituents (Figure 8.1).

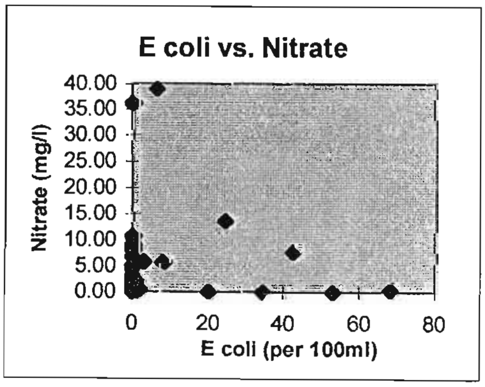


Figure 8.1 E. coli (per 100ml) compared to nitrate (mg/l).

41 out of 62 boreholes sampled (66%) provided water with acceptable (DWAF Class 0 and Class 1) *E. coli* and nitrate levels, where as only 12 out of 55 springs sampled (22%) produced acceptable samples. Considering that reticulated systems are essentially boreholes, they showed anomalous levels of *E. coli* and nitrate. Only 1 out of 5 (20%) were acceptable. This can be partially explained by the construction of the reticulated systems, which often consist of windmills pumping borehole water into a circular, concrete storage reservoir. In some cases water is obtained directly from taps on the outside the reservoir. However, the windmills only operate on windy days, and following periods of little wind, the water level in the reservoirs is quickly depleted, forcing the consumers to climb over the reservoir walls (when no cover exists) and scoop water off the bottom, obviously leading to contamination of the supply (Plate 2.2). Another explanation is that protected springs may have been mistaken for reticulated systems during sampling. Shallow wells (e.g. ZQCZDUD2F and ZQCZMAS1F) were hand dug in dry river beds in order to access water during the dry season, and were especially vulnerable to contamination (Plate 2.3).

The soil profile acts as a natural purification system which filters out faecal micro-organisms and breaks down chemical compounds. The effectiveness of the system is dependant on the host rock, degree of weathering and soil type. Where the host rock is fractured without a well developed weathering profile the contaminants travel freely along the fractures into the groundwater. However, given adequate thickness of weathering and sufficient distance (>20 m) between the contaminant source, e.g. the base of the pit latrine, and the water table natural processes will adequately reduce the amount of nitrate and ammonia which reach the groundwater.

Connelly and Tausig (1994) discussed the process by which effluent enters the unsaturated zone and gradually clogs pores creating a crust. This clogging increases the effectiveness of the natural purification system, as does the thickness of the unsaturated zone. Thus newly established pit latrines were found to cause greater pollution until the crust developed sufficiently. Further, a lateral distance of at least 200 m between latrines and water sources is recommended (Taylor and Howard, 1994). However, in the Umkomazi area 55% of sampled boreholes and 48% of sampled springs where located less than 200 m from pit latrines. In the Umfolozi area 45% of boreholes and 9% of springs where less than 200 m from pit latrines. Clearly, it would be useful to know whether boreholes were located up or down hydraulic gradient from the latrines, but this information was unobtainable within the limitations of the sampling process.

Borehole contamination may have resulted partially from inadequate construction practices including 1) insufficient and low quality well casing, 2) poor placement of formation seal between the borehole casing the bore wall, 3) inadequate welding of casing joints and 4) lack of sanitary covers (Drennan Maud and Partners, 1995 a). Sanitary borehole abandonment practices were not adhered to likely resulting in local contamination of water supplies.

Springs were rarely properly protected and ponding water was common around both borehole and spring sources. The accumulated water was generally polluted and likely percolated back into the water source. Evidence of clothes washing was frequent. In the Umkomazi area human excreta was observed near 29% of sampled boreholes and 70% of sampled springs. In the Umfolozi area excreta was found near 40% of boreholes and 61% of springs. Animal dung and animals were frequently seen in the proximity of water sources (Plate 8.1).

Plate 8.1 Cattle near a borehole.

In the Umkomazi area animals were observed near 68% of boreholes (median distance of 40 m) and 82% of springs (median distance = 15 m). In the Umfolozi area animals were near 55% of boreholes and 83% of springs (both with a median distance = 10m). Sampling methods were designed to take samples representative of the aquifer. Taps were sterilised and sterile sample bottles were used, thus samples analysis may show better quality water than is consumed, e.g. contamination from plastic drums during transportation is likely.

Though agricultural fields were common near water sources they were generally used for subsistence farming and use of fertilisers is unlikely. With the exception of the coastal belts, it is probably that nitrates accumulate in the soil during the dry season and are leached into the groundwater with the heavy down pours of the rainy season, which is from November to March (Chilton *et al*, 1994). The time dependant nature of groundwater contaminants was outside the scope of this investigation. Comparison between the two catchment areas shows similar median *E. coli* and nitrate levels, though averages show greater variation (Table 8.1).

Table 8.1 *E. coli* and Nitrate Levels Separated by Area and Source Type.

Area and Source	*E. coli* (average) #/100ml	*E. coli* (median) #/100ml	Nitrate (average) mg/l	Nitrate (median) mg/l
Umkomazi				
Boreholes	42	0	3.19	1.26
Springs	498	49	2.83	1.74
Umfolozi				
Boreholes	13	0	11.15	3.71
Ret. System	162	4	18.45	16.15
Springs	802	50	3.36	1.19

Due to numerous unknown variables, such as the depth to the water table, the distance from the base of the latrine to the watertable, details of the soil type and direction of the hydraulic gradient it is difficult to quantify a relationship between distance to the nearest latrine and *E. coli* and nitrate contamination. Thus, graphing distance to pit latrine against *E. coli* and nitrate levels shows wide scatter, e.g. $R^2 = 0.0004$ (Figures 8.2 and 8.3).

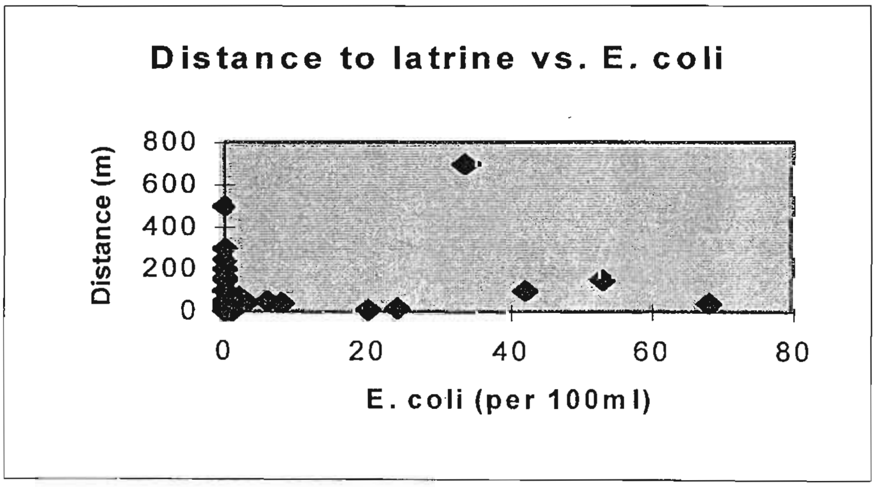


Figure 8.2 Comparison between distance to nearest pit latrine and E. coli count.

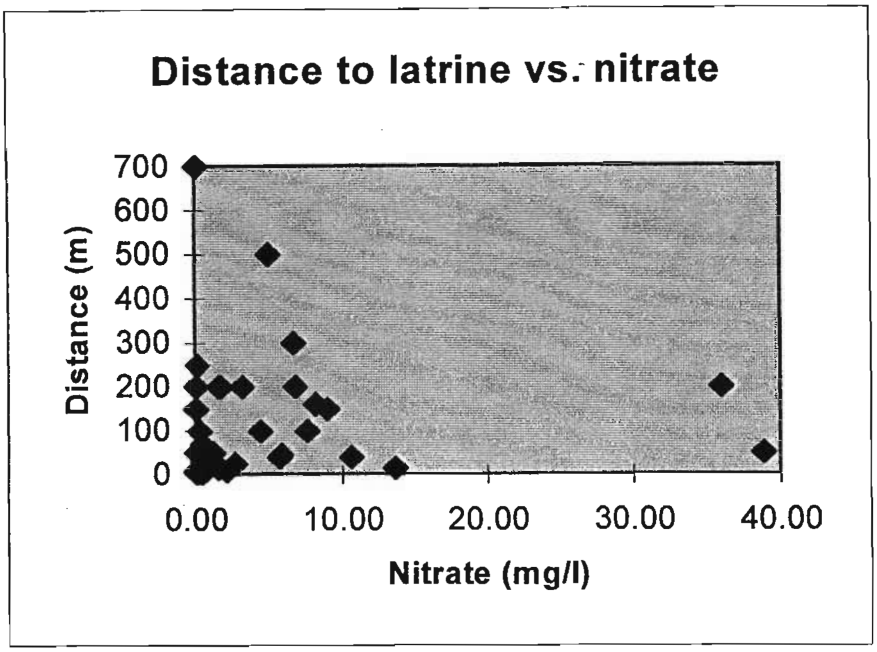


Figure 8.3 Comparison between distance to nearest pit latrine and nitrate concentration.

However, comparison of water sources with acceptable (DWAF Class 0 and Class 1) *E. coli* and nitrate levels with unacceptable (DWAF Class 2 and Class 3) sources shows that a lower percent of acceptable sources are within 200 m of a latrine. 62% of unacceptable boreholes are less than 200 m from a latrine, compared to only 46% of acceptable boreholes. 30% of unacceptable springs are less than 200 m from a latrine, compared to 25% of acceptable springs. A similar trend is seen for boreholes and occurrence of human excreta and animals in the vicinity, however this relationship does not hold for springs (Table 8.2).

Table 8.2 Acceptability of Water Sources Compared to Faecal Occurrence

Source	Count	Within 200m of latrine	Human excreta near source	Animals in proximity
Acceptable boreholes	41	46%	29%	54%
Unacceptable boreholes	21	62%	30%	71%
Acceptable springs	12	25%	67%	100%
Unacceptable springs	43	30%	63%	33%

In conclusion, along with proper borehole location and construction (Braune, 1996), community education is recommended as the best method for reducing the microbiological and nitrate contamination of water sources (Sutton, 1994). Communities should be educated regarding water related diseases, and methods of water collection and transportation (Plate 8.2) that would reduce further contamination (Ward, 1994). Water sources should be fenced off from animals and community members should understand the implication of human excreta near water sources. Springs should be adequately protected to ensure they are not polluted by run off or users (Woodhouse, 1994).

Plate 8.2 Transporting water.

9. CONCLUSIONS

This research was motivated by the importance of providing clean drinking water for citizens of developing countries, coupled with the lack of information regarding the quality of water sources in rural South African communities. This research was conducted with the aim of establishing a relationship between the groundwater quality in the rural Umkomazi and Umfolozi catchment areas and variables such as:

- lithology, e.g. environment of deposition and mineralogy;
- hydrogeology, e.g. type of aquifer and occurrence of discontinuities;
- source type, e.g. boreholes, springs, wells, reticulated systems;
- mean annual rainfall (MAR);
- coastal proximity; and
- landuse activities, e.g. farming, agriculture, distance to pit latrines.

A secondary goal of this research was assisting the collaborators of the DWAF Pilot Study achieve their objective of understanding of the types and the extent of water quality problems experienced by rural communities.

Previous authors, Bond (1946), Van Wyk (1963), Davies Lynn and Partners (1995 a and b), Drennan Maud and Partners (1995 a and b) and E. Martinelli and Associates (1995), looked at water samples in and around the study areas, however, no conclusive or quantitative relationship was drawn between groundwater quality and the above factors. As suggested by several of the above authors, the first impression of the water quality data suggests little relationship between absolute concentrations of constituents and lithology. This is largely due to the secondary nature of the aquifers in the study areas. Groundwater mainly occurs in joints, faults and other discontinuities which are poorly connected to each other through the relatively impermeable intact rock. Thus infiltration and chemical concentrations are dependant on the permeability and orientation of discontinuities which are intercepted by the boreholes. Further, concentrations are dynamic along any given flow path and aquifers are interconnected. Drillers often aim for contacts between geological units and influence of hidden dolerite sills was likely, especially in the Umfolozi area. The wide range of concentrations for each given lithology is seen by examining the GIS views. Relative concentrations of major ions also show variability within a given lithology, as evidenced by the well spread clusters on the Piper diagrams and the variety of shapes produced on Stiff diagrams, with the exception of the Vryheid Formation fingerprint.

Comparison of median values for each lithology, however, revealed a clear correlation between concentrations of most constituents (excluding those derived from anthropogenic pollution) and lithology. Groundwater derived from Dwyka Tillite was found to have the highest median concentrations of major ions in Umkomazi and Umfolozi springs and Umkomazi boreholes. Water derived from the Vryheid formation shows the highest borehole TDS concentrations in the Umfolozi area. This high salinity is attributed to marine influence during deposition and frequently results in aesthetic problems and possibly health problems to sensitive individuals, e.g. infants. High salinity is particularly noticeable in the Umfolozi area which is underlain by a higher percent of sedimentary rocks and experiences a lower mean annual rainfall.

Fluoride is highest in water derived from the granitic basement rocks of the Natal Structural and Metamorphic Province due to the isomorphous relationship between the fluoride ion and the hydroxyl ion in silicate minerals. The fluoride ion replaces hydroxylapatite with fluorapatite in teeth and bones, which may be beneficial at low concentrations, but harmful at slightly higher levels. Aqueous fluoride concentrations were shown to vary inversely with aqueous calcium concentrations through the formation of relatively insoluble calcium fluoride.

The trace metals manganese, iron and zinc are responsible for wide spread aesthetic problems, and possible health problems. They are derived from the weathering of basement minerals, such as the ferromagnesium mineral pyroxene and nickel rich pentlandites found in the Karoo dolerite. While springs generally show lower concentrations than boreholes, trace metals are occasionally higher in springs due to the facilitation of hydrolysis and oxidation processes in the soil.

Electrical conductivity was shown to vary inversely with mean annual rainfall, except near the coast where high salinity mists are carried inland from the Indian Ocean. High nitrate and *E. coli* are linked to landuse activities, e.g. the present of human and animal excreta near the water source and the distance to the nearest latrine.

This research project was limited by several factors including inaccuracies incurred during sampling, labelling and use of the GPS. Further inaccuracies may have arisen from bacteriological sample analyses, which were done in the field, and by chemical analyses, which were done in the laboratories. Hidden sills and boundary contacts between lithological units may have caused a misrepresentation of samples points and associated lithology. Some boreholes probably yielded water derived from more than one lithology, and this would have confused the interpretation of the groundwater geochemistry (Back and Freeze, 1983). Because the laboratory reported a value for total alkalinity, instead of listing bicarbonate and carbonate separately, inaccuracies resulted in converting milligrams per litre to milliequivalents per litre. Statistical results depended on whether the mean, median or mode was chosen to represent middle tendencies, and these methods masked extreme tendencies. The statistical significance of this work was limited by the low number of samples taken during the pilot study. The correlation between lithology and water quality was limited by a skewed sampling design. Also, because sources were only sampled once, the time dependant nature of water quality could not be examined in this study.

It is recommended that communities be educated regarding the nature and importance of good quality groundwater. Springs generally provide water of lower chemical concentrations than boreholes but they are more vulnerable to anthropogenic pollution and drought. Water sources should be fenced off from animals and free from human excreta. Pit latrines must be appropriately located. Consumers should be educated regarding water related diseases and proper methods of water collection and transportation. Also consumers should be educated regarding trace metals. Discoloration and staining caused by trace metals does not usually indicate that the water is unhealthy, except possibly for sensitive individuals. Groundwater usually has less biological pollution than surface water, though the later may be more appropriate for laundry in areas where groundwater causes staining. If individuals notice teeth mottling from high fluoride levels they should stop using fluorinated toothpaste and mouth wash and stop drinking tea, as tea drinkers consume, on average, an extra mg/l of fluoride each day.

ACKNOWLEDGEMENTS

The author kindly acknowledges Georgina King for the invitation to work on the Pilot Study, Mark Salter for assistance digitising geology coverage, Colin Jermy and Carol Marsh for proof reading multiple rough drafts, and Anthony Crook ♥ for use of his computer and support. Finally, a sincere thank you to the reviewers of this thesis.

References

Ashley, R. P and M. J. Burley (1994). *Controls on the occurrence of fluoride in groundwater in the Rift Valley of Ethiopia*. In Groundwater Quality. Chapman & Hall, London.

Back, W. and Freeze, A. (1983). *Chemical Hydrogeology*. Hutchinson and Ross, Stroudsburg, Pennsylvania

Back, W. And Letolle, R., (1982). *Symposium on Geochemistry of Groundwater*. Elsevier Scientific Publishing Company, Amsterdam.

Bates, R. L., and Jackson, J. A. (1984). *Dictionary of Geological Terms*. Anchor Books, New York.

Bayer, A. W. (1938). *An Account of the Plant Ecology of the Coastal belt and Midlands of Zululand*: Ann. Natal Mus.

Bond, G.W. (1946). Geochemical survey of the underground water supplies of the Union of South Africa, *Mem. 41*, geol. Surv. S. Africa.

Braune, E. (1996). *Groundwater: Guidelines for Boreholes*. Compiled by Borehole Water Association of South Africa, CSIR, Depart. Agriculture, Depart. Of Water Affairs and the Geological Society of South Africa.

Bredenkamp, D. B., Botha, L.J., Van Tonder, G. J., and Janse van Rensburg, H. (1995). *Manual on qualitative estimation of groundwater recharge and aquifer storativity*. Water Research Commission, South Africa.

British Geological Survey (1988). *Iron in Rural Groundwater*. Information booklet adapted from World Water, p. 19.

Chilton, P. J., Lawrence A. R. And Stuart, M. E. (1994). *The Impact of tropical agriculture on groundwater quality. In Groundwater Quality*. Chapman & Hall, London.

City of Los Angeles Water Services (1995 a). *Water Quality - Primary Standards*. Internet, Web Ferret Search.

City of Los Angeles Water Services (1995 b). *Water Quality Analysis Table for 1995: Additional Constituents (No Standards Exists)*. Internet, Web Ferret Search.

City of Los Angeles Water Services (1996). *City of Los Angeles Water Services - Water Quality*. Internet, Web Ferret Search.

Connelly, R. J. And Taussig, D. (1994). *Nitrate contamination of groundwater in the Kutama and Sinthumule districts of Venda, South Africa*. In Groundwater Quality. Chapman & Hall, London.

Crook, A. D. (1997). National Diploma of Surveying. *pers. Comm.*

Crowley, F. W., Jackson, C. R., and Heard T. R. (1985). Application of science to water supply projects in developing countries. *JIWES*, Vol, 39, pp 46 - 57.

Davies Lynn and Partners (1995 a). *Characterisation and Mapping of the Groundwater Resources of Mapping Unit 4 of the Kwazulu-Natal Province*. DWAF Report.

Davies Lynn and Partners (1995 b). *Characterisation and Mapping of the Groundwater Resources of Mapping Unit 8 of the Kwazulu-Natal Province*. DWAF Report.

Department of Water Affairs and Forestry (1996). *A Guide for the Health Related Assessment of the Quality of Water Supplies*.

Domenico, P. A. and Schwartz F. W. (1990). *Physical and Chemical Hydrogeology*. John Wiley & Sons, Inc., Singapore.

Drennan Maud and Partners (1995 a). *Characterisation and Mapping of the Groundwater Resources of Mapping Unit 3 of the Kwazulu-Natal Province*. DWAF Report.

Drennan Maud and Partners (1995 b). *Characterisation and Mapping of the Groundwater Resources of Mapping Unit 10 of the Kwazulu-Natal Province*. DWAF Report

Du Plessis, J. B. (1997). *What would be the Maximum Concentration of Fluoride in Water that will not cause Dental Fluorosis*? Depart. of Stomatological Studies, MEDUNSA. Internet, Web Ferret Search.

Dutlow, R., (1996). *Use of a GIS in the assessment of borehole water quality*. Project proposal, Water Quality Scientific Services (unpubl.).

E. Martinelli and Associates (1995). *Characterisation and Mapping of the Groundwater Resources of Mapping Unit 5 of the Kwazulu-Natal Province*. DWAF Report.

Edmunds, W. M. (1994 a). *Groundwater Chemistry and Development*. In Groundwater Quality. Chapman & Hall, London.

Edmunds, W. M. (1994 b). *Characterisation of groundwaters in semi-arid and arid zones using minor elements*. In Groundwater Quality. Chapman & Hall, London.

Edmunds, W. M. and Smedley, P. L. (1996). *Trace Elements in Groundwater and Their Significance in terms of Health and Environmental Protection*. In Environmental Geochemistry and Health with Special Reference to Developing Countries. The Geological Society, London.

ESRI (1996). Environmental Systems Research Institute Inc., Redlands, California, USA.

Fleischer, M. (1972). *Fluorine*: *The Relation of Selected Trace Elements to Health and Disease*. A report of the workshop at the Asilomar Conference Grounds Pacific Grove, California.

Frommurze, H. F. (1953). *Hydrological research in arid and semi-arid areas in the union of South Africa and Angola*. Reviews of Research on Arid Zone Hydrology UNESCO.

Ginster, M. And Fey, M. V. (1997). *Soil and Plant Responses to Irrigation with a Fluoride-rich Waste Water*. Depart. of Geological Sciences, University of Cape Town. Internet, Web Ferret Search.

Hamill, L. and Bell, F.G. (1986), *Groundwater Resource Development*. Butterworths, London. 344 pp.

Herbert, R. (1994). *A Rural Water Supplies Organiser for the weathered crystalline basement aquifers*. In Groundwater Quality. Chapman & Hall, London.

Hileman, B. (1988). Fluoridation of Water: Questions about health risks and benefits remain after more than 40 years. *Chemical & Engineering News*. Vol 66, No. 31, pp 26 - 42.

Institute of Water Quality Studies (1996 a). Pilot Study into Community Water Quality Status: Training notes for Map Reading, GPS Application and Water Sampling. (unpubl.).

Institute for Water Quality Studies (1996 b). A Pilot Study to Assess the Health-Related Quality of Community Water Supplies in Selected Areas in KwaZulu-Natal. (unpubl.).

Isiorho, S. A., and Nkereuwem, T. O., (1996) Reconnaissance Study of the Relationship Between Lineaments and Fractures in the Southwest Portion of the Lake Chad Basin. *Journal of Environmental and Engineering Geophysics*, Vol 1, Issue 1 pp. 47-54.

Jha, L. B., and Jha, M. (1982). Fluoride Pollution in India. *Intern. J. Environmental Studies*, Vol. 19, pp 225 - 230.

Kattenhorn, S. A. (1994). *Mechanisms of Sill and Dyke Intrusion*. MSc Thesis (unpubl.). Department of Geology and Applied Geology, University of Natal.

Kempster, P. L., Hattingh, W.H.J. and Van Vliet, H. R. (1982). Summarized Water Quality Criteria. Technical Report. Department of Environment Affairs, Pretoria.

Kienzle, S. W. (1993). *The Role of Atmospheric Salt Input and Evapoconcnetration on River Salination in the Breede River Catchment, Western Cape Province, South Africa.* Paper presented at conference proceedings of the Sixth South African National Hydrological Symposium. pp 637 - 645.

Leary, W. P., Reyes, A. J., Lockett, C. J, Arbuckle, D. D., and Van der Byl, K. (1997). *Magnesium and deaths ascribed to ischaemic heart disease in South Africa.* Departments of Experimental and Clinical Pharmacology and Community Health, University of Natal, Durban. Internet, Web Ferret Search.

Linstrom, W. (1987). Explanation of *The Geology of the Dundee Area*, Government Printer.

Lloyd, J. W. (1994). *Groundwater and Salinity.* In Groundwater Quality. Chapman & Hall, London.

McCaffrey, L.. P. (1997). *Distribution and Origin of High Fluoride Groundwater in the Western Bushveld.* Depart. of Geological Sciences, University of Cape Town. Internet, Web Ferret Search.

Meyer, J. A, Casey, N.H., and Coetzee, C. B. (1997). *A New Approach to define the Target Water Quality Range for Fluoride in the Drinking Water for Livestock.* Depart. of Animal and Wildlife Sciences, Univerisity of Pretoria. Internet, Web Ferret Search.

Mokrzynska, A. M. (1995). Fluoride-Magnesium Interaction. *J. of the International Society for Fluoride Research.* Vol. 28, No. 4, pp 175 = 177.

Piper, A. M. (1944). A graphic procedure in the geochemical interpretation of water-analyses. *Am. Geophys.* Union Trans. 25:914-923.

Punsar, S. And Karvonen, M. J. (1979). Drinking Water Quality and Sudden Death: Observations from West and East Finland. *Cardiology* 64, pp 24 - 34.

Rudolph, M. J., Molefe, M., and Chikte, U.M.E. (1997). Dental Fluorosis with Varying Leveles of Fluoride in Drinking Water. Depart. of Community Dentistry, Univerity of the Witwatersrand. Internet, Web Ferret Search.

Stiff, H. A. (1953). The interpretation of chemical water analysis by means of patterns. Jour. Petroleum Technology 3, No. 10, Secton 1, 15-16; Secton 2, 3.

Sutton, S. E. (1994). *Microbiological quality of groundwater supplies in rural Zambia. In Groundwater Quality.* Chapman & Hall, London.

Taylor, R. G. And Howard, K. W. F. (1994). *Groundwater quality in rural Uganda: hydrochemical considerations for the development of aquifers within the basement complex of Africa.* In Groundwater Quality. Chapman & Hall, London.

Thomas, R.J. (1988). Explanation of *The Geology of the Port Shepstone Area*, Government Printer.

Truswell, J. F, (1970). *An Introduction to the Historical Geology of South Africa.* Purnell, Cape Town.

Umgeni Water (1996). Pilot Study in KwaZulu-Natal: Training in Sampling Groundwater, Surface Water and Faecal Coliform Analysis. (unpubl.).

Van Wyk, W. L., (1963). Ground-water Studies in Northern Natal, Zululand and Surrounding Areas. *Memoir 52* Geol. Surv. Dep. S.A.

Wagner, W. and Sukrisno (1994). *Natural groundwater quality and groundwater contamination in the Bandung Basin, Indonesia.* In Groundwater Quality. Chapman & Hall, London.

Ward, C. F. (1994). *Impact of Human Activity on Groundwater Quality in Rural Areas.* In Groundwater Quality. Chapman & Hall, London.

Woodhouse, M., (1994). *Salinity and shallow wells: a view from the field.* In Groundwater Quality. Chapman & Hall, London.

Geological Maps:

Sheet 2830 Dundee

Sheet 3030 Port Shepstone

APPENDICES

APPENDIX 1: SAMPLE FORM

GROUNDWATER AND SURFACE WATER SAMPLING FOR HEALTH RELATED WATER QUALITY (FOR PILOT STUDIES ONLY)

District: ☐ Village/Farm name ☐

Date: ☐ Time: ☐

Topo sheet no. ☐ Drainage region ☐

Co-ordinates:	Latitude:	Degrees:	☐	Minutes: ☐	Seconds:	☐	south
	Longitude:	Degrees:	☐	Minutes: ☐	Seconds:	☐	east

Co-ordinates obtained from ☐ GPS ☐ map New record: ☐ Yes ☐ No

Sampling point type ☐ river ☐ borehole ☐ well ☐ spring

Field borehole no. ☐ Pump type ☐

Is the equipment operational ☐ If NO, what is the problem?: ☐

Spring: ☐ protected ☐ unprotected

Estimated no. of people using the source: ☐

Landuse activities in the vicinity of water source:

Mining: if any, explain how it can impact on water quality ☐

Agricultural: Closest animals ☐ distance in metres

☐ Animal dung near source

Agricultural fields:

Distance of nearest field: ☐ distance in metres

Are fertilisers used? ☐ Yes ☐ No ☐ Don't know

Nearest dwellings ☐ distance in metres

Nearest pit latrine ☐ distance in metres ☐ no pits

Does any discharge entering the water source come from human activities?

☐ Yes ☐ No Type of activity ☐

Is the source protected and formalised?: ☐ Yes ☐ No

Is the source susceptible to contamination from storm water/human excreta?: ☐ Yes ☐ No

If answer is YES, please specify: ☐

Sampling No. H. No. ☐ T. No. ☐

ZQC No. ☐

Field EC: ☐ Field pH: ☐

Turbidity: ☐ for surface water only

Name of sampler: ☐ Dept: ☐

APPENDIX 2: WATER QUALITY STANDARDS

APPENDIX 2 A: South African Standard for Drinking Water (SABS 241/1984)

Element	Unit	Minimum acceptable value	Minimum guideline value	Maximum guideline value	Maximum acceptable value
pH		5.50	6.00	9.00	9.50
Electrical conductivity	mS / m	0.0	0.0	70.0	300.0
Total dissolved solids	mg / L	0	0	N.S.	N.S.
Temp.	°C	0.0	0.0	25.0	30.0
Specific gravity	mg / L	0.000	0.000	10.000	10.000
Calcium	mg / L	0	0	150	200
Magnesium	mg / L	0	0	70	100
Sodium	mg / L	0	0	100	400
Potassium	mg / L	0.0	0.0	200.0	400.0
Silicon	mg / L	0.0	0.0	N.S.	N.S.
Phenol-phthalein alkalinity	mg / L	0	0	N.S.	N.S.
Total alkalinity	mg / L	0	0	N.S.	N.S.
Methyl orange acidity	mg / L	0	0	N.S.	N.S.
Phenol-phthalein acidity	mg / L	0	0	N.S.	N.S.
Chloride	mg / L	0	0	250	600
Sulphate	mg / L	0	0	200	600
Nitrate (as N)	mg / L	0.0	0.0	5.0	9.0
Fluoride	mg / L	0.0	0.0	1.0	105
Aluminium	mg / L	0.00	0.00	0.15	0.50
Arsenic	mg / L	0.000	0.000	.0100	0.300
Boron	mg / L	0.000	0.000	0.500	2.000
Cadmium	mg / L	0.000	0.000	0.010	0.020
Cyanide	mg / L	0.000	0.000	0.200	0.300
Chromium	mg / L	0.000	0.000	0.100	0.200
Copper	mg / L	0.000	0.000	0.500	1.000
Iron (total)	mg / L	0.00	0.00	0.10	1.00
Manganese	mg / L	0.000	0.000	0.050	1.000

Element	**Unit**	**Minimum acceptable value**	**Minimum guideline value**	**Maximum guideline value**	**Maximum acceptable value**
Lead	mg / L	0.000	0.000	0.050	0.100
Strontium	mg / L	0.000	0.000	N.S.	N.S.
Zinc	mg / L	0.000	0.000	1.000	5.000
Carbonate	mg / L	0	0	N.S.	N.S.
Bicarb.	mg / L	0	0	N.S.	N.S.
Calcium hardness	mg / L	0	0	500	N.S.
Magnesium hardness	mg / L	0	0	N.S.	N.S.
Langelier index		N.S.	N.S.	N.S.	N.S.
Total dissolved solids (EC*7)	mg / L	0	0	N.S.	N.S.
Total dissolved solids (Σ)	mg / L	0	0	N.S.	N.S.
Σ Cations	meq / L	0.00	0.00	N.S.	N.S.
Σ Anions	meq / L	0.00	0.00	N.S.	N.S.
Ion-balance error	%	-10.00	-5.00	5	10.00
Color	mg / L Pt	0	0	20	20
Odor	TON	0	0	1	5
Dissolved oxygen	%	30	30	100	100
Chemical oxygen demand	mg / L	0	0	N.S.	N.S.
Taste	TTN	0	0	1	5
Turbidity	NTU	0.0	0.0	1.0	5.0
Nitrite (as N)	mg / L	0.00	0.00	6.00	10.00
Nitrogen (Kjeldahl)	mg / L	0.00	0.00	N.S.	N.S.
Phenols	mg / L	0.00	0.00	5.00	10.00
Phosphate	mg / L	0.00	0.00	N.S.	N.S.
Hydrogen sulfide	mg / L	0.000	0.000	0.100	0.300
Soap	mg / L	0.00	0.00	N.S.	N.S.
E. coli	No / 100ml	0	0	N.S.	N.S.
Bromide	mg / L	0.00	0.00	N.S.	N.S.
Chlorine	mg / L	0.20	0.20	5.00	5.00

Element	**Unit**	**Minimum acceptable value**	**Minimum guideline value**	**Maximum guideline value**	**Maximum acceptable value**
(free risidual)					
Dissolved organic carbon	mg / L	0.00	0.00	5.00	10.00
Sulfide	mg / L	0.00	0.00	N.S.	N.S.
Methyl blue sub.	LAS	0.00	0.00	0.50	1.00
Silver	mg / L	0.000	0.000	0.020	0.050
Gold	mg / L	0.000	0.000	0.002	0.005
Barium	mg / L	0.000	0.000	0.500	1.000
Beryllium	mg / L	0.000	0.000	0.112	0.005
Bismuth	mg / L	0.000	0.000	0.250	0.500
Cesium	mg / L	0.000	0.000	1.000	2.000
Cobalt	mg / L	0.000	0.000	0.250	0.500
Mercury	mg / L	0.000	0.000	0.005	0.010
Iodine	mg / L	0.000	0.000	0.500	1.000
Lithium	mg / L	0.000	0.000	2.500	5.000
Molybdenum	mg / L	0.000	0.000	0.050	0.100
Nickel	mg / L	0.000	0.000	0.250	0.500
Antimony	mg / L	0.000	0.000	0.050	0.100
Selenium	mg / L	0.000	0.000	0.020	0.050
Tellurium	mg / L	0.000	0.000	0.002	0.005
titanium	mg / L	0.000	0.000	0.100	0.500
Thallium	mg / L	0.000	0.000	0.005	0.01
Uranium	mg / L	0.000	0.000	1.000	4.000
Vanadium	mg / L	0.000	0.000	0.250	0.500
Tungsten	mg / L	0.000	0.000	0.100	0.500
Platinum	mg / L	0.0	0.0	0.0	0.0
Ammonia (as N)	mg / L	0.00	0.00	1.00	2.00

APPENDIX 2 B: Water Standards for the European Community (EC), the United Kingdom (UK), the United States (US) and the World Health Organisation (WHO).

Constituent	EC	UK	US	WHO
Conductivity (mS/m)	40.0			
Aluminium (mg/l)	0.2	0.2		0.2
Calcium (mg/l)	100			
Magnesium (mg/l)	50.0	50.0		
Sodium (mg/l)	150.0	150.0		200.0
Potassium (mg/l)	12.0	12.0		
Iron (mg/l)	0.2		0.3	0.3
Manganese (mg/l)	0.05	0.05	0.05	0.1
Nitrate (mg/l)	50.0	50.0	10.0	50.0
Chloride (mg/l)	200.0		250.0	250.0
Fluoride (mg/l)	1.5	1.5	4.0	1.5
Sulphate (mg/l)	250.0	250.0	250.0	250.0
Faecal coliforms (E. Coli) No/100ml	0	0	0	0

APPENDIX 2C: Summary of World Opinion

Determinant	Unit	Minimum	Median	Maximum
Aesthetic & Physical				
Ammonium (as N)	mg / l	0	0.5	2
Chlorine (disinfectant)	mg / l	0	0	0.2
Colour	Pt-Co units	5	15	150
Conductivity	mS / m	30	100	200
Hydrogen sulphide	mg / l	0	0.05	0.3
Iron	µg / l	50	300	1000
Manganese	µg / l	10	50	1000
Odour	TON	3	3	4
Oil and Grease	mg / l	0	0.2	0.5
Oxygen (dissolved)	mg / l	>3	>5	>7
pH	pH units	5.0	6.5 - 9.0	9.5
Phenols	µg / l	0.5	1	5
Suspended solids	mg / l	25	25	25
Taste	subjective			
Temperature	°C	15	25	25
Turbidity	NTU	0	5	250
Biological				
Coliforms, faecal	Nos / 100 ml	0	0	2000*
Coliforms, total	Nos / 100 ml	0	10	50,000*
Enteroviruses	Nos / 10 l		0	
Streptococci, Faecal	Nos / 100 ml	0	20	20,000*
High Toxicity				
Antimony	µg / l	0.2	50	50
Beryllium	µg / l	0.2	0.2	1000

Determinant	Unit	Minimum	Median	Maximum
Cadmium	µg / l	1	10	50
Gold	µg / l	-	20	
Lead	µg / l	30	50	100
Mercury	µg / l	0.1	2	20
Aldrin (pesticide)	µg / l	1	1	17
Chlordane (pesticide)	µg / l	3	3	3
Dieldrin (pesticide)	µg / l	1	1	17
Edrin (pesticide)	µg / l	0.2	0.5	1
Heptachlor (pesticide)	µg / l	0.1	0.1	50
Lindane (γBHC), pest.	µg / l	4	5	56
Parathion (pesticide)	µg / l	3	35	100
Toxaphene (pesticide)	µg / l	5	5	5
-2,4, 5-TP (pesticide)	µg / l	10	10	30
Polychloro-biphenyl	µg / l		1	
Polycyclic aromatics	µg / l	0.2	3	5
Radium	µg / l		1	
Selenium	µg / l	1	10	50
Tellurium	µg / l		10	
Thallium	µg / l		5	
Thorium	µg / l		0.5	
Yttrium	µg / l		1	
Moderate Toxicity				
Arsenic	µg / l	10	50	500
Bismuth	µg / l	100		500
Bromine	µg / l	200		3000
Chromium	µg / l	30	50	500

Determinant	**Unit**	**Minimum**	**Median**	**Maximum**
Cyanide	μg / l	10	200	200
Fluoride	mg / l	0.7	1.5	2.4
Nickel	μg / l	30	50	1000
Nitrate & Nitrite (as N)	mg / l	6	10	23
DDT (pesticide)	μg / l	42	50	100
Malathion (pesticide)	μg / l	50	100	100
Mehoxychlor (pesticide)	μg / l	10	100	1000
-2, 4-D (pesticide)	μg / l	20	100	1000
-2, 4, 5-T	μg / l	2	100	100
Radioactivity ($\alpha+\beta$)	Bq / l	0.15	0.2	1.22
Silver	μg / l	10	50	50
Tin	μg / l		50	
Titanium	μg / l	100	100	100
Tungsten	μg / l	100	100	500
Vanadium	μg / l	0	100	1000
Low Toxicity				
Aluminium	mg / l	0.05	0.15	0.5
Barium	mg / l	0.1	1	4
Boron	mg / l	1	1	5
Cerium	mg / l		2	
Cobalt	mg / l	0.05	1	5
Copper	mg / l	0.01	1	10
Detergents (as MBAS)	mg / l	0.5	0.5	3
Iodide	mg / l		10	
Lithium	mg / l		5	
Molybdenum	mg / l	0.5		0.5
Organic carbon	mg / l	2		8

Determinant	**Unit**	**Minimum**	**Median**	**Maximum**
Strontium	mg / l	2		10
Uranium	mg / l	0.02	0.6	4.4
Non Toxic				
Alkalinity (as $CaCO_3$)	mg / l	30	500	500
Calcium	mg / l	75	200	300
Chloride	mg / l	100	250	1000
Hardess, total (Ca CO_3)	mg / l	200	500	1000
Magnesium	mg / l	30	150	200
Phosphate (as P)	mg / l	0.06	0.1	0.20
Phosphate, total (P)	mg / l	0.1	0.25	2.0
Potassium	mg / l	12		2000
Rubidium	mg / l		5.0	
Silica (as Si)	mg / l		18	
Sodium	mg / l	100	270	1000
Sulphate	mg / l	100	250	500
Zinc	mg / l	0.2	5.0	15

*before chlorination

APPENDIX 2 D: Modified Bond Classification

Highly mineralised Chloride-(Sulphate) Water

Bond defined Group A as having total solids greater than 1000 ppm with Chloride greater than 27%, suphate greater than 5% and permanent hardness greater than 12% calcium carbonate. Van Wyk described Group A as having greater than 3,500 ppm dissolved salts, thus making it unsuitable for domestic or stock watering. The chloride content exceeded 30% and soda alkalinity was never present.

Slightly saline Chloride Water

Bond described Group B water as having between 300 and 500 mg/l total solids, with chloride greater than 27% and sulphate less than 3%. Van Wyk redefined slightly saline chloride waters as Group C, which included water with TDS less than 600 mg/l and chloride greater than 30%.

Saline Chloride Water

Maud defined this group as having TDS between 2000 and 3500 mg/l and/or chloride greater than 30%.

Slightly Saline Water

Maud defined this group as having TDS between 500 and 2000 mg/l and chloride usually less than 30%.

Temporary hard (Carbonate) Water

Bond's Group C (TDS < 800 mg/l, total hardness > 70%, Temporary hardness >67%, permanent hardness <7%, chloride < 7% and pH > 7.6), was adopted by Van Wyk as Group D. Van Wyk kept the TDS limit the same but reduced temporary hardness to > 40%.

Alkaline Soda Carbonate Water

Defined as Group D by Bond, but not mentioned by the others, these waters had TDS values less than 1000 mg/l, Na_2CO_3 or $NaHCO_3$ greater than 15%, and no permanent hardness.

Pure Waters

Bond defined Group E as pure water with TDS less than 150 mg/l and pH values below 7.1. Van Wyk did not include a pure water group, however, Maud lists Fresh Water (TDS $<$ 500 mg/l) as his fourth group.

APPENDIX 3: DATA

DEPARTMENT OF WATER AFFAIRS AND FORESTRY
INSTITUTE FOR WATER QUALITY STUDIES
PRIVATE BAG X313 PRETORIA 0001

WATER QUALITY EVALUATION REPORT - ALL DETERMINANTS
19-May-1998 4:02 PM

PROVINCE: KWAZULU NATAL DRAINAGE REGION: U10 PERIOD: 31-7-1996 to 19-9-1996

ZQC No	Latitude	Longitude	Village & Seq. No.	Sample date	Time.	Faecal coliform /100ml	pH	Na mg/l	Cl mg/l	F mg/l	Mg mg/l	NO_3 mg/l	K mg/l	SO_4 mg/l	EC mS/m	Mn mg/l	Fe mg/l	Zn mg/l	Cd mg/l	Overall class
ZQCZAMA1B	30 13 48	30 43 49	Amahlongwa 1	16-Sep-96	12:50	0	7.70	104.00	140.00	0.63	16.00	<0.05	4.41	<0.16	77.20	0.250	8.850	0.240	<0.001	3
ZQCZAMA2F	30 13 42	30 44 02	Amahlongwa 2	17-Sep-96	14:45	32	5.90	46.40	71.40	<0.01	10.80	1.73	6.23	48.00	41.20	0.020	0.260	<0.020	<0.001	3
ZQCZAMA1R	30 17 21	30 36 44	Amahlongwa 3	18-Sep-96	11:05	1600	8.50	69.30	77.40	0.44	14.20	<0.05	2.75	17.90	49.80	0.020	0.340	<0.002	<0.001	3
ZQCZAMA1S	30 13 55	30 42 49	Amahlongwa 4	16-Sep-96	14:10	0	9.50	39.20	53.50	0.31	8.21	0.93	3.46	32.00	36.50	<0.010	0.120	0.060	<0.001	2
ZQCZAMA2B	31 11 27	30 37 17	Amahlongwa 5	31-Jul-96	11:46	?	8.30	49.00	49.00	1.90	11.00	0.06	1.00	6.00	48.30	0.130	0.061	0.129	<0.001	2
ZQCZAMA2F	30 11 43	30 37 02	Amahlongwa 6	31-Jul-96	10:42	?	8.00	63.00	85.00	0.20	8.00	8.39	0.70	7.00	45.70	<0.001	<0.003	<0.003	<0.001	1
ZQCZAMA3F	30 13 42	30 43 27	Amahlongwa 7	19-Sep-96	10:55	0	9.10	36.00	47.00	0.30	7.00	1.02	2.20	27.00	34.90	0.003	0.073	0.042	<0.001	1
ZQCZAMA2R	30 14 02	30 43 31	Amahlongwa 8	16-Sep-96	13:50	300	7.70	29.00	5.90	1.38	5.10	2.00	2.50	0.31	21.20	0.030	0.730	<0.020	<0.001	3
ZQCZAMA3B	30 13 55	30 43 15	Amahlongwa 9	16-Sep-96	13:20	53	7.90	159.00	183.00	2.02	19.00	<0.05	1.80	13.00	115.00	0.110	0.240	0.170	<0.001	3
ZQCZAMA4B	30 12 16	30 49 00	Amahlongwa 10	18-Sep-96	12:45	34	7.90	199.00	380.00	0.78	36.80	<0.05	10.30	<0.16	171.00	0.280	4.230	2.100	<0.001	3
ZQCZBHE1F	30 10 57	30 32 46	Bhewula 11	18-Sep-96	14:05	134	7.60	150.00	163.00	1.20	19.00	16.69	1.10	31.00	99.80	<0.001	0.346	0.107	<0.001	3
ZQCZBHE2B	30 10 22	30 34 21	Bhewula 12	18-Sep-96	12:41	8	8.00	51.00	28.00	0.70	17.00	5.73	2.90	20.00	45.10	0.057	0.330	3.384	<0.001	2
ZQCZCHO1F	30 06 11	30 38 25	Ichobe 13	16-Sep-96	12:35	28	6.90	41.00	64.00	0.39	17.00	2.30	3.00	43.00	51.40	0.240	0.550	<0.020	<0.001	3
ZQCZDLA2B	30 11 23	30 36 25	Dlangezwa 14	18-Sep-96	13:40	0	7.70	122.00	204.00	1.06	36.90	<0.05	4.77	<0.16	103.00	0.280	1.590	<0.020	<0.001	2
ZQCZDON1F	30 06 23	30 38 55	Donsa 15	16-Sep-96	13:30	366	7.20	25.00	35.00	<0.094	3.40	0.20	1.80	6.60	17.40	1.600	<0.003	<0.003	<0.001	3
ZQCZDUD1B	30 10 57	30 32 46	Dududu 16	19-Sep-96	11:55	20	7.60	46.00	42.00	1.20	8.00	0.06	1.00	11.00	37.90	0.189	0.447	0.419	<0.001	3
ZQCZDUD1F	30 11 44	30 36 15	Dududu 17	19-Sep-96	11:40	186	7.60	42.00	48.00	0.10	6.00	7.67	0.70	8.00	34.20	0.018	0.067	0.24	<0.001	3
ZQCZDUD2B	30 11 36	30 36 56	Dududu 18	17-Sep-96	13:00	0	7.40	41.30	48.40	0.42	9.05	<0.05	1.75	7.20	33.20	0.730	18.500	5.63	<0.001	3
ZQCZDUD2F	30 10 57	30 32 46	Dududu 19	19-Sep-96	12:26	69	7.30	24.00	36.00	<0.10	7.00	1.34	2.30	21.00	26.10	0.006	0.923	0.14	<0.001	3
ZQCZDUD3B	30 11 20	30 38 43	Dududu 20	17-Sep-96	13:25	24	8.00	87.80	111.00	2.28	20.00	13.60	4.08	20.50	75.80	0.020	0.210	2.4	<0.001	3
ZQCZDUD4B	30 11 38	30 35 06	Dududu 21	17-Sep-96	13:45	0	8.50	78.30	33.60	5.97	8.20	<0.05	3.38	1.86	43.10	<0.010	0.070	0.05	<0.001	3
ZQCZDUD5B	30 11 53	30 35 09	Dududu 22	17-Sep-96	14:15	0	7.70	55.90	38.80	2.17	11.80	1.30	3.88	<0.16	39.10	0.060	0.100	[illegible]	<0.001	2
ZQCZDUD6B	30 11 50	30 35 20	Dududu 23	17-Sep-96	13:33	3	7.20	31.10	32.70	0.56	3.48	5.86	1.44	1.75	21.20	<0.010	0.150	0.53	<0.001	2

KEY CLASS: 0 Ideal for potable use 1 Suitable for potable use 2 Suitable for short term potable use 3 Not suitable for potable use

DEPARTMENT OF WATER AFFAIRS AND FORESTRY
INSTITUTE FOR WATER QUALITY STUDIES
PRIVATE BAG X313 PRETORIA 0001

WATER QUALITY EVALUATION REPORT - ALL DETERMINANTS
19-May-1998 4:02 PM

PROVINCE: KWAZULU NATAL DRAINAGE REGION: U10 PERIOD: 31-7-1996 to 19-9-1996

ZQC No	Latitude	Longitude	Village & Seq. No.		Sample date	Time.	Faecal coliform /100ml	pH	Na mg/l	Cl mg/l	F mg/l	Mg mg/l	NO_3 mg/l	K mg/l	SO_4 mg/l	EC mS/m	Mn mg/l	Fe mg/l	Zn mg/l	Cd mg/l	Overall class
ZQCZDUM3F	30 07 34	30 27 14	KwaDumisa	24	19-Sep-96	12:42	980	7.20	15.00	14.00	0.20	2.00	9.82	1.10	10.00	12.40	0.095	1.024	0.171	<0.001	3
ZQCZDUM5B	30 08 53	30 27 32	KwaDumisa	25	19-Sep-96	12:35	0	7.50	47.00	62.00	1.40	8.00	2.70	1.00	21.00	43.20	0.022	0.701	0.169	<0.001	2
ZQCZEMB1F	30 03 40	30 27 26	Embuthisweni	26	16-Sep-96	13:40	115	6.90	11.00	8.00	0.10	2.00	5.10	2.10	4.00	12.40	0.004	0.612	0.642	<0.001	3
ZQCZEMB2F	30 03 21	30 28 19	Embuthisweni	27	16-Sep-96	14:15	142	6.80	15.00	12.00	0.20	1.00	1.72	0.90	10.00	12.90	<0.001	0.557	0.109	<0.001	3
ZQCZENK1B	30 09 48	30 45 07	Enkangala	28	17-Sep-96	10:15	0	8.20	87.00	106.00	0.70	27.00	4.45	1.10	22.00	77.20	0.002	0.295	0.456	<0.001	2
ZQCZENK2B	30 09 29	30 44 37	Enkangala	29	17-Sep-96	10:30	0	8.10	83.00	60.00	0.80	22.00	3.20	1.00	15.00	64.30	0.042	0.072	0.077	<0.001	2
ZQCZENK3B	30 09 11	30 44 11	Enkangala	30	17-Sep-96	10:45	0	7.00	32.00	45.00	1.10	5.00	0.04	4.20	6.00	23.80	0.191	0.270	0.069	<0.001	2
ZQCZENK4B	30 08 54	30 43 34	Enkangala	31	17-Sep-96	11:00	0	7.70	86.00	107.00	1.30	24.00	1.21	1.30	14.00	72.30	<0.001	0.041	0.158	<0.001	2
ZQCZENT1R	30 08 01	30 33 11	Entshenkombo	32	1-Aug-96	10:44	?	7.90	10.00	10.00	0.20	4.00	0.25	1.10	14.00	12.00	0.220	0.410	0.620	<0.001	2
ZQCZESI1B	30 10 39	30 39 02	Esidakeni	33	17-Sep-96	12:35	0	7.80	68.20	75.60	0.46	19.60	<005	3.07	6.30	64.30	0.400	0.600	<0.003	<0.001	2
ZQCZESI1F	30 17 21	30 36 44	Esidakeni	34	17-Sep-96	13:25	0	7.40	39.10	32.50	0.34	5.66	2.93	1.90	6.40	26.70	0.140	1,570	<0.020	<0.001	2
ZQCZESI2B	30 10 14	30 37 20	Esidakeni	35	31-Jul-96	13:00	?	7.80	47.00	48.00	1.30	10.00	0.22	3.20	10.00	41.50	0.027	0.420	0.684	<0.001	2
ZQCZESI2F	30 09 29	30 44 37	Esidakeni	36	19-Sep-96	10:50	3	8.00	29.00	26.00	0.20	5.00	2.53	0.70	16.00	24.40	0.044	1.163	0.112	<0.001	2
ZQCZEZE1F	30 09 11	30 44 11	Ezembeni	37	19-Sep-96	11:50	145	8.20	52.00	61.00	0.20	7.00	0.38	1.10	12.00	37.60	0.060	4.320	0.186	<0.001	3
ZQCZEZE1R	30 10 48	30 38 53	Ezembeni	38	18-Sep-96	15:02	7900	7.50	30.00	34.90	0.10	6.46	<0.05	2.03	14.90	25.00	0.470	1.17	<0.020	<0.001	3
ZQCZEZE2F	30 11 38	30 35 06	Ezembeni	39	17-Sep-96	13:40	0	7.50	32.70	45.30	0.13	7.67	1.74	1.71	10.60	25.40	0.470	1.170	<0.020	<0.001	2
ZQCZEZE2R	30 10 39	30 39 02	Ezembeni	40	17-Sep-96	15:15	7200	7.70	27.60	35.40	0.04	4.92	0.10	1.48	14.20	19.90	0.020	0.310	<0.020	<0.001	3

KEY CLASS: 0 Ideal for potable use 1 Suitable for potable use 2 Suitable for short term potable use 3 Not suitable for potable use

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

INSTITUTE FOR WATER QUALITY STUDIES

PRIVATE BAG X313 PRETORIA 0001

WATER QUALITY EVALUATION REPORT - ALL DETERMINANTS

19-May-1998 4:02 PM

PROVINCE: KWAZULU NATAL DRAINAGE REGION: U10 PERIOD: 31-7-1996 to 19-9-1996

ZQC No	Latitude	Longitude	Village & Seq. No.		Sample date	Time.	Faecal coliform /100ml	pH Units	Na mg/l	Cl mg/l	F mg/l	Mg mg/l	NO_3 mg/l	K mg/l	SO_4 mg/l	EC mS/m	Mn mg/l	Fe mg/l	Zn mg/l	Cd mg/l	Overall class
ZQCZEZE3B	30 11 26	30 35 12	Ezembeni	41	17-Sep-96	13:55	0	6.80	60.00	61.00	1.22	11.00	8.20	2.70	10.00	44.50	0.020	0.530	2.820	<0.001	2
ZQCZLWA1B	30 59 35	31 34 08	Lwasini	42	19-Sep-96	14:25	0	8.60	542.00	336.00	20.30	1.00	0.05	1.60	33.00	245.00	0.058	0.573	0.862	<0.001	3
ZQCZLWA1R	30 12 33	30 41 49	Lwasini	43	19-Sep-96	14:35	210	8.40	82.00	88.00	0.70	17.00	0.18	1.40	22.00	57.10	<0.001	0.1340	<0.003	<0.001	3
ZQCZLWA2R	30 12 37	30 42 05	Lwasini	44	19-Sep-96	14:45	700	8.50	83.00	88.00	0.70	17.00	0.15	1.40	18.00	57.30	0.025	0.466	0.185	<0.001	3
ZQCZMAD1B	30 07 57	30 41 51	Madundubala	45	17-Sep-96	9:20	1	8.00	115.00	123.00	0.70	25.00	0.10	1.50	10.00	81.40	0.067	0.241	1.055	<0.001	2
ZQCZMAH1B	30 10 39	30 34 46	Mahwaqa	46	18-Sep-96	10:38	0	8.10	42.00	32.00	1.00	5.00	0.04	3.70	4.00	29.10	0.005	0.604	0.269	<0.001	2
ZQCZMAM1B	30 06 32	30 39 39	Mampungushe	47	17-Sep-96	13:09	0	8.10	377.00	566.00	1.86	6.80	1.55	7.40	64.00	26.00	<0.010	0.260	5.640	<0.001	2
ZQCZMAM1R	30 06 28	30 36 11	Mampungushe	48	16-Sep-96	11:56	920	7.90	37.50	50.10	0.27	9.11	<0.05	1.81	19.00	30.90	0.020	0.400	<0.020	<0.001	3
ZQCZMAM2R	30 06 32	30 35 45	Mampungushe	49	16-Sep-96	12:40	2	6.60	37.10	55.50	0.36	9.18	<0.05	2.00	19.10	31.80	<0.010	0.130	<0.020	<0.001	2
ZQCZMGA1F	30 08 28	30 42 25	Mgangeni	50	17-Sep-96	11:30	193	7.80	61.00	99.00	0.20	16.00	0.42	2.40	13.00	49.50	0.042	0.268	0.096	<0.001	3
ZQCZMGW1B	30 05 23	30 31 27	Mgwenya	51	17-Sep-96	11:22	1	7.50	1983.00	634.00	4.00	25.00	2.10	3.00	420.00	1118.00	0.290	2.800	<0.010	<0.001	3
ZQCZMGW1R	30 05 29	30 31 49	Mgwenya	52	17-Sep-96	11:44	426	8.10	59.00	141.00	0.71	4.40	<0.05	3.20	342.00	53.80	<0.010	0.070	<0.020	<0.001	3
ZQCZMGW2B	30 05 11	30 31 46	Mgwenya	53	17-Sep-96	12:25	0	7.50	91.00	54.00	2.18	22.00	1.50	4.30	27.00	93.20	0.340	13.100	5.400	<0.001	3
ZQCZMJU1F	30 10 51	30 37 41	Mjunundwini	54	14-Sep-96	13:00	6000	7.30	19.00	15.00	0.10	2.00	0.29	0.50	20.00	14.50	<0.001	<0.003	<0.003	<0.001	3
ZQCZMJU1R	30 09 58	30 39 57	Mjunundwini	55	17-Sep-96	14:23	8000	7.60	43.30	38.40	0.36	7.26	1.71	2.11	17.40	28.30	0.040	1.160	<0.020	<0.001	3
ZQCZMJU2R	30 10 18	30 38 53	Mjunundwini	56	19-Sep-96	10:23	600	8.20	43.00	39.00	0.20	5.00	1.84	0.30	11.00	28.90	<0.001	<0.003	<0.003	<0.001	3
ZQCZMJU5B	30 10 06	30 39 32	Mjunundwini	57	17-Sep-96	15:00	1	7.70	111.00	37.00	3.46	25.00	3.90	4.30	3.05	21.20	0.070	0.580	0.960	<0.001	2
ZQCZMKH1B	30 08 23	30 24 42	Mkhunya	58	19-Sep-96	13:29	0	7.60	19.00	12.00	0.20	5.00	0.06	2.90	12.00	24.50	0.151	0.685	4.548	<0.001	2
ZQCZMKH1F	30 07 33	30 26 28	Mkhunya	59	19-Sep-96	11:47	29	7.60	18.00	18.00	<0.10	2.00	3.27	3.50	7.00	14.60	0.096	0.263	<0.003	<0.001	3
ZQCZMKH2B	30 07 58	30 24 13	Mkhunya	60	19-Sep-96	13:38	0	6.70	14.00	18.00	0.10	2.00	1.73	2.50	4.00	13.50	0.008	0.690	0.670	<0.001	2
ZQCZMKH2F	30 07 49	30 26 51	Mkhunya	61	19-Sep-96	12:05	25	7.60	16.00	17.00	0.20	2.00	0.15	1.20	10.00	11.40	<0.001	0.631	0.072	<0.001	3
ZQCZMKH3B	30 06 02	30 24 16	Mkhunya	62	19-Sep-96	14:00	0	8.10	191.00	384.00	0.50	54.00	10.68	2.50	38.00	165.00	0.131	0.187	0.719	<0.001	2
ZQCZMKH3F	30 07 54	30 27 48	Mkhunya	63	19-Sep-96	12:22	124	7.30	21.00	15.00	0.20	3.00	2.69	0.50	15.00	16.10	<0.001	0.504	0.155	<0.001	3

KEY CLASS: 0 Ideal for potable use ▨ Suitable for potable use 2 Suitable for short term potable use 3 Not suitable for potable use

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

INSTITUTE FOR WATER QUALITY STUDIES

PRIVATE BAG X313 PRETORIA 0001

WATER QUALITY EVALUATION REPORT - ALL DETERMINANTS

19-May-1998 4:02 PM

PROVINCE: KWAZULU NATAL DRAINAGE REGION: U10 PERIOD: 31-7-1996 to 19-9-1996

ZQC No	Latitude	Longitude	Village & Seq. No.		Sample date	Time.	Faecal coliform /100ml	pH	Na mg/l	Cl mg/l	F mg/l	Mg mg/l	NO_3 mg/l	K mg/l	SO_4 mg/l	EC mS/m	Mn mg/l	Fe mg/l	Zn mg/l	Cd mg/l	Overall class
ZQCZMKH4B	30 06 41	30 24 18	Mkhunya	64	19-Sep-96	14:11	0	7.20	72.00	157.00	0.20	20.00	3.00	1.90	13.00	65.20	0.053	4.428	4.780	<0.001	3
ZQCZMKH4F	30 07 57	30 23 01	Mkhunya	65	19-Sep-96	14:25	4560	7.80	16.00	13.00	0.10	2.00	0.07	1.50	9.00	12.80	0.177	0.396	0.140	<0.001	3
ZQCZMKH5B	30 07 55	30 27 49	Mkhunya	66	19-Sep-96	12:34	0	7.60	25.00	14.00	1.50	5.00	0.05	0.90	14.00	20.00	<0.001	6.309	1.395	<0.001	3
ZQCZMKO1R	30 05 36	30 31 56	Umkomazi river	67	17-Sep-96	12:30	197	8.10	19.00	17.00	0.20	6.00	0.21	0.70	13.00	22.40	0.008	0.429	0.098	<0.001	3
ZQCZMPO1R	30 06 47	30 34 28	Mpompi	68	16-Sep-96	14:37	99	8.20	74.00	120.00	0.94	14.00	0.80	2.10	32.00	57.50	<0.010	0.130	<0.020	<0.001	3
ZQCZNDA1F	30 06 18	30 38 19	Ndaya	69	16-Sep-96	12:13	296	7.10	67.00	124.00	0.42	18.00	6.60	1.40	25.00	63.50	0.180	1.750	<0.020	<0.001	3
ZQCZNDA2B	30 06 51	30 39 32	Ndaya	70	17-Sep-96	10:00	0	7.90	129.00	118.00	5.33	15.00	0.30	3.60	4.30	83.00	<0.010	0.960	0.060	<0.001	3
ZQCZNDA4F	30 06 45	30 38 35	Ndaya	71	16-Sep-96	14:00	2	6.00	22.40	28.00	0.13	5.40	0.08	1.52	24.00	20.10	0.010	0.940	<0.020	<0.001	2
ZQCZNDA5F	30 06 42	30 38 59	Ndaya	72	16-Sep-96	14:20	4	5.50	37.00	38.40	0.07	5.20	4.93	1.54	13.10	24.10	<0.010	0.060	<0.020	<0.001	1
ZQCZNDA6F	30 06 32	30 39 32	Ndaya	73	17-Sep-96	10:15	7	7.30	46.00	52.00	0.85	6.90	0.40	1.20	13.00	31.60	<0.010	0.150	<0.020	<0.001	2
ZQCZNDA7F	30 06 36	30 40 05	Ndaya	74	17-Sep-96	10:35	1200	7.50	119.00	177.00	0.49	24.00	0.60	5.30	64.00	89.00	0.250	7.560	0.040	<0.001	3
ZQCZNDA8F	30 06 23	30 40 17	Ndaya	75	17-Sep-96	11:00	24	6.20	113.00	164.00	0.41	22.00	1.00	1.70	70.00	80.70	<0.010	0.200	<0.020	<0.001	3
ZQCZNGO1B	30 09 12	30 28 00	Ngodini	76	19-Sep-96	14:16	0	7.90	33.00	25.00	0.40	7.00	0.46	0.50	7.00	33.30	<0.001	1.143	1.783	<0.001	2
ZQCZNJA1R	30 06 09	30 38 59	Njangwini	77	17-Sep-96	10:42	645	7.80	19.40	29.00	<0.1	4.50	0.20	1.61	6.70	16.40	<0.010	0.180	<0.020	<0.001	3
ZQCZNKA3F	30 10 52	30 36 12	Nkampule	78	17-Sep-96	14:15	8	6.70	35.00	33.00	0.80	3.70	3.60	2.50	3.55	24.20	0.040	2.200	<0.020	<0.001	3
ZQCZNSO1R	30 07 10	30 35 18	Nsongeni	79	16-Sep-96	13:34	280	7.90	21.00	24.00	0.24	6.90	0.20	1.80	11.00	21.70	0.020	0.100	<0.020	<0.001	3
ZQCZNTS1F	30 07 37	30 28 24	Ntshepheni	80	19-Sep-96	13:02	462	8.10	56.00	49.00	0.80	9.00	5.95	0.90	21.00	42.60	0.018	1.404	0.124	<0.001	3
ZQCZNTS2F	30 07 47	30 28 35	Ntshepheni	81	19-Sep-96	13:29	812	7.30	43.00	27.00	0.20	3.00	0.08	1.90	39.00	25.20	0.035	1.040	0.137	<0.001	3
ZQCZOKH1F	30 09 34	30 29 04	Okhalweni	82	19-Sep-96	13:44	3	7.20	27.00	28.00	0.20	5.00	2.18	0.70	28.00	23.80	0.006	0.991	0.054	<0.001	2
ZQCZQIK1B	30 09 46	30 31 28	KwaQiko	83	19-Sep-96	11:30	0	7.20	66.00	61.00	0.80	13.00	<0.04	2.30	40.00	45.60	0.336	2.753	1.785	<0.001	3
ZQCZTHE1B	30 07 07	30 41 16	Thenjane	84	17-Sep-96	11:20	1440	7.20	66.00	85.00	2.36	12.00	0.50	4.80	35.00	57.80	0.180	1.680	<0.020	<0.001	3
ZQCZTHE1F	30 07 04	30 41 06	Thenjane	85	17-Sep-96	11:30	4	6.20	65.00	71.00	0.29	7.60	3.90	1.78	30.00	39.90	<0.010	0.320	<0.020	<0.001	2
ZQCZTHE1R	30 07 57	30 39 41	Thenjane	86	17-Sep-96	12:45	750	8.40	20.00	<2	0.30	6.40	<0.1	1.80	?	21.10	<0.010	0.060	0.030	<0.001	3

KEY CLASS: 0 Ideal for potable use ■ Suitable for potable use 2 Suitable for short term potable use 3 Not suitable for potable use

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

INSTITUTE FOR WATER QUALITY STUDIES

PRIVATE BAG X313 PRETORIA 0001

WATER QUALITY EVALUATION REPORT - ALL DETERMINANTS

19-May-1998 4:02 PM

PROVINCE: KWAZULU NATAL DRAINAGE REGION: U10 PERIOD: 31-7-1996 to 19-9-1996

ZQC No	Latitude	Longitude	Village & Seq. No.		Sample date	Time.	Faecal coliform /100ml	pH	Na mg/l	Cl mg/l	F mg/l	Mg mg/l	NO_3 mg/l	K mg/l	SO_4 mg/l	EC mS/m	Mn mg/l	Fe mg/l	Zn mg/l	Cd mg/l	Overall class
ZQCZTHE2B	30 07 01	30 41 04	Thenjane	87	17-Sep-96	11:50	0	7.70	54.00	69.00	1.22	12.00	<005	4.60	16.00	47.80	0.480	5.030	5.170	<0.001	3
ZQCZTHE3B	30 07 33	30 40 06	Thenjane	88	17-Sep-96	12:15	0	7.20	208.00	283.00	2.36	16.00	36.00	2.20	136.00	129.00	0.010	0.520	8.660	<0.001	3
ZQCZTSH1F	30 05 36	30 31 56	Tshenkombo	89	18-Sep-96	10:58	8	7.70	17.00	3.00	0.20	5.00	3.43	2.10	23.00	21.70	0.076	1.451	0.071	<0.001	2
ZQCZTSH1R	30 05 36	30 31 56	Tshenkombo	90	18-Sep-96	12:12	34000	8.00	42.00	45.00	0.40	7.00	0.50	1.40	22.00	32.80	1.450	0.071	<0.003	<0.001	3
ZQCZTSH2F	30 05 36	30 31 56	Tshenkombo	91	18-Sep-96	11:36	1	7.70	22.00	23.00	0.30	2.00	1.17	0.80	11.00	17.00	<0.001	1.245	0.164	<0.001	3
ZQCZTSH3B	30 05 36	30 31 56	Tshenkombo	92	18-Sep-96	11:18	0	7.40	33.00	24.00	1.10	3.00	1.57	1.70	8.00	25.10	0.003	0.486	7.793	<0.001	2
ZQCZVUL1R	30 09 08	30 38 38	Vulindlela	93	19-Sep-96	13:40	1000	8.30	95.00	108.00	0.90	16.00	0.94	1.40	23.00	64.40	<0.001	0.168	0.059	<0.001	3

KEY CLASS: 0 Ideal for potable use ■ Suitable for potable use 2 Suitable for short term potable use 3 Not suitable for potable use

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

INSTITUTE FOR WATER QUALITY STUDIES

PRIVATE BAG X313 PRETORIA 0001

WATER QUALITY EVALUATION REPORT - ALL DETERMINANTS

19-May-1998 4:02 PM

PROVINCE: KWAZULU NATAL DRAINAGE REGION: W22 PERIOD: 31-7-1996 to 19-9-1996

ZQC No	Latitude	Longitude	Village & Seq. No.		Sample date	Time.	Faecal coliform /100ml	pH	Na mg/l	Cl mg/l	F mg/l	Mg mg/l	NO_3 mg/l	K mg/l	SO_4 mg/l	EC mS/m	Mn mg/l	Fe mg/l	Zn mg/l	Cd mg/l	Overall class
ZQCZBHE1B	28 13 15	31 28 46	KwaBhekinkantolo	94	2-Sep-96	13:37	42	8.50	26.00	30.00	0.10	15.00	7.63	0.30	8.00	38.40	<0.001	<0.003	0.468	<0.001	3
ZQCZBHE1P	28 13 39	31 28 34	KwaBhekinkantolo	95	2-Sep-96	14:20	830	7.60	28.00	29.00	0.50	6.00	0.33	4.20	19.00	22.80	0.053	20.632	0.137	<0.001	3
ZQCZBHU1B	28 09 08	31 37 18	KwaBhungane	96	4-Sep-96	13:20	0	8.00	226.00	339.00	0.40	138.00	7.70	2.50	50.00	224.00	0.001	0.006	7.310	<0.001	3
ZQCZBHU1R	28 08 45	31 37 22	KwaBhungane	97	4-Sep-96	13:35	430	8.60	38.00	30.00	0.40	19.00	0.14	1.30	31.00	42.70	<0.001	0.715	0.063	<0.001	3
ZQCZDUM1F	28 04 09	31 46 20	KwaDuma	98	3-Sep-96	12:04	90	8.00	29.00	28.00	0.10	9.00	0.11	3.00	10.00	27.00	<0.001	1.124	0.054	<0.001	3
ZQCZDUM2F	28 03 49	31 46 16	KwaDuma	99	3-Sep-96	12:22	0	7.10	18.00	19.00	0.10	3.00	0.67	1.30	<4	13.90	<0.001	0.330	0.449	<0.001	2
ZQCZDUM3F	28 03 31	31 46 32	KwaDuma	100	4-Sep-96	12:41	0	7.90	23.00	27.00	0.10	13.00	2.95	0.80	<4	28.80	<0.001	0.449	<0.003	<0.001	2
ZQCZDUM4B	28 03 49	31 46 16	KwaDumisa	101	19-Sep-96	12:22	2	8.30	32.00	26.00	0.50	8.00	0.46	0.50	8.00	35.90	<0.001	0.119	1.635	<0.001	2
ZQCZDUM5F	28 09 30	31 29 02	KwaDumisa	102	19-Sep-96	12:07	4000	7.80	15.00	15.00	0.20	4.00	0.69	1.30	21.00	14.70	<0.001	0.625	<0.003	<0.001	3
ZQCZJIK1B	28 12 16	31 28 00	KwaJikaza	103	5-Sep-96	10:38	0	8.00	87.00	172.00	0.60	91.00	1.96	0.40	42.00	154.00	0.009	0.780	2.247	<0.001	2
ZQCZJIK2B	28 11 12	31 28 38	KwaJikaza	104	5-Sep-96	10:55	0	8.10	136.00	106.00	0.30	53.00	0.26	1.90	20.00	114.20	<0.001	1.429	0.671	<0.001	2
ZQCZKHU1B	28 14 34	31 40 13	Khukho	105	4-Sep-96	12:25	0	8.00	169.00	233.00	0.50	168.00	109.21	1.00	89.00	266.00	<0.001	0.311	3.885	<0.001	3
ZQCZKHU2S	28 15 52	31 40 45	Khukho	106	4-Sep-96	13:22	0	7.90	144.00	248.00	0.70	109.00	48.31	1.90	52.00	218.00	0.030	1.175	1.798	<0.001	3
ZQCZLAN1B	28 18 12	31 30 45	Langakazi	107	3-Sep-96	11:29	0	7.90	121.00	190.00	0.60	54.00	16.73	0.90	25.00	127.60	<0.001	0.103	2.407	<0.001	2
ZQCZLAN1F	28 17 44	31 31 06	Langakazi	108	3-Sep-96	12:00	120	8.20	110.00	113.00	0.70	33.00	7.18	1.40	20.00	90.00	0.045	0.640	0.060	<0.001	3
ZQCZLOM1B	28 13 04	31 38 04	Lomo	109	4-Sep-96	11:36	0	6.40	960.00	2076.00	0.60	265.00	<0.1	8.90	242.00	723.00	0.367	0.754	7.931	<0.001	3
ZQCZMAH1F	28 04 03	31 43 21	Mahaza	110	3-Sep-96	10:47	0	8.10	11.00	8.00	0.10	2.00	0.10	1.00	4.00	10.40	0.011	0.368	0.186	<0.001	2
ZQCZMAK1R	28 08 11	31 46 39	Makheme	111	4-Sep-96	11:42	340	8.70	57.00	82.00	0.20	59.00	22.42	0.90	27.00	94.70	<0.001	0.729	<0.003	<0.001	3
ZQCZMAN1F	28 02 14	31 39 21	Manzawayo	112	3-Sep-96	9:24	0	7.60	13.00	12.00	0.10	2.00	1.10	1.30	<4	10.90	0.014	0.476	1.611	<0.001	2
ZQCZMAP1B	28 02 16	31 40 48	Maphophoma	113	3-Sep-96	10:18	0	8.20	13.00	9.00	0.10	4.00	0.69	0.50	<4	16.40	<0.001	1.633	0.143	<0.001	2
ZQCZMAP1F	28 02 06	31 40 32	Maphophoma	114	3-Sep-96	10:03	87	7.60	8.00	9.00	0.10	2.00	<0.1	0.60	<4	7.90	<0.001	0.225	0.168	<0.001	3
ZQCZMAP2F	28 02 13	31 40 45	Maphophoma	115	3-Sep-96	10:29	0	7.40	11.00	9.00	0.10	2.00	0.25	0.90	<4	9.90	0.046	1.065	0.572	<0.001	2
ZQCZMAS1F	28 59 36	31 41 32	Masundwini	116	5-Sep-96	9:23	1600	7.20	52.00	74.00	0.10	7.00	5.79	1.80	4.00	35.00	0.024	2.055	0.174	<0.001	3
ZQCZMAT2F	28 02 32	31 40 07	Matheni	117	3-Sep-96	9:48	40	7.60	8.00	8.00	0.10	2.00	0.11	0.70	<4	8.20	0.064	1.578	0.441	<0.001	3
ZQCZMAT1B	28 03 23	31 37 50	Matshemhlophe	118	5-Sep-96	11:02	1	7.60	5.00	7.00	0.10	4.00	0.18	0.60	4.00	10.10	<0.001	0.567	1.697	<0.001	2
ZQCZMAT1F	28 03 22	31 39 54	Matshemhlophe	119	5-Sep-96	10:46	200	7.40	9.00	11.00	0.10	2.00	1.19	0.90	7.00	9.40	<0.001	4.070	<0.003	<0.001	3
ZQCZMAY1F	28 08 27	31 46 30	Maye	120	4-Sep-96	12:01	1870	8.50	65.00	38.00	0.10	19.00	17.57	0.50	11.00	56.70	0.007	0.689	0.144	<0.001	3
ZQCZMLA1R	28 18 21	31 32 35	KwaMlaba	121	3-Sep-96	12:25	100	8.40	[illegible]	[illegible]	0.60	[illegible]	1.48	2.00	19.00	[illegible]	[illegible]	0.524	<0.003	<0.001	3
ZQCZMLA2S	28 18 49	31 31 24	KwaMlaba	122	3-Sep-96	12:43	4	8.10	[illegible]	[illegible]	0.90	[illegible]	16.15	1.60	11.00	152.00	<0.001	0.262	0.971	<0.001	2

KEY CLASS: 0 Ideal for potable use ▨ Suitable for potable use 2 Suitable for short term potable use 3 Not suitable for potable use

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

INSTITUTE FOR WATER QUALITY STUDIES

PRIVATE BAG X313 PRETORIA 0001

WATER QUALITY EVALUATION REPORT - ALL DETERMINANTS

19-May-1998 4:02 PM

PROVINCE: KWAZULU NATAL DRAINAGE REGION: W22 PERIOD: 31-7-1996 to 19-9-1996

ZQC No	Latitude	Longitude	Village & Seq. No.	Sample date	Time.	Faecal coliform /100ml	pH	Na mg/l	Cl mg/l	F mg/l	Mg mg/l	NO_3 mg/l	K mg/l	SO_4 mg/l	EC mS/m	Mn mg/l	Fe mg/l	Zn mg/l	Cd mg/l	Overall class
ZQCZMNQ1B	28 11 40	31 36 40	Mnqawe 123	4-Sep-96	11:40	0	8.40	508.00	572.00	1.60	108.00	12.48	4.00	120.00	332.00	0.027	0.789	0.094	<0.001	3
ZQCZMNQ1P	28 11 06	31 36 19	Mnqawe 124	4-Sep-96	12:09	0	8.10	229.00	600.00	0.40	69.00	0.85	7.00	25.00	241.00	0.040	0.679	0.186	<0.001	3
ZQCZMNQ2B	28 11 39	31 36 40	Mnqawe 125	4-Sep-96	9:48	0	8.50	531.00	647.00	1.20	115.00	13.03	4.50	134.00	302.00	<0.001	0.280	0.434	<0.001	3
ZQCZMNQ2R	28 11 13	31 38 38	Mnqawe 126	4-Sep-96	10:59	0	8.60	41.00	34.00	0.40	20.00	<0.1	1.40	29.00	45.10	0.059	1.045	0.847	<0.001	2
ZQCZMVA2B	28 15 58	31 41 16	Mvalo 127	5-Sep-96	9:51	81	8.00	678.00	919.00	1.40	37.00	<0.1	3.60	61.00	382.00	0.117	12.240	11.520	<0.001	3
ZQCZNCE1S	28 20 08	31 40 19	Ncemaneni 128	5-Sep-96	10:43	670	8.30	325.00	618.00	1.00	115.00	25.48	4.00	24.00	258.00	<0.001	0.545	0.337	<0.001	3
ZQCZNCE3B	28 21 02	31 39 39	Ncemaneni 129	5-Sep-96	11:23	6	7.80	126.00	284.00	0.70	89.00	38.87	1.20	32.00	172.00	<0.001	1.177	5.415	<0.001	3
ZQCZNDL1B	28 06 48	31 45 41	Ndlozane 130	4-Sep-96	10:21	68	8.00	402.00	621.00	1.20	45.00	0.39	2.80	25.00	248.00	0.080	0.528	3.489	<0.001	3
ZQCZNDL1F	28 06 37	31 46 06	Ndlozane 131	4-Sep-96	10:02	110	8.40	37.00	43.00	0.10	13.00	11.20	0.30	<4	38.80	1.429	1.499	0.607	<0.001	3
ZQCZNDL1R	28 07 25	31 45 09	Ndlozane 132	4-Sep-96	10:44	470	8.70	87.00	68.00	0.30	41.00	0.80	0.40	11.00	57.90	<0.001	0.702	0.404	<0.001	3
ZQCZNDL2F	28 08 13	31 45 32	Ndlozane 133	4-Sep-96	11:14	9400	8.60	117.00	137.00	0.50	52.00	8.12	0.80	8.00	67.30	0.028	1.515	0.088	<0.001	3
ZQCZNGO1R	28 10 41	31 46 04	Ngolotshe 134	4-Sep-96	12:30	1510	8.60	51.00	49.00	0.40	22.00	<0.1	1.40	30.00	61.90	0.002	0.920	0.018	<0.001	3
ZQCZNGW1R	28 10 39	31 42 00	Ngwabi 135	2-Sep-96	10:52	1	8.60	48.00	43.00	0.40	20.00	<0.1	1.30	31.00	63.10	<0.001	0.790	0.349	<0.001	2
ZQCZNHL1S	28 18 26	31 30 20	Nhlungwane 136	3-Sep-96	11:02	0	8.50	120.00	130.00	0.60	42.00	2.22	1.20	22.00	102.60	<0.001	0.438	0.556	<0.001	2
ZQCZNKA1R	28 00 20	31 41 53	Nkalaneni 137	5-Sep-96	9:52	1600	8.20	32.00	30.00	0.10	10.00	0.43	1.40	6.00	26.80	0.027	0.760	0.076	<0.001	3
ZQCZNTA1B	28 15 24	31 28 27	Ntandakuwela 138	3-Sep-96	10:00	0	7.90	42.00	31.00	0.20	18.00	8.99	0.30	<4	42.60	<0.001	0.555	<0.003	<0.001	2
ZQCZNTA1R	28 20 43	31 36 21	Ntabankulu 139	5-Sep-96	12:13	10	8.30	195.00	341.00	0.60	76.00	4.88	2.40	32.00	172.00	0.073	0.946	0.523	<0.001	3
ZQCZNTA3B	28 16 46	31 29 54	Ntandakuwela 140	3-Sep-96	10:34	0	7.90	52.00	50.00	0.30	15.00	<0.1	1.10	<4	45.10	0.233	0.541	0.949	<0.001	2
ZQCZNTA5B	28 20 01	31 36 08	Ntabankulu 141	5-Sep-96	13:00	0	8.40	235.00	374.00	0.90	81.00	6.85	2.90	14.00	219.00	0.038	0.575	1.038	<0.001	2
ZQCZNZA1F	28 11 07	31 40 04	Nzangamandla 142	4-Sep-96	13:09	10	8.50	38.00	35.00	0.40	18.00	<0.1	1.00	31.00	41.10	<0.001	0.666	0.324	<0.001	3
ZQCZNZA1R	28 11 45	31 39 40	Nzangamandla 143	2-Sep-96	13:33	2130	8.60	41.00	38.00	0.40	18.00	<0.1	1.30	31.00	46.90	<0.001	2.834	0.513	<0.001	3
ZQCZNZA2F	28 10 37	31 39 34	Nzangamandla 144	4-Sep-96	13:14	0	8.30	36.00	35.00	0.30	18.00	<0.1	1.00	35.00	44.60	<0.001	0.829	0.830	<0.001	2
ZQCZNZA3F	28 10 53	31 39 44	Nzangamandla 145	4-Sep-96	13:24	0	8.40	36.00	33.00	0.30	18.00	<0.1	1.00	29.00	44.10	<0.001	0.292	<0.003	<0.001	2

KEY CLASS: 0 Ideal for potable use 1 Suitable for potable use 2 Suitable for short term potable use 3 Not suitable for potable use

DEPARTMENT OF WATER AFFAIRS AND FORESTRY

INSTITUTE FOR WATER QUALITY STUDIES

PRIVATE BAG X313 PRETORIA 0001

WATER QUALITY EVALUATION REPORT - ALL DETERMINANTS

19-May-1998 4:02 PM

PROVINCE: KWAZULU NATAL DRAINAGE REGION: W22 PERIOD: 31-7-1996 to 19-9-1996

ZQC No	Latitude	Longitude	Village & Seq. No.		Sample date	Time.	Faecal coliform /100ml	pH	Na mg/l	Cl mg/l	F mg/l	Mg mg/l	NO_3 mg/l	K mg/l	SO_4 mg/l	EC mS/m	Mn mg/l	Fe mg/l	Zn mg/l	Cd mg/l	Overall class
ZQCZOTH1F	28 05 06	31 43 06	Othinsangu	146	3-Sep-96	11:02	10	7.90	23.00	22.00	0.10	13.00	1.48	0.60	8.00	30.40	<0.001	1.895	0.266	<0.001	2
ZQCZOTH2F	28 05 17	31 43 10	Othinsangu	147	3-Sep-96	11:14	50	7.30	31.00	33.00	0.10	5.00	2.88	1.50	<4	24.10	0.143	1.664	0.627	<0.001	2
ZQCZOTH3F	28 05 08	31 44 35	Othinsangu	148	3-Sep-96	11:35	810	7.50	47.00	60.00	0.10	11.00	5.25	1.80	<4	39.40	0.024	0.739	<0.003	<0.001	2
ZQCZQON1F	28 03 02	31 38 56	Qonqo	149	3-Sep-96	9:03	0	8.20	37.00	33.00	0.10	4.00	6.22	2.60	<4	25.10	0.019	2.576	0.309	<0.001	3
ZQCZSIG1F	28 05 06	31 40 59	Sigubudo	150	2-Sep-96	14:43	68	7.20	25.00	22.00	0.10	7.00	3.02	1.20	<4	25.70	0.025	0.404	0.486	<0.001	2
ZQCZSIP1B	28 12 59	31 32 22	Siphethu	151	4-Sep-96	14:15	0	8.30	141.00	159.00	1.00	45.00	8.84	4.40	13.00	117.10	0.070	2.249	2.782	<0.001	3
ZQCZSIZ1R	28 07 05	31 38 22	Sizinda	152	5-Sep-96	11:45	200	8.40	24.00	24.00	0.10	10.00	0.46	0.80	4.00	29.00	<0.001	1.095	0.406	<0.001	3
ZQCZSPH1B	28 10 23	31 37 35	Sphiva	153	4-Sep-96	12:41	49	7.90	466.00	613.00	0.60	99.00	0.16	7.80	38.00	328.00	0.192	0.410	0.492	<0.001	3
ZQCZVUT1B	28 12 35	31 29 42	KwaVuthela	154	3-Sep-96	9:48	0	8.20	43.00	147.00	0.30	37.00	<0.1	1.20	<4	66.20	0.020	1.169	0.188	<0.001	2
ZQCZVUT1P	28 12 42	31 29 48	KwaVuthela	155	3-Sep-96	11:07	680	8.10	27.00	25.00	0.30	5.00	0.94	6.70	27.00	24.00	3.423	26.120	0.806	<0.001	3
ZQCZVUT2B	28 12 49	31 29 53	KwaVuthela	156	3-Sep-96	10:20	1	7.60	44.00	38.00	0.20	18.00	0.48	0.20	13.00	44.60	0.177	0.579	16.570	<0.001	3
ZQCZWEL1R	28 14 34	31 32 12	Wela	157	4-Sep-96	14:31	6000	8.80	129.00	163.00	0.60	48.00	0.81	1.70	15.00	109.00	<0.001	0.090	<0.003	<0.001	3
ZQCZXAS1S	28 09 27	31 55 22	KwaXasana	158	4-Sep-96	10:40	140	7.80	354.00	481.00	0.50	81.00	<0.1	3.20	66.00	260.00	0.121	1.207	1.620	<0.001	3
ZQCZXOL1B	28 11 23	31 32 08	KwaXolo	159	3-Sep-96	11:36	0	8.00	190.00	242.00	0.90	57.00	18.60	3.30	15.00	155.00	0.080	0.470	0.153	<0.001	2
ZQCZXOL1P	28 11 01	31 32 51	KwaXolo	160	3-Sep-96	13:39	750	8.10	23.00	23.00	0.40	7.00	<0.1	3.70	22.00	26.20	0.115	30.550	<0.003	<0.001	3
ZQCZXOL2B	28 11 10	31 33 28	KwaXolo	161	3-Sep-96	12:16	1	8.10	354.00	592.00	0.40	94.00	0.11	5.90	36.00	282.00	0.092	1.219	0.229	<0.001	2
ZQCZXOL3B	28 10 39	31 33 03	KwaXolo	162	3-Sep-96	13:23	8	8.20	422.00	767.00	0.50	103.00	<0.1	6.50	40.00	328.00	[illegible]	0.401	[illegible]	<0.001	3
ZQCZXOL4B	28 12 09	31 34 23	KwaXolo	163	3-Sep-96	14:22	0	8.30	355.00	509.00	0.50	75.00	<0.1	4.90	24.00	279.00	1.067	<0.003	1.307	<0.001	3

KEY CLASS: 0 Ideal for potable use ■ Suitable for potable use 2 Suitable for short term potable use 3 Not suitable for potable use

APPENDIX 4: LANDUSE ACTIVITIES

ZQC No	Village &seq.No	Soource	People using source	Mining activity	Animals in proximity	Animal dung near source	Agric. field	Fertilisers used	Nearest dwellings	Nearest pit latrines	Discharge near source	Human activity	Human excreta near source	Source Protected
ZQCZAMA 1B	Amahlongwa 1	Borehole	2500	None	2m	Yes	200m	No	250m	50m	No	None	Yes	Yes but water ponding
ZQCZAMA 2F	Amahlongwa 2	Spring	1000	None	10m	2m	20m	No	20m	40m	Yes	Washing clothes	No	Yes
ZQCZAMA 1R	Amahlongwa 3	River	Not applicable	None	None	Yes	None	No	1000m	None	Yes	Washing clothes	Yes	Not applicable
ZQCZAMA 1S	Amahlongwa 4	Borehole	Not applicable	None	30m	No	20m	No	30m	35m	No	None	No	Yes
ZQCZAMA 2B	Amahlongwa 5	Borehole												
ZQCZAMA 2F	Amahlongwa 6	Spring												
ZQCZAMA 3F	Amahlongwa 7	Spring	1000	None	5m	Yes	None	No	None	10m			Yes	No water ponding
ZQCZAMA 2R	Amahlongwa 8	River	300	None	20m	Yes	30m	No	50m	30m	Yes	Washing clothes	Yes	Pit latrine close to source
ZQCZAMA 3B	Amahlongwa 9	Borehole	800	None	100m	5m	80m	Don't know	200m	150m	Yes	Washing clothes	No)	No water ponding
ZQCZAMA 4B	Amahlongwa 10	Borehole	Not applicable	None	None	No	None	No	500m	700m	No	None	No	No
ZQCZBHE1 F	Bhewula 11	Spring	400	None	100m	No	150m	Don't know	150m	150m	No	None	Yes)	No runoff
ZQCZBHE2 B	Bhewula 12	Borehole	200	None	200m	No	30m	Don't know	40m	40m	No	None	No	No
ZQCZCHO1 F	Ichobe 13	Spring	130	None	2m	Yes	100m	No	50m	50m	Yes	Washing clothes	Yes	No Spring open
ZQCZDLA2 B	Dlangezwa 14	Borehole	None	Not applicable	None	No	300m	Don't know	None	None	No	None	No	No
ZQCZDON1 F	Donsa 15	Spring	165	None	500m	Yes	50m	Yes	200m	200m	No	None	Yes	No Spring open

ZQC No	Village &seq.No	Soource	People using source	Mining activity	Animals in proximity	Animal dung near source	Agric. field	Fertilisers used	Nearest dwellings	Nearest pit latrines	Discharge near source	Human activity	Human excreta near source	Source Protected
ZQCZDUD1B	Dududu 16	Borehole	1000	None	5m	Yes	35m	Don't know	20m	10m	Yes	Washing clothes	Yes	No water ponding
ZQCZDUD1F	Dududu 17	Spring	Not applicable	None	100m	No	10m	Don't know	10m	None	Not applicable	None	No	Yes
ZQCZDUD2B	Dududu 18	Borehole	2000	None	None	No	10m	Don't know	10m	None	No	None	Yes	Yes but water ponding
ZQCZDUD2F	Dududu 19	Well	2000	None	10m	Yes	5m	Don't know	30m	30m	Yes	Washing clothes	Yes	No water ponding
ZQCZDUD3B	Dududu 20	Borehole	30	None	50m	No	30m	Yes	10m	15m	No	None	No	No
ZQCZDUD4B	Dududu 21	Borehole	300	None	50m	No	25m	Yes	3m	6m	No	None	No	No
ZQCZDUD5B	Dududu 22	Borehole	250	None	30m	3m	3m	Don't know	20m	25m	No	None	No	No
ZQCZDUD6B	Dududu 23	Borehole	320	None	15m	10m	30m	Don't know	50m	45m	Yes	Washing clothes	Yes	No water ponding
ZQCZDUM3F	KwaDumisa 24	Spring	300	None	None	No	100m	Don't know	60m	90m	Yes	Washing clothes	No	No
ZQCZDUM5B	KwaDumisa 25	Borehole	500	None	None	No	150m	Don't know	300m	250m	No	None	No	Yes
ZQCZEMB1F	Embuthisweni 26	Spring	560	None	Drinking	No	30m	No	50m	100m	No	None	Yes (slope)	No
ZQCZEMB2F	Embuthisweni 27	Spring	650	None	20m	Yes	20m	Don't know	>100m	>100m	Yes	Agriculture	Yes (slope)	inadequate
ZQCZENK1B	Enkangala 28	Borehole	250	None	None	No	None	No	100m	100m	No	None	No	No
ZQCZENK2B	Enkangala 29	Borehole	150	None	None	No	None	No	200m	200m	No	None	No	No
ZQCZENK3B	Enkangala 30	Borehole	<100	None	None	No	None	No	200m	200m	No	None	No	No

ZQC No	Village &seq.No	Soource	People using source	Mining activity	Animals in proximity	Animal dung near source	Agric. field	Fertilisers used	Nearest dwellings	Nearest pit latrines	Discharge near source	Human activity	Human excreta near source	Source Protected
ZQCZENK4B	Enkangala 31	Borehole	25	None	>100m	No	None	No	50m	50m	No	None	No	No
ZQCZENT1R	Entshenkombo 32	River												
ZQCZESI1B	Esidakeni 33	Borehole	None	None	None	No	1m	Don't know	50m	None	No	None	No	No
ZQCZESI1F	Esidakeni 34	Spring	800	None	10m	Yes	5m	Don't know	150m	None	No	None	Yes_	Spring Not protected
ZQCZESI2B	Esidakeni 35	Borehole												
ZQCZESI2F	Esidakeni 36	Spring	Not applicable	None	5m	No	50m	Don't know	400m	350m	No	None	Yes	No
ZQCZEZE1F	Ezembeni 37	Spring	500	None	20m	1m	30m	Don't know	50m	55m	Yes	Washing clothes	No	No
ZQCZEZE1R	Ezembeni 38	River	1000	None	2m	None	3m	Don't know	30m	25m	No	None	Yes	Not applicable
ZQCZEZE2F	Ezembeni 39	Spring	1500	None	15m	Yes	200m	Don't know	200m	200m	No	None	No	No
ZQCZEZE2R	Ezembeni 40	River	Not applicable	None	5m	No	None	No	40m	None	Yes	Not applicable	Yes	Not applicable
ZQCZEZE3B	Ezembeni 41	Borehole	1000	None	None	No	10m	Don't know	150m	160m	No	None	Yes	No water ponding
ZQCZLWA1B	Lwasini 42	Borehole	1000	None	10m	Yes	None	No	20m	None	No	None	Yes	No water ponding
ZQCZLWA1R	Lwasini 43	River	1000	None	5m	Yes	100m	Don't know	200m	None	Yes	Washing clothes	Yes	Not applicable
ZQCZLWA2R	Lwasini 44	River	Not applicable	None	5m	Yes	None	Don't know	500m	None	Yes	Not applicable	Yes	Not applicable
ZQCZMAD1B	Madundubala 45	Borehole	160	None	None	No	None	No	50m	>50m	No	None	No	No

ZQC No	Village &seq.No	Soource	People using source	Mining activity	Animals in proximity	Animal dung near source	Agric. field	Fertilisers used	Nearest dwellings	Nearest pit latrines	Discharge near source	Human activity	Human excreta near source	Source Protected
ZQCZMAH 1B	Mahwaqa 46	Borehole	400	None	200m	Yes	200m	Don't know	200m	200m	No	None	Yes	No water ponding
ZQCZMAM 1B	Mampungushe 47	Borehole	240	Not applicable	1m	Yes	15m	Yes	17m	15m	Yes	Farming & washing clothes	Yes (No sanitary seal)	No
ZQCZMAM 1R	Mampungushe 48	River	48	Not applicable	1m	Yes	3m	Don't know	±200m	±200m	Yes	Washing clothes	Yes (from fields, roads, bushes)	Not applicable
ZQCZMAM 2R	Mampungushe 49	River	240	Not applicable	1m	Yes	20m	Yes	300m	300m	Yes	Washing clothes & drinking	Yes	Not applicable Most have no toilets
ZQCZMGA 1F	Mgangeni 50	Spring	80	None	None	No	100m	Don't know	100m	100m	No	None	Yes	No
ZQCZMGW 1B	Mgwenya 51	Borehole	495	Not applicable	1m	Yes	100m	No	100m	10m	Yes	Washing clothes, drinking &cooking	Yes	No Pit latrine seepage
ZQCZMGW 1R	Mgwenya 52	River	750	Not applicable	1m	Yes	20m	No	200m	200m	Yes	Washing clothes, drinking &cooking	Yes (poor sanitation facilities)	No
ZQCZMGW 2B	Mgwenya 53	Borehole	405	Not applicable	1m	Yes	5m	Don't know	100m	None	Yes	Washing clothes, drinking &cooking	Yes	No No sanitation facilities
ZQCZMJU1 F	Mjunundwini 54	Spring	Not applicable	None	500m	None	None	No	300m	None	No	None	No	No
ZQCZMJU1 R	Mjunundwini 55	River	3000	None	20m	Yes	None	No	500m	500m	Yes	Not applicable	Yes	Not applicable
ZQCZMJU2 R	Mjunundwini 56	Spring	Not applicable	None	None	Yes	115m	Don't know	300m	320m	Yes	Not applicable	Yes	No

ZQC No	Village &seq.No	Soource	People using source	Mining activity	Animals in proximity	Animal dung near source	Agric. field	Fertilisers used	Nearest dwellings	Nearest pit latrines	Discharge near source	Human activity	Human excreta near source	Source Protected
ZQCZOTH3F	Othinsangu 55	Spring	4000	Not applicable	1m	Yes	0m	Don't know	600	400	Yes	Washing clothes	Yes human excreta	No
ZQCZQON1F	Qonqo 56	Spring	5000	Not applicable	200m	Yes	None	No	500m	Not applicable	No	None	Yes human excreta	No
ZQCZSIG1F	Sigubudo 57	Well	2000	Not applicable	None	No	0m	Yes	500m	None	No	None	Yes	No
ZQCZSIP1B	Siphethu 58	Borehole	400	Not applicable	None	No	None	No	20m	None	No	None	No	Yes
ZQCZSIZ1R	Sizinda 59	River	2000	Not applicable	500m	Yes	800m	Don't know	200m	None	Yes	Human excreta	Yes runoff & human excreta	Not applicable
ZQCZSPH1B	Sphiva 60	Borehole	200	Not applicable	None	Yes	None	No	200m	None	No	None	No	Not applicable
ZQCZVUT1B	KwaVuthela 61	Borehole	100	Not applicable	5m	Yes	5m	Don't know	2m	3m	Yes	Washing clothes	Yes cattle drinking	No
ZQCZVUT1P	KwaVuthela 62	Pan	Not applicable	Not applicable	1m	Yes	10m	Don't know	10m	10m	Yes	Swimming	Yes human excreta	No
ZQCZVUT2B	KwaVuthela 63	Borehole	80	Not applicable	1m	Yes	2m	Yes	3m	4m	Yes	Washing clothes	Yes waste by runoff	No
ZQCZWEL1R	Wela 64	River	Not applicable	Not applicable	1m	Yes	None	No	None	None	Yes	Washing clothes	Yes .swimming / washing clothes /cattle	Not applicable
ZQCZXAS1S	KwaXasana 65	Borehole - windmill	300	Not applicable	300m	No	400m	Don't know	300m	None	No	None	No	No Wind Mill

ZQC No	Village &seq.No	Soource	People using source	Mining activity	Animals in proximity	Animal dung near source	Agric. field	Fertilisers used	Nearest dwellings	Nearest pit latrines	Discharge near source	Human activity	Human excreta near source	Source Protected
ZQCZNGO1R	Ngolotshe 41	River	3000	Not applicable	10m	Yes	500m	Don't know	600m	None	No	None	Yes human excreta	Not applicable
ZQCZNGW1R	Ngwabi 42	River	Not applicable	Not applicable	2m	Yes	10m	Don't know	Not applicable	None	No	None	No	Not applicable
ZQCZNHL1S	Nhlungwane 43	Borehole	90	Not applicable	None	No	None	No	200m	None	No	None	No	Yes
ZQCZNKA1R	Nkalaneni 44	River	1500	Not applicable	10m	Yes	500m	Yes	500m	500m	Yes	Human faeces	Yes runoff & human excreta	Not applicable
ZQCZNTA1B	Ntandakuwela 45	Borehole	90	Not applicable	None	No	40m	Don't know	150m	150m	Yes	Washing clothes	No	No
ZQCZNTA1R	Ntabankulu 46	River	200	Not applicable	1m	Yes	400m	Don't know	400m	None	Yes	Bathing & washing clothes	Yes	Not applicable
ZQCZNTA3B	Ntandakuwela 47	Borehole	350	Not applicable	Not applicable	Not applicable	None	No	250m	250m	No	None	No	No
ZQCZNTA5B	Ntabankulu 48	Borehole	200	Not applicable	150m	No	200m	Don't know	200m	200m	No	None	No	Yes
ZQCZNZA1F	Nzangamandla 49	Spring	2500	Not applicable	2m	Yes	100m	Don't know	100m	None	Yes	Washing clothes	No	No
ZQCZNZA1R	Nzangamandla 50	River	Not applicable	Not applicable	2m	Yes	1000m	Don't know	500m	None	No	None	No	Not applicable
ZQCZNZA2F	Nzangamandla 51	Spring	2000	Not applicable	5m	Yes	None	No	15m	None	Yes	Washing clothes	Yes human excreta	No
ZQCZNZA3F	Nzangamandla 52	Spring	2000	Coal	20m	Yes	500m	Don't know	800m	None	Yes	Washing clothes	Yes human excreta	No
ZQCZOTH1F	Othinsangu 53	Spring	3000	Not applicable	50m	Yes	None	Don't know	1000m	None	Yes	Washing clothes s	Yes human excreta	No
ZQCZOTH2F	Othinsangu 54	Spring	3000	Not applicable	None	No	0m	Don't know		None	Yes	Washing clothes	Yes human excreta	No

ZQC No	Village &seq.No	Soource	People using source	Mining activity	Animals in proximity	Animal dung near source	Agric. field	Fertilisers used	Nearest dwellings	Nearest pit latrines	Discharge near source	Human activity	Human excreta near source	Source Protected
ZQCZMNQ1B	Mnqawe 30	Borehole	100	Not applicable	None	Yes	None	No	20m	None	Yes	Washing clothes	Yes	Yes but minimal
ZQCZMNQ1P	Mnqawe 31	Well in river bed	Not applicable	Not applicable	None	Yes	None	No	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	No
ZQCZMNQ2B	Mnqawe 32	Borehole	100	Not applicable	1m	Yes	None	No	300m	None	No	None	No	No
ZQCZMNQ2R	Mnqawe 33	River	100	Not applicable	1m	Yes	Far	Don't know	250m	None	Yes	Washing clothes	Yes runoff	Not applicable
ZQCZMVA2B	Mvalo 34	Borehole	120	Not applicable	1m	Yes	None	Don't know	300m	None	Yes	Washing clothes	Yes Human & cattle excreta	No
ZQCZNCE1S	Ncemaneni 35	Borehole	150	Not applicable	200m	No	None	Don't know	100m	10m	No	None	No	Yes
ZQCZNCE3B	Ncemaneni 36	Borehole	320	Not applicable	None	No	None	No	50m	50m	No	Yes bathing & washing clothes	Yes	No
ZQCZNDL1B	Ndlozane 37	Borehole	2000	Not applicable	150m	Yes	None	No	30m	40m	No	None	Yes human excreta	No
ZQCZNDL1F	Ndlozane 38	Spring	3500	Not applicable	3m	Yes	4m	Don't know	400m	300m	Yes	Washing clothes	Yes human excreta	No
ZQCZNDL1R	Ndlozane 39	River	2000	Not applicable	20m	Yes	10m	Don't know	800m	None	No	None	Yes human excreta	Not applicable
ZQCZNDL2F	Ndlozane 40	Spring	1500	Not applicable	800m	Yes	1000m	Don't know	500m	None	Yes	Washing clothes	No	No

ZQC No	Village &seq.No	Soource	People using source	Mining activity	Animals in proximity	Animal dung near source	Agric. field	Fertilisers used	Nearest dwellings	Nearest pit latrines	Discharge near source	Human activity	Human excreta near source	Source Protected
ZQCZLAN1F	Langakazi 15	Well	Not applicable	Not applicable	100m	No	None	No	250m	250m	No	None	Yes	No
ZQCZLOM1B	Lomo 16	Borehole	300	Not applicable	None	No	None	No	50m	50m	No	None	No	Yes
ZQCZMAH1F	Mahaza 17	Spring	3000	Not applicable	300m	Yes	500m	Don't know	10m	None	No	None	Yes human excreta	No
ZQCZMAK1R	Makheme 18	River	2000	Not applicable	60m	Yes	50m	Don't know	Not applicable	None	Yes	Washing clothes	Yes human excreta	Not applicable
ZQCZMAN1F	Manzawayo 19	Spring	3000	Not applicable	2m	Yes	None	No	5m	5m	No	None	No	Yes
ZQCZMAP1B	Maphophoma 20	Borehole	Not applicable	Not applicable	200m	No	0m	Yes	0m	50m	No	None	No	Yes
ZQCZMAP1F	Maphophoma 21	Spring	5000	Not applicable	None	Yes	None	No	0m	None	No	None	No	Inadequate
ZQCZMAP2F	Maphophoma 22	Spring	6000	Not applicable	500m	Yes	1000m	Don't know	600m	None	No	None	No	Yes ,
ZQCZMAS1F	Masundwini 23	Well	2000	Not applicable	10m	Yes	100m	Yes	1000m	1000m	No	None	Yes (runoff)	No
ZQCZMAT2F	Matheni 24	Spring	4000	Not applicable	2m	Yes	1m	Yes	3m	None	No	None	No	No
ZQCZMAT1B	Matshemhlophe 25	Borehole	NOT APPLICABLE	Not applicable	20m	Yes	50m	Yes	20m	None	No	None	No	No
ZQCZMAT1F	Matshemhlophe 26	Spring	200	Not applicable	Not applicable	No	100m	Yes	20m	20m	No	None	No	No
ZQCZMAY1F	Maye 27	Spring	2500	Not applicable	500m	Yes	4m	Don't know	400m	None	No	None	No	No
ZQCZMLA1R	KwaMlaba 28	River	220	Not applicable	10m	Yes	15m	Don't know	15m	15m	Yes	Washing clothes	No	Not applicable
ZQCZMLA2S	KwaMlaba 29	Borehole	160	Not applicable	None	No	100m	Don't kNow	50m	50m	No	None	No	No-Reservoir (Windmill)

ZQC No	Village &seq.No	Soource	People using source	Mining activity	Animals in proximity	Animal dung near source	Agric. field	Fertilisers used	Nearest dwellings	Nearest pit latrines	Discharge near source	Human activity	Human excreta near source	Source Protected
ZQCZBHE1B	KwaBhekinkantolo 1	Borehole	50	Not applicable	1m	Yes	20m	Yes kraal manure	100m	100m	No	None	Yes cow dung	No
ZQCZBHE1P	KwaBhekinkantolo 2	Dam	50	Not applicable	1m	Yes	50m	Don't know	200m	None	Yes	Washing clothes /swimming	Yes cow dung	No
ZQCZBHU1B	KwaBhungane 3	Borehole	100	Not applicable	Not applicable	Yes	20m	Don't know	100m	None	Yes	Washing clothes	Yes cow dung	No
ZQCZBHU1R	KwaBhungane 4	River	300	Not applicable	1m	Yes	No	None	200m	None	Yes	Washing clothes & swimming	Yes cattle	Not applicable
ZQCZDUM1F	KwaDuma 5	Spring	3500	Not applicable	2m	Yes	3m	Don't know	500m	None	Yes	Washing clothes	Yes human excreta	No
ZQCZDUM2F	KwaDuma 6	Spring	Not applicable	Not applicable	20m	Yes	No	No	500m	None	Yes	Washing clothes	Yes human excreta	No
ZQCZDUM3F	KwaDuma 7	Spring	3500	Not applicable	1m	Yes	10m	Don't know	200m	None	Yes	Washing clothes	Yes human excreta	No
ZQCZDUM4B	KwaDumisa 8	Borehole	300	None	10m	No	None	No	70m	70m	No	None	No	Yes
ZQCZDUM5F	KwaDumisa 9	Spring	500	None	3m	Yes	200m	Don't know	40m	None	No	None	No	No
ZQCZJIK1B	KwaJikaza 10	Borehole												
ZQCZJIK2B	KwaJikaza 11	Borehole												
ZQCZKHU1B	Khukho 12	Borehole	300	Not applicable	50m	Yes	None	No	200m	200m	No	None	No	No
ZQCZKHU2S	Khukho 13	Borehole	Not applicable	Not applicable	None	No	10m	Don't know	100m	100m	No	None	No	Yes
ZQCZLAN1B	Langakazi 14	Borehole	210	Not applicable	None	Yes	None	No	300m	300m	No	None	No	Yes

ZQC No	Village &seq.No	Soource	People using source	Mining activity	Animals in proximity	Animal dung near source	Agric. field	Fertilisers used	Nearest dwellings	Nearest pit latrines	Discharge near source	Human activity	Human excreta near source	Source Protected
ZQCZTHE1B	Thenjane 84	Borehole (tank)	±298	None	1000m	Yes	1500m	Don't know	0m	20m	No	None	No	Yes
ZQCZTHE1F	Thenjane 85	Spring	±200	None	100m	Yes	500m	Don't know	500m	500m	Yes	Washing clothes	No	semi-protected
ZQCZTHE1R	Thenjane 86	River	±500	None	0m	Yes	500m	Don't know	500m	None	Yes	Washing clothes	Yes	No open running water
ZQCZTHE2B	Thenjane 87	Borehole	±50	None	0m	Yes	500m	Don't know	500m	500m	No	None	No	Yes
ZQCZTHE3B	Thenjane 88	Borehole	±200	Escavation	500m	Yes	50m	Don't know	200m	200m	No	None	No	Yes
ZQCZTSH1F	Tshenkombo 89	Spring	300	None	50m	Yes	20m	Don't know	40m	40m	Yes	Washing clothes	Yes (	No water ponding
ZQCZTSH1R	Tshenkombo 90	River	Not applicable	None	50m	Not applicable	90m	Don't know	110m	Not applicable		Not applicable	Not applicable	Not applicable
ZQCZTSH2F	Tshenkombo 91	Spring	150	None	20m	Not applicable	Not applicable	Not applicable	60m	60m	Not applicable	Not applicable	Not applicable	Yes
ZQCZTSH3B	Tshenkombo 92	Borehole	150	None	20m	Yes	30m	Don't know	40m	40m	Not applicable	Not applicable	Yes	No water ponding
ZQCZVUL1R	Vulindlela 93	River	3000	None	Not applicable	Not applicable	Not applicable	Not applicable	2000m	None	Yes	Washing clothes	Yes	Not applicable

ZQC No	Village &seq.No	Soource	People using source	Mining activity	Animals in proximity	Animal dung near source	Agric. field	Fertilisers used	Nearest dwellings	Nearest pit latrines	Discharge near source	Human activity	Human excreta near source	Source Protected
ZQCZNDA4 F	Ndaya 71	Spring	±100	None	0m	Yes	500m	Don't know	500m	None	No	None	Yes	No - open spring
ZQCZNDA5 F	Ndaya 72	Spring	150	None	100m	Yes	50m	Don't know	50m	None	Yes	Washing clothes	Yes	No - open spring
ZQCZNDA6 F	Ndaya 73	Spring	±200	None	1000m	Yes	1000m	Don't know	500m	450m	No	None	Yes	No - open spring
ZQCZNDA7 F	Ndaya 74	Spring	±100	None	1000m	Yes	300m	Don't know	350m	None	No	None	Yes	No - open spring
ZQCZNDA8 F	Ndaya 75	Spring	±100	None	1000m	Yes	1000m	Don't know	1000m	None	No	None	Yes	No - open spring
ZQCZNGO1 B	Ngodini 76	Borehole	250	None	50m	No	50m	Don't know	20m	30m	No	None	Yes	No water ponding
ZQCZNJA1 R	Njangwini 77	River	330	Not applicable	100m	Yes	4m	Don't know	200m	200m	Yes	Washing clothes & bathing	Yes	Poor sanitation facilities
ZQCZNKA3 F	Nkampule 78	Well	100	None	2m	Not applicable	300m	Don't know	500m	None	No	None	Yes	Not protected
ZQCZNSO1 R	Nsongeni 79	River	1500	None	1m	Yes	5m	Don't know	10m	10m	Yes	Farming ,washing clothes & swimming	Yes	Poor sanitation facilities
ZQCZNTS1 F	Ntshepheni 80	Spring	Not applicable	None	None	Yes	50m	Don't know	70m	70m	No	None	Yes	No runoff
ZQCZNTS2 F	Ntshepheni 81	Spring	350	None	1m	Yes	100m	Don't know	150m	120m	No	None	Yes	No runoff
ZQCZOKH1 F	Okhalweni 82	Spring	400	None	None	Yes	140m	Don't know	100m	100m	Yes	Washing clothes	Yes	No water ponding
ZQCZQIK1 B	KwaQiko 83	Borehole	300	None	None	No	50m	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Not applicable	Yes