GROUNDWATER QUALITY MONITORING: AN APPROACH TO GROUNDWATER RESOURCE QUALITY PROTECTION

By

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ABSTRACT

Resource protection is considered by the National Water Act (Act No. 36, 1998) of South Africa as one of the methods that can lead to resource management. Furthermore, the Water Services Act (Act No. 108, 1997) regards people as having rights of access to basic water supply of sufficient quality. In this thesis the importance of water resource quality monitoring as a means of water resource protection is highlighted. The aim is towards management and sustainability of water resources in order to serve the current and future generation. The protection measures also focus on ecosystem protection to maintain as well as to restore ecological integrity. Several methods to protect water resources are outlined. The review also focuses on Resource Quality Objectives (RQOs) as form of groundwater resource protection. In such, several attributes onto which the RQOs can be applicable to are highlighted. On the water quality monitoring side, an emphasis is placed on the bacteriological quality of water for protection of public health. Several methods of identifying bacteria in water are discussed as well as the methods of reporting the analyses. The bacteriological quality of water is discussed under the light of water for basic human needs (domestic purposes). The way to interpret the results from a bacteriological examination point of view is also highlighted.

On application, the KwaZulu-Natal Coastal aquifer has been chosen for groundwater protection purposes. The specific site is Mbazwana, in Northern KwaZulu-Natal. The wells of this region were sampled for bacteriological as well physico-chemical water quality. The results from the tests revealed that the domestic waters of this region are contaminated, with 61% of the tested/ sampled wells polluted by bacteria of faecal origin. Both the H_2S strip method and the standard method of bacteriological water quality examination were used for these purposes. In terms of physico-chemical water quality, the water sampled proved to be suitable for drinking purposes i.e. they meet the requirements of South African water quality guidelines. The bacteriological water quality does not meet

the above-mentioned guidelines, therefore the RQOs set plays a role to improve the water resources of this region to a desired state that will be unlikely to pose health risks to public. Based on categories of modifications of water resource units, the groundwater resources of the Northern KwaZulu-Natal revealed to be moderately modified with apparent modifications observed. This means that management rules to protect, manage and conserve the water resources are required. These management rules are RQOs, that are set to avoid further unnecessary water quality degradation while improving the current status of water resources.

DECLARATION

I declare that *Groundwater Quality Monitoring: An Approach to groundwater resource quality protection* is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Full name: **Tholeka Mafanya** Date: **September 2002**

Signed.....................................

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Ms. Tholeka Mafanya

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ABBREVIATIONS

Abbreviation	Description
m bgl	Metres below ground level
BHN	Basic Human Needs
cfu	Coliform forming unit
CRW	Community ring well
CRD	Cumulative rainfall departure
CSIR	Council of Scientific and Industrial Research
CTW	Community tube well
DOC	Dissolved Organic Carbon.
DWAF	Department Of Water Affairs and Forestry
EC	Electrical Conductivity (mS/m)
FRW	Family ring well
FTW	Family tube well
GIS	Geographic Information System
IWQS	Institute for Water Quality Studies
Mg/l	Milligrams per litre
NWA	National Water Act
PiD	Partners in Development
ppb	Parts per billion
ppm	Parts per million
RDMs	Resource Directed Measures

RQOs	Resource Quality Objective
RT-PCR	Reverse Transcriptase-Polymerase Chain Reaction
SACS	South African Committee for Stratigraphy
SDMs	Source Directed Measures
SVF	Saturated volume fluctuation
TDS	Total Dissolved Solids
UWC	University of the Western Cape
WHO	World Health Organization
WSA	Water Services Act
WHPA	Wellhead Protection Area

1 INTRODUCTION

1.1 Preface

The quality of water supplied to the people is a critical issue that should always be monitored. Many developing countries, including South Africa, tend to face the problem of quality deterioration of both surface and groundwater resources. This mainly results from the natural degradation of water due to local and environmental factors, but input from the people (pollution) has a great contribution. Poor sanitation practices leads to the deterioration of quality of the water resources of this country (Cotton et al., 1995).

In South Africa, most of the population lives in rural areas, where groundwater is the vital source for domestic and agricultural purposes. It is therefore of importance to ensure that waters supplied to people is of good quality. In this regard, the Water Services Act (Act No.108, 1997) of South Africa was introduced to guarantee that everyone has a right to basic water supply that is free from any hazards that pose health problems to people.

After the Water Services Act was passed, it was still an issue on how to ensure that the water supplied to people is of good quality i.e. it cannot have health complications to people. The National Water Act (Act No. 36, 1998) was introduced for the purpose of water resource management. The aim of its introduction was to ensure that the water resources are protected from harmful hazards as well as from degradation, so that the current and future generations benefit. The measures to do this were outlined and monitoring of water resources to ensure quality protection was included.

The monitoring to be conducted is a step forward to what has been done in terms of groundwater quality protection.

1.2 Aims and Objectives

The primary goal of any groundwater monitoring and assessment programme is to support water management as well as to protect water resources (Uil et al 1999). It is of importance to state clearly that the study will not deviate from the aim mentioned; instead it will be supportive towards the goal to promote quality protection of water resources. The ultimate aim of this study, therefore, can be said to be the protection of groundwater from vulnerability to pollutants thus improving the quality of drinking water.

The objectives of the study can be outlined as:

- Assessment of the current status of groundwater quality in terms of the physicochemical and microbiological quality for the Mbazwana area in northern KwaZulu-Natal, i.e. naturally occurring constituents and contaminants associated with human activities will be presented
- Identification of potential hazards for contamination existing within the area mentioned above.
- Characterize water quality, based on water samples obtained, in relation to published drinking water quality standards or guidelines.
- Highlight the areas requiring attention for protection based on current data (data collected) and necessary steps to follow for protection.

The monitoring is pursued in compliance with national, provincial and local legislation of the country in order to achieve the goal of supplying water that is not likely to pose health problems and to achieve the goal of protection based on the quality of groundwater.

1.3 Previous Investigations

Recently, groundwater resource protection has been given attention in South Africa with the aim of assisting in the management of water resources. Therefore, it can be said that studies on groundwater protection listed below are still in their initial stages, with few of them finished.

1.3.1 Department of Water Affairs and Forestry (DWAF)

The Department of Water Affairs and Forestry greatly contributed to studies on groundwater protection. In 1998, Mackay produced an article on the *Classification system for water resources in South Africa*. The focus in this paper is on a classification system for water resources of South Africa with the goal to acknowledge water resources as a finite resource that needs to be exploited equitably and sustainably, with backup of protection. The protection focused on surface water resources. A year later, DWAF produced a report on *Resource Direct Measures for protection of water resources: Groundwater component*. DWAF focused on methodologies and guidelines that can be followed when determining the reserve component of groundwater, with clear statements on the necessary issues to be considered as well as the desired protection and management actions. Xu et al. (2000) published an article on the *Comprehensive determination of resource direct measures for groundwater in South Africa*. The article is based on necessary measures to be followed when protecting a groundwater resource.

1.3.2 Consultants

The consultants have done a remarkable job in contributing to studies on the protection of groundwater resources. Conrad and van de Voort (2000) followed the footsteps of Mackay (1998), but focussed on the groundwater component and published a paper on *Classification of groundwater resources under the South African National Water Act*. In this classification system, water resources are grouped in terms of levels of protection required, depending on the sensitivity of the particular water resource. Hatton (2000) gave in a *Review of the Water Research Commission Program, The comprehensive determination of water* *resource reserve: Groundwater component,* which basically compares the Australian and South African policy and management of groundwater resources. Parsons and Mackay (2000) published a paper on the *Determination of the groundwater component of the reserve using the intermediate reserve determination method*. The paper outlines the procedure to be followed when determining the groundwater component of the reserve.

1.3.3 Other countries

1.3.3.1 Australia

Australia has been and is still the country that has done extensive work on groundwater resource protection. Several documents published by the Water and Rivers Commission are centred on the protection of groundwater resources. The published documents show that the guidelines towards protection of the resources exist, while the current focus is on the implementation of the guidelines. The measures of setting a reserve, then Resource Quality Objectives as a form of protection of groundwater resources seem to work well in Australia. Several water resources have been proclaimed as water reserves like the *Ledge Point Water Reserve Water Source Protection Plan* (Water and Rivers Commission, 1999), the *Coomberdale Water Reserve Source Protection Plan* (Water and Rivers Commission, 1999) and the *Gingin Water Reserve Water Source Protection Plan* (Taylor, 1997).

1.3.3.2 USA

The United States of America is also engaged in water resource protection, with a focus on the quality of water resources at a watershed scale. The attention is given to areas where problems and pollutants have the most negative impact (Billman-Golemme, 2001; USEPA, 2001). The protection of water resources has been implemented since 1970s, with several ways of protecting the water resources being introduced (USEPA, 2001). These include laws pertaining to water resource protection. Their main objective is to reduce pollutants that impair the quality of the water resources. Besides the methods mentioned above, the protection of water resources is also encouraged through user participation in watershed management (Johnson et al., 2001). According to the authors, user participation is critical in watershed development and management, and therefore, it can promote efficiency and effectiveness in water resource management. This watershed management also aims at protection and improvement of the health as well as viability of ecosystem (Swallow et al., 2001).

1.3.3.3 Others

In China, groundwater is one of the resources sustaining the livelihood of the people, but it is facing huge problems of pollution, salinity degradation, and contamination as well as land subsidence (Ward and Liang 1995; Maurer et al., 1998 and Zaisheng, 2000). The problem is worse with surface waters, which were noted to be contaminated by wastewater (Ward and Liang, 1995). This is posing health risks to the people of this country, where several waterborne diseases have been reported (Maurer et al., 1998). The authors have noted that the inadequate investments in drinking water supply, sewage treatment supply and failure to make the protection of public health a priority are the chief deficiencies in this country. Management and protection of resources in this country is still one of the measures that need to be taken into consideration.

The Czech Republic has moved towards resource protection focussing on the monitoring of groundwater resources (Krejcik et al., 1999; Vrba, 2000; Kram and Hruska, 2002). The aim of this monitoring is the integrated management and protection of water resources in the areas influenced by human activities (Krejcik et al., 1999). The monitoring is done on several scales i.e. local, regional and national scales and has served as a protection measure to prevent deterioration of groundwater resources. Besides this, principles pertaining to the protection of water resources against pollution from agricultural sources exist (Johanovsky et al., 2002).

1.4 Define research scope

1.4.1 Selection of title

During 1998, the South African government recognized that water is one of the scarce resources in this country. Therefore, the government took measures that acknowledge its responsibility to deal with the beneficial and equitable distribution of water resources. The measures taken were based on rationalization of policy and legislation regarding the protection, utilization, conservation and management of water resources. The ultimate aim was to manage and sustain such resources for the benefit of all people. Trying to achieve that, the methods leading to sustainable utilization of water resources were outlined in the National Water Act (NWA, 1998). The methods include the protection of water resource, which entails the measures like classification of water resources, determination and setting of the reserve and setting of Resource Quality Objectives.

From the above it can be noted that the National Water Act (1998) promotes the protection of water resources with the main aim being the protection of the water resources of this country. Therefore, the title *Groundwater Quality Monitoring: An approach to groundwater resource quality protection* is selected for this study. The title focuses on water quality issues thus addressing the need for protection from a water quality point of view. The research focussed on water quality studies without incorporating Resource Directed Measures (RDMs) i.e. protection measures. Furthermore, the implementation of the NWA (1998) is one of the current concerns in South Africa, and as mentioned earlier, most studies are still in their infancy. Therefore, it can be said that the proposed research will contribute effectively to the implementation of the NWA (1998). Resource Quality Objectives (RQOs) are measures through which the water resources and ecosystems will be maintained in a desired state. The research will attempt to address the gap between the management and utilization of groundwater resources thus improving the resource sustainability. The results will not only contribute to the protection of the resources but also to the development and sustainability of the groundwater resources of this country.

1.4.2 Focus Areas

The Resource Quality Objectives (RQOs) cover several aspects within the field of groundwater protection. The aspects include the physical, chemical and biological character of water quality, the water quantity, water levels and ecosystem or environmental aspects (Xu et al., 2001b). It is therefore of importance to focus on one of the subtopics in order to apply appropriate RQOs for resource protection.

In this case, the study will focus on the quality of groundwater for basic human needs, highlighting the measures that can be taken to protect groundwater resources from degradation. The purpose will, of course, be the protection of groundwater from vulnerability to pollutants as well as provision of safe drinking water with measures in mind, controlling and protecting the resource from deterioration and degradation. The study will review situational analyses for water quality issues, assess the current status of groundwater quality in terms of its physicochemical and microbiological constituents and highlight the areas requiring attention for protection based on current data. This means the assessment of the quality of local aquifer systems by sampling the public and private wells for selected constituents and contaminants. The data obtained will be compared to drinking water quality standards.

If consideration is given to surface and groundwater as a unitary resource, as stipulated in the National Water Act (1998) of South Africa, then a holistic management and protection is required, where costly measures like rehabilitating and treating water resource are eluded.

1.4.3 Organization of the thesis

An introduction and framework for the study is provided as the first chapter. A detailed literature review on the relevant research is included in chapter two. This literature review entails all the aspects that the case study is based on. The methodology is described; detailing the required tasks to achieve the set objectives. The case study, which considers the implementation of what is explained in previous chapters follow. Conclusions and recommendations serve as the last chapter wrapping up the entire study into a summary, with key points noted.

An introduction is provided for each chapter to keep the thesis flowing and to orient the reader about what follows in the next chapter. The data is presented in tables and figures within the text to make reading much easier. Where huge tables and less important but useful diagrams/ figures for explanation exist, an appendix is used to present such data.

1.4.4 Site Selection

The National Water Act (1998) of South Africa introduced the concept of the protection of water resources. This not only required the formulation of guidelines, but also the practical implementation of proposed measures to protect water the resources. Therefore, when selecting a study area it is essential to look for potential areas requiring protection. In this case, the criteria for selecting the study area were:

- The area should have a shallow water table.
- One of the groundwater uses should be the supply of water for basic human needs.
- The groundwater should be potentially vulnerable to contaminants and hazardous materials

The last condition means that the groundwater flow conditions, the thickness to saturated zone, the hydraulic properties, chemical as well as biochemical soil properties and geology must favour the conditions of vulnerability. According to the criteria stated above, primary aquifers with relatively shallow groundwater levels will be the focus of this study. The geology, in this case, would be unconsolidated material (sands). The northern KwaZulu –Natal coastal aquifer, with its shallow water tables seems to favour all the above conditions, where Quaternary sands serve as underlying geology. Furthermore, the groundwater is used for domestic purposes and the aquifer is vulnerable to anthropogenic contamination.

2 WATER RESOURCE QUALITY PROTECTION

2.1 Introduction

The National Water Act (NWA) of South Africa has embarked on protection of water resources (NWA, 1998). This includes sustainable usage, conservation and development measures that will protect groundwater at a catchment scale, prevent it from over-utilization, harmful hazards and impacts as well as providing remedies in cases of pollution, thus guaranteeing the functioning of the ecosystem.

In this study, groundwater quality monitoring is used as a method to protect water resources. The emphasis is placed on the microbiological water quality (bacteriological and virological quality) of drinking water. Bacteriological examination of water samples provides a responsive test for the discovery of not only recent faecal pollution but also a hygienic assessment of water quality that is not normally incorporated in chemical analyses. The frequent examination of water quality is one of the critical issues that should be given attention because contamination may take place at inconsistent intervals. This means that sampling one borehole and carry out an advanced test may not be enough to draw conclusions about the water quality for a particular region. It is therefore important to carry out a simple test and cover a large area for the examination of water quality as this is required at frequent intervals (WHO, 1984).

Carrying out a bacteriological examination of water quality is one issue of concern in South Africa. Most regions in this country have recently had an outbreak of water-borne diseases. There is no doubt that studies of this nature are required to find out the underlying cause for such outbreaks. With such threats, a focus needs to be placed on public health based on microbiology as well as water quality. Furthermore, Water Services Act (Act No.108, 1997) also encourages studies of this nature.

2.2 A need for water resource protection

With the beginning of the century, South Africa is facing many challenges in terms of its water resources. The challenges (i.e. the deterioration of water quality resources, over-abstraction of water resources, deterioration of ecosystem integrity as well as variable rainfall patterns related to climatic changes) have led to South African government taking action on protection of the water resources (NWA, 1998).

It can be said therefore; other factors (i.e. from the list above) result from natural phenomena e.g. climatic changes and cannot be controlled. In addition to problems faced by South Africa with regard to its water resources, current water resources seem to be unable to accommodate the population of the country resulting in water supply shortages due to high demands. Furthermore, improper sanitation and agricultural practices (as in the case of leaching of nitrates due to use of fertilizers) are still problematic in this country and are some of the major factors leading to water quality deterioration (Colvin, 1999). It is for these reasons that the South African government embarked on the protection of water resources so as to sustain living not only for current but future generations.

The water resources are protected to conserve the ecological integrity. Both quality deterioration as well as conflicts within the ecosystem is observed when pollution takes place. These conflicts when severe, can lead to population change as well as extinction i.e. the non-functioning of the ecosystem

2.3 Protection of water resources

The implementation of the National Water Act (1998) necessitates measures that can be used to ensure the sustainability of the water resources for the future generations. The central idea to this is the proper management of water resources. From this NWA (1998), terms like the protection of water resources against harmful hazards as well as over-abstraction were introduced. A broad term 'water resources' was used to incorporate both surface and groundwater resources. The protection of water resources was looked under broader aspects such as Resource Directed Measures (RDMs), which are the methods aiming at the protection of water resources. The Source Directed Controls are the incentives focussing on the protection of water resources by controlling both the point and non- point pollution sources by means of authorization. The RDMs, therefore can be applied for both surface and groundwater resources. In this study, an emphasis is placed on the protection of groundwater resources.

2.4 Resource Directed Measures (RDMs)

The Resource Directed Measures (RDMs) as mentioned above are methods aiming at protection of water resources. These methods include the *classification of water resources*, the *setting and quantification of the reserve* and *Resource Quality Objectives* (NWA, 1998). The NWA encourages the protection of water resources so that they can be developed, conserved and managed while being utilized. Further, the measures were introduced to ensure that water resources are maintained in a desired state not only for human needs but for ecosystem health as well. The introduction, as well as application of RDMs is based on existing tools e.g. water quality monitoring, with the objective of the resource protection. A procedure on how to apply the RDMs is outlined by Xu et al. (2001b). From their work it is clear that a need to understand the study area (i.e. delineate the study area) in terms of geohydrological units and response is required. Like any other study, current conditions are always important and are not ignored in the application of RDMs. Following this are the RDMs attributes, with classification first, then Reserve and finally Resource Quality Objectives. In conclusion, a monitoring program is recommended.

2.4.1 The Resource Classification

Protection of water resources can be achieved by classifying water resources according to classes. The class depends on the level of risk the water resources are subjected to, i.e. how sensitive (ecological sensitivity) is the water resource which is dealt with. The basis for setting classes is to minimize the risk of pollution. The risk allowed is weighted against the requirements for long-term protection and sustainability of water resources. When classifying water resources, classes are set with requirements that should be maintained. The requirements may include water for basic human needs and ecosystem functioning. If the requirements for classes to be set are to be maintained, reference conditions prior to setting of the class need to be assessed. The reference conditions will need to be assessed for quality, quantity and ecological aspects. For groundwater, reference conditions are assumed to include (DWAF, 1999):

- Water level, the seasonal and inter-annual variability of water level;
- Water quality - the concentrations of key water quality constituents, including their seasonal and inter-annual variability;
- Aquifer structure and composition.

This means a procedure on application of RDMs needs to be considered. Conrad and van de Voort (2000) did a detailed study on the classification of groundwater resources, while Mackay (1998) puts forward details on surface water resource classification.

2.4.2 The Reserve

The reserve is defined by the NWA (1998) as the quality and quantity of water required for:

- Basic human needs by securing a basic supply of water to the people for current and future needs.

- Protection of aquatic ecosystem in order to secure ecological sustainable development and utilization of relevant water resources.

The Reserve in simple terms refers to the amount of water set aside to ensure ecosystem functioning (Xu et al., 2001b). It is set first, prior to allocation of water for other uses. This holds true if the reserve encompasses the quality and quantity of water required for basic human needs and the protection of the aquatic ecosystem. These are the two parameters ensuring that an ecosystem is functioning and people's needs are met. In the case of basic human needs as emphasized in the Water Services Act (1997), the level is set to 25L/p/d thus ensuring an equitable share for all. The amount of water required for aquatic ecosystem protection depends on expert judgment (Xu et al., 2000). In this case, background knowledge as well as historic data for the area being dealt with will be helpful. For any water to be allocated for other uses, a reserve study needs to be conducted. Various scales under which the reserve may be determined exist. These include a desktop; rapid, intermediate and comprehensive reserve determination (DWAF, 1999). Once the reserve is set, guiding rules and measures on how to protect it (the reserve) so that functioning of the ecosystem is ensured are required. These are termed Resource Quality Objectives; and they should be set in order to ensure that the desired conditions, as well as improvement of the resources are sustained. Detailed research on reserve quantification is pursued by Xu et al., (2000) and is an on-going activity.

2.4.3 The Resource Quality Objectives

Resource Quality Objectives (RQOs) serve as goals for resource protection as they are guidelines limiting what should be done and how should it be done in terms of resource management (Xu et al., 2001b). In essence, RQOs can be seen as a means to water resource sustainability. They represent the actual decisions regarding the policy, the way resources should be managed, controlled and developed for the current and future needs. RQOs should be viewed as determinants of the direction for the resource protection and they take control over management, hence indirectly improving resource development. They are set according to rules associated with the class being set.

The decision process amongst the stakeholders, Management Authority, interested people and the Minister of Water Affairs represents the effectiveness as well as the constructiveness of the set RQOs will be (Xu et al., 2001b). The central idea is that the sustainability of groundwater resources can only be achieved if and only if there can be recognition of a need to protect and improve the ecosystem and groundwater resources at large.

The NWA (1998) relates RQOs to the reserve, instream flow, water levels, and concentrations of particular substances in water, quality of water resources as well as instream and riparian habitat. The last and the most important one is the regulation or prohibition of instream or land based activities, which may have a negative effect on the quality and quantity of the water resource (Xu et al., 2001b). The water quality and quantity referred to, is incorporated from the reserve determination. Guiding rules for water utilization are mainly based on the requirements of classification, i.e. the purpose the class is suitable for (drinking or stock farming). From the above points, it is clear that RQOs aim at protection of quality and quantity of the water resource as well as the ecosystem. The RQOs set can either be descriptive or numerical but the main objective should be protection (Xu et al., 2000) .

Protection of resources is a response on realization that our resources are threatened and now we are taking measures to maintain them in their acceptable levels, while not forgetting that the current and future generations should benefit from them (Mackay 1998; NWA, 1998). This means ensuring the maintenance of the ecological integrity as well as preservation of its diversity. Resource protection should be seen as an effort towards balancing the societal and ecological values. The point of focus is on resources at risk and the multiple stressors affecting them and finally the way to alleviate them.

It should be noted that setting Resource Quality Objectives for any resource is a process and is based on scientific integrity (Xu et al., 2001b). As mentioned earlier, RQOs take into account the quality, quantity and ecological value of the resource as well as ecosystem sensitivity. It should, therefore, not be biased nor compromised. It can be noticed that all the RDM measures are linked to ensure improvement and continuity of water resource development. It is an interdisciplinary programme that requires monitoring.

2.5 Source Directed Controls

The Source Directed Controls (SDCs) are used in conjunction with RDMs to protect water resources. They are mainly based on control of pollution at the source to assist statutory authorities in meeting errands for protection of the water resources. The strategy on setting them is aiming at integrated control of source pollution that is likely to pose threats to water resources at large. The ultimate aim is to minimize the pollution at source with incentives like the following:

- Treatment and neutralisation of waste;
- Detoxification of waste;
- Recycling and re-use of wastewater.

The prevention and remedy options are main aims for SDCs as stipulated in section 19 of the NWA (1998). The principle of the “polluter takes responsibility” applies. Another measure is the issuing of licenses and authorizations that will be the effective intervention on development activities which are likely to impact on water resources. This also includes the prevention of land use practices threatening water resources.

The SDCs are aiming at agricultural, mining, urban development and industrial sectors for waste control and management. Like the RDMs, the studies on SDCs are still at infancy with guidelines for the sectors mentioned above being formulated.

On application, the SDCs are applied on a differentiated approach based on vulnerability and importance of the water resource, i.e. for Basic Human Needs (BHN) meaning that portion of water allocated for domestic uses (DWAF, 2000). This means that both the SDCs and RDMs are considered in this instance. Alternatively, the SDCs can also be applied based on precautionary principles. This means that water containing waste being discharged will have to meet the Waste Discharge Standards set by DWAF (1998). The standards will at least serve as minimum requirements.

2.6 The role of groundwater monitoring in water resource protection

Several aspects are deemed when considering resource protection. The National Water Act (1998) of South Africa tries to pull all these aspects under one term of RDMs. Not forgetting the SDCs on the other side, they are used too for protection purposes. If all these methods mentioned above are applicable and useful in the groundwater protection, one would ask 'why groundwater monitoring?'. The attributes carried by the methods specified allows evaluation of the status of the water resource or prevention of the potential polluting agents coming to water resource and finally the necessary stringent controls to protect the water resources. Consequently, to ensure that the status of water resources is maintained in a desired state and to ensure that necessary controls set are met, a monitoring programme is required. In simple terms groundwater monitoring can be declared as a technique/ approach that serves as the baseline to protection of water resources. It is true that invention of new methods to protect water resources can be developed and declared, but the question still remains on how to ensure that the current status of a particular water resource is maintained or improved. It can be noted in several publications (i.e. Mackay, 1998; DWAF, 1999; Xu et al, 2001b) that whenever one speaks about protection of water resources, the methods to do so will come first and lastly the monitoring of water resources. Therefore, water monitoring can be said to form the baseline for protection of water resources and its significance to the water resource protection is to indicate whenever there are deviations from reference conditions. Finally, groundwater monitoring can be described as a major protection technique as it takes place over a long period thus telling about changes the water resource is undertaking. Figure 2-1 shows the relationship between protection of water resources and monitoring. All the measures and attributes associated with protection are included.

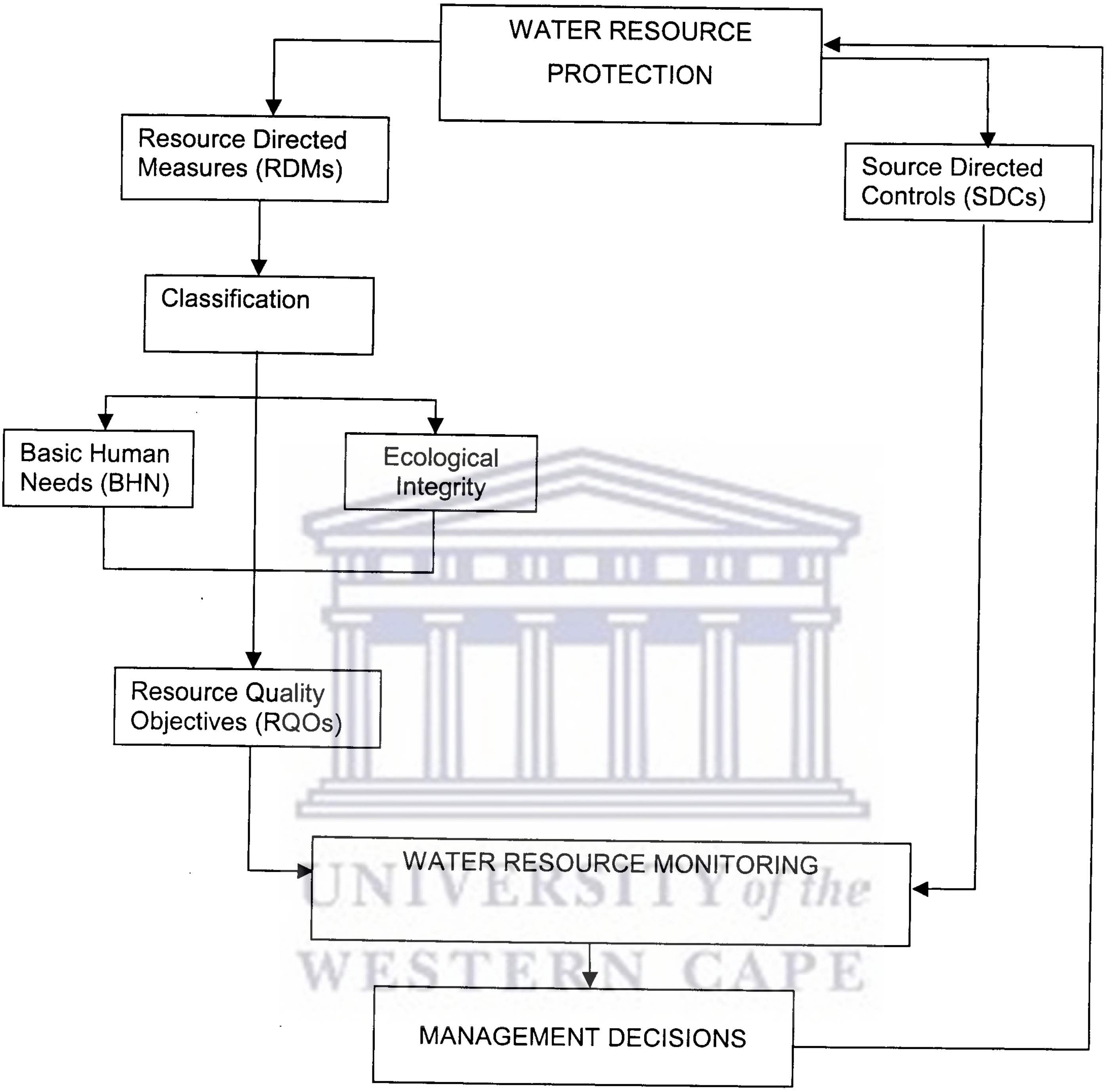

Figure 2-1 A relationship between water resource monitoring and water resource protection.

3 APPRAISAL OF MONITORING ISSUES

3.1 Introduction

It is important to identify changes in water quality early so that remediation measures can be taken. These changes can be pinpointed through groundwater monitoring. The monitoring allows observation of changes within the ecosystem. It is from the monitoring programme that determination of the nature, the extent and vulnerabilty of a water resource can be done. Depending on the objective of the monitoring programme, e.g. specification for Basic Human Needs, the ultimate goal is the management and long-term sustainability of water resources for current and future generations. Within this chapter all the possible methods applicable to groundwater quality monitoring which can be used to protect water resources are presented.

3.2 Identification of problematic areas

3.2.1 Legal aspects

An increase in the population of South Africa has led to a greater dependence on natural resources, including groundwater resources. This has resulted in excessive strain on the groundwater resources of this country. In this regard, the Water Services Act (WSA) (Act No. 108 of 1997) introduced a policy, which entitles an individual to 25l/p/d within a 200m walking distance. The basic aim of the Act is the provision of an equitable share of water resources to people. A year later, the National Water Act (1998) was introduced that referred to the protection of groundwater resources through various measures such as the classification of groundwater resources, determination and setting of the reserve and setting of RQOs, as mentioned earlier. The NWA (1998) encourages no degradation of quality of water supplied to people, hence emphasizing the protection of water resources.

Both Acts are being implemented in South Africa, ensuring an equitable resource allocation to the people as well as ensuring rights of access to basic water supply that is not harmful and unfit for human consumption.

3.2.2 Technical aspects

The RQOs ensures proper utilization of the resources, i.e. allowing a desired of the environment and ecosystem functioning, with no compromise of any of its attributes. The second step is the protection of resources, because RQOs are statements guiding what should be done and how it should be done hence ensuring the benefit of the future generation.

In the case of groundwater, the problem is said to lie with the water levels, the chemical and biological quality of water as well as with dependent ecosystem. These should at least be maintained at acceptable levels that will not disturb the functioning of the ecosystem or result in the deterioration of water quality.

3.2.2.1 Water level related

The main point of focus here is monitoring of water levels. Water levels are monitored to control the regular supply of water (Mannathoko et al., 1994). Water levels, as an aspect of control in groundwater protection, should always be maintained so that damages from abstractions are avoided. Wright and Xu (2000) note that where there is exploitation of groundwater, natural conditions tend to change. Therefore, monitoring is required to assist managers in maintaining a desired state of the environment and hence providing access of resources to future generations.

Recently it has been of concern to monitor water levels after clearance of alien vegetation within catchment scale. The alien vegetation is believed to consume more water that is required to increase the reservoir yields (Maclear and Kotze, 2000). The whole effort has been done to increase the quantities of abstractable amounts of groundwater resulting in an increase in water supply to the people. Monitoring will ensure reliable records, not only of the temporal variations, but also for the long-term understanding of the aquifer. Bredenkamp et al. (1995) made a major contribution to recharge studies, not only for different geological scenarios of South Africa, but also by formulating the manual to quantitatively estimate the groundwater recharge. This manual includes cumulative rainfall departure (CRD) method and saturated volume fluctuation (SVF) method that uses water level fluctuations. A further follow up on importance of groundwater monitoring and water resource evaluation has been done, with emphasis on water level monitoring (Bredenkamp, 2000). The major component of the study is based on the validation of water level observation, with the CRD method favoured because of its simplistic approach to groundwater balance and water level monitoring. Xu and van Tonder (2001) revisited the CRD method, modifying it so that it can accommodate several scenarios, in order to interpret and monitor groundwater levels.

Apart from what has been mentioned above, the water level monitoring studies have been incorporated within the pump testing investigations and assessment of borehole yields to observe the characteristic response of an aquifer to abstraction. This tends to be the temporal matter, which is monitored for over a few days to a few weeks.

Still underestimated, especially in South Africa, is a concept of groundwater evapotranspiration as a factor that has a great contribution to fluctuation of water levels and the groundwater balance. Thus far, it is incorporated as a parameter under the topic of groundwater recharge. Evapotranspiration has a great influence in water level variations especially in arid and semi-arid regions and in those areas characterized by alluvial sediments.

3.2.2.2 Chemistry

The basic aim is to ensure that water supplied to people is of good quality i.e. potable water. The protection measures set for this category will ensure that the water resources are secured from pollutants, thus protecting them from harmful hazards (Xu et al., 2001b). They stipulate the acceptable ranges for chemical constituents in water fit for human consumption, as well as stock and agricultural purposes.

The drinking water quality standards formulated by DWAF (1996) serve as the step forward towards protection of water quality resources. These standards specify the acceptable levels of certain elements in water as well as those that are not allowed at all. The introduction of water quality standards by DWAF took over the general and Special Standards for effluent that existed and served as water quality protection measures prior to 1993 (DWAF, 1993). Besides the water quality guidelines set by DWAF (1996), the World Health Organization (WHO) has its own drinking water quality guidelines to ensure the quality of water for health purposes (WHO 1984). The WHO drinking water quality guidelines function effectively in countries without water quality guidelines for drinking, but can also be used in conjunction with national drinking water quality standards. Furthermore, a monitoring programme is pursued by DWAF (Institute of Water Quality Studies) and is done on national scale. The data collected is stored in a Water Monitoring System. Almost the entire country's groundwater is sampled on a six-month's interval. Articles and papers have been published from this data highlighting its usefulness in decision-making (Rossouw and Hohls, 2000; Venter, 2001). There is still a need for assessment of the current status of groundwater quality, highlighting the suitability for human consumption as well as those areas that needs attention for protection against pollution.

The water quality guidelines play their role to ensure that water supplied is of a desirable state, but there is still a need to come up with a proper protection plan. This can only be achieved by assessing the quality status of a water resource (i.e. elements existing in water). The elements found in water can be categorized into several groups based on their chemical nature (Uil et al, 1999). These categories include the following: descriptive parameters, major ions, heavy metals, organic substances, microbes, radionuclides and gases. It should be noted that all the categories mentioned above can be used for assessment of water chemistry, but the objectives of the study will always be the limit, i.e. the purpose of the water quality assessment (purposes like drinking water quality purposes or agricultural purposes). In the case of analyses of water for domestic purposes, it becomes a problem to just select according to the categories mentioned above, as other elements tend to be very important. Therefore, it is important to choose for specific elements to be assessed in water depending on potential polluting agent. For this study, the microbiological indicators will be of concern since the assessment is done on the basis of water quality for human needs (including drinking purposes).

Vulnerability mapping of the water resources is proposed by the South African government although the required action like protection is still lacking. As a result, studies focussing on resource protection, like this one, have to be undertaken to ensure the proper protection of water resources. Xu and Braune (1995) formulated guidelines on groundwater protection for community water supply and sanitation. It is of importance to revisit these guidelines and implement them in order to protect the water resources.

South Africa is moving towards water resource protection by formulating guidelines i.e. Resource Directed Measures. It is also important to implement these guidelines, to see if they are really feasible or not.

3.2.2.2.1 <u>Changes in water quality</u>

The quality of water tends to change naturally due to chemical reactions with its environment (Todd, 1976). This is driven by the factors such as the underlying geology, the climate, geomorphology as well as the vegetation. The unstable minerals in various lithological units, when in contact with water, tend to dissolve and the constituents get released into water, thus increasing the concentration of major ions. The dissolution is due to high di-electric constant of water and the fact that molecules tend to combine with ions to form hydrated ions (Freeze and Cherry, 1979). Decay of vegetation allows for humic acids to be released to water, leading to a change in pH of water. When the constituents of weathered rocks and of decaying vegetation dissolve in water, ion exchange (cation exchange) and ion adsorption takes place. The reactions taking place during this are thermodynamically or kinetically controlled (Senior, 1996). The direction of exchange normally takes place towards the equilibrium of bases present in water. The sequence of evolution for water is from bicarbonate dominated type to sulphate dominated and finally to chloride type of water (Freeze and Cherry, 1979). The evolution sequence takes place along the groundwater flow paths. The effect may also change the natural state of water i.e. it softens water. Once equilibrium is reached, the quality of water remains stable with time as observed in groundwater because of its slow movement and long residence time within a given lithology or formation (Todd, 1976). The natural quality of surface water resources and shallow aquifers change due to inputs from rainfall, recharge and discharge resulting in fluctuations in salinity levels (Todd, 1976). High salinity levels in water make it unusable for human needs (Todd, 1976).

Besides the natural factors mentioned above, the quality of water might change due to the effects of human activities (Todd, 1976; Freeze and Cherry 1979). The contamination mainly results from improper sanitation practices or the improper disposal of waste either from mines, industries or land-use practices (DWAF, 1996). These may include agricultural practices and wastewater effluents. For these factors or agents to get into water, the principal determinant is geology. The geology is the main factor contributing to the vulnerability of the water resource. The infiltration rates (i.e. velocity) and soil or hydraulic properties are the key parameters that will always determine the rate of transportation of pollutants to the water resource (Uil et al., 1999). In fractured rock aquifers, preferential flow takes place, thus transporting contaminants to groundwater, while alluvial aquifers may allow filtering of the contaminants to some extent (Xu and Braune, 1995, Engelbrecht and Tredoux, 2000). Surface waters are more susceptible to contamination than groundwater, due to overland flow that carries all the dirt from the land surface to water bodies. The transfer of contaminants affects the concentration of the species in water due to their solubility (Stumm and Morgan 1981).

The water resources are protected from the anthropogenic factors. The other factor that is known to adversely affect water quality is seawater intrusion. Its effect is normally observed by increased salinity content of the water (Todd, 1976). Like anthropogenic factors, protection of water resources against seawater intrusion is necessary. It should be noted these changes can only be detected through assessment and monitoring of water resources.

The changes mentioned above may take place through time and can thus be seasonal or long-term. According to Senior (1996), the seasonal changes are mainly due to differences in recharge rates and microbial activity. Long-term changes results from changes in groundwater recharge rates or land-use practises in groundwater recharge areas (Todd, 1976).

3.2.2.3 Physico-chemical Quality

In specifying the quality, it is always crucial to look at the physico-chemical parameters of water. Specifying which parameters to determine may depend on the sampler (Lehloesa and Muyima, 2000). In such, the descriptive parameters like pH, EC, temperature, etc. are usually determined in-situ as they change with time and space.

The pH is mostly influenced by the geology (specifically mineral weathering) in its natural state, but acid mine drainage waste can contribute to its fluctuations (DWAF, 1996). The effect is normally a decrease in pH (i.e. acidity). The acceptable levels range between 6-9, with no toxicity from dissolved metal ions (DWAF, 1996). Alkaline conditions may result in dissolution of metal ions.

The electrical conductance (EC), mostly expressed in milli-siemens per metre or milligrams per litre, measures the ability of water to conduct electric current (DWAF, 1996). Electrical conductance is related to the Total Dissolved Solids (TDS). That is, the higher the concentration of dissolved salts, the higher is the electrical conductance. The type and quantity of dissolved solids are known to be the chief determinants of water quality (Senior, 1996). Higher solubility of minerals of varying sources can account for higher levels of EC. Besides the mentioned factors, anthropogenic sources may contribute significantly to increased levels of EC. The WHO (1984) recommends maximum limit of 1000mg/L of dissolved solids.

Temperatures of water cannot be controlled in their natural state, but water with moderate temperatures is preferred. The temperatures of surface and groundwater vary widely, but the overlying surface environment influences the temperature of shallow groundwater (Todd, 1976). Besides these variations, groundwater temperatures increase with depth below the earth surface, corresponding to geothermal gradients. High water temperatures have a tendency of allowing bacterial growth while too low temperature waters may not be easily treated, thus increasing adverse effects to drinking water. According to WHO (1984) and the South African drinking water quality standards (DWAF, 1996), there is no specified limit for water temperature since it cannot be controlled.

The chemical parameters may include nutrients (i.e. the nitrates, nitrites, phosphates, sulphates), fluoride and major ions. Nitrates and nitrites tend to occur naturally in groundwater but in low concentrations (Todd, 1976). Higher concentrations may be due to contamination from anthropogenic sources like sewage effluents, agriculture, urban development etc. (DWAF, 1996). Excessive nitrate levels in water tend to pose health risks, such as methamoglobineamia, which is very dangerous to infants (DWAF, 1996). In some instances, biological processes like denitrification can mediate reactions contributing to elevated concentrations of nitrates in water (Senior, 1996). The South African water quality guidelines recommend a limit 10mg/l of nitrates intake per day.

The occurrence of sulphate in water results from the dissolution of sulphate minerals in soil and rocks. The higher levels of sulphate, in association with other ions such as Mg and Ca may result in diarrhoea. (DWAF, 1996). Other than the natural concentrations, the higher levels of sulphate may result from discharged mine waste, textile mills, etc. A limit for sulphate not to pose health problems is set at 200mg/l (DWAF, 1996).

The effect of phosphates on the water quality is the growth of algae. Phosphates as well as nutrients contribute to the growth of algae. The algae contain toxins that may be dangerous. Like other nutrients, its elevated concentrations may be due to wastewater effluents and agricultural practices (DWAF, 1996).

The appreciable amounts of fluoride in drinking water help in reduction of dental carries (DWAF 1996; Muller et al., 1998). Appreciable amounts mainly come from soils and geology. Excessive amounts can result in dental fluorosis and dental mottling (DWAF, 1996). Mottling of teeth can resume at levels of 0.7 to 0.9 mg/L of fluoride (Muller et. al, 1998). The WHO (1984) recommends a limit level of 0.7mg/L of fluoride intake per day.

Major ions, as mentioned earlier, are affected by the geology (mineral dissolution from rocks) and vegetation (Todd, 1976). Major ions comprise most of the dissolved solids in water. They include potassium, magnesium, sodium, calcium, carbonates, bicarbonates, chloride and few of the nutrients i.e. sulphate.

Hardness i.e. the state of water being hard due to dissolved salts, is always important to determine (DWAF, 1996). Geology as well as soluble salts influences the natural hardness of water. Hardness is expressed as the total concentration of Ca^{2+} and Mg^{2+} dissolved in water (Freeze and Cherry, 1979). The concentration of elements specified is expressed as milligrams per litre. Hardness of water does not have health related problems, but can cause scaling of metals. A limit of between 150-200mg/L is set to avoid scale deposition (WHO 1984; DWAF, 1996).

3.2.2.4 Presentation of chemical data

The chemical data is normally interpreted as water quality trends. This is made easier and possible through graphic representation, where several graphical methods have been designed. Such graphical methods include the Piper diagram, the Durov diagrams, Fingerprint diagrams, Schoeler diagrams, Stiff diagrams and pie charts (Todd, 1976, Freeze and Cherry, 1979). The diagrams aid in visually describing the differences in the major ion chemistry of groundwater. The diagrams are based on major ions and do not accommodate other elements e.g. trace elements that occur in water. The main objective for their use is to compare the elements analysed.

Another way of presenting data is in table format. This is useful for comparing the water quality standards to the analysis obtained. In this regard, units like mg/L, ppm and ppb of the concentration of certain elements or constituents are used. The comparison allows maintenance of the constancy of various components in water. For heavy metals and trace elements a GIS based software and Surfer (software) can be useful for presentation of analysis.

3.2.2.5 Microbiological Quality

The most common and widest health risk associated with drinking water is contamination by human or animal faeces (Lehloesa and Muyima, 2000). The animal or human faeces carry bacteria, viruses and pathogens that are known to be among the most dangerous contaminants in drinking water (Maurer et al, 1998). Microbiological indicators[1] (i.e. pathogens) related to water-borne diseases usually indicate the contamination of water (Table 3-1). Such indicators include the total coliforms, faecal coliforms and *E coli*. The bacteria and viruses result in diseases like hepatitis, typhoid fever, cholera etc. (Sinton et al., 1999). Therefore, indicators such as faecal or total coliforms allow determination of polluted water by bacteria of faecal origin. The universal criteria for examining the microbial quality of water is to determine the total and faecal coliforms because such micro-organisms do not normally grow in natural waters, but are found in animal and human faeces thus indicating contamination of water by human or animal waste (Boyd, 1984).

Water in remote areas of South Africa poses serious problems and threat to the public health due to the presence of micro-organisms of faecal origin. Untreated or inadequately treated contaminated water causes most of the water-borne disease outbreaks in this country (e.g. the KwaZulu-Natal case).

The bacterial potability of water is determined by testing for indicator organisms. In South Africa the indicator organisms and standards have been established to measure potability of water quality (DWAF, 1996). The underlying principle is that drinking water should be free from faecal contamination to prevent the spread of diseases. According to the South African drinking water quality standards (DWAF, 1996) as well as WHO drinking water quality guidelines (WHO, 1984) water should not have any bacteria i.e. 0cfu/100ml (colony forming units, cfu). If more than one faecal coliform colony is detected in water, it means the water is vulnerable to contamination by human and animal waste.

Senior (1996) suggests that it is not wise to sample water for microbial quality analysis in winter since the faecal coliform bacteria dies quickly in water at or near freezing point temperatures. Therefore sampling during winter months can

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[1] Microbiological water quality incorporates both bacteriological and virological water quality.

be declared as futile. This may not be the case with KwaZulu-Natal since warm temperatures are mostly observed throughout the year.

Since there is a link between surface and groundwater, contaminated surface water by overland flow from faecal deposition, ranging from fertilizers to human waste, should also be considered as another factor resulting in groundwater contamination. In the case of groundwater, shallow topsoil accompanied by porous or fractured aquifers can result in the direct contamination of groundwater due to infiltrating water (preferential flow in the case of fractured aquifers). These factors may determine the rate and extent at which the pathogens are transported to the groundwater.

BACTERIA/VIRUSES	DISEASES	SOURCE OF WASTE MATERIAL
Aciunonetobacter calcoaceticus	Nosocomial	Water, human skin and mouth
Mycobacterium tuberculosis	Tuberculosis	Wastewater
Salmonella typhi	Typhoid fever	Wastewater
Vibrio cholerae	Asiatic cholera	Wastewater
Reoviruses	Infantile diarrhoea	Wastewater
Picarnoviruses	Infectious hepatitis	Wastewater
Escherichia coli	Gastroenteritis	Wastewater
Klebsiella pnuemoniae	Pneumonia, bacteraemia and nosocomial	Water, faeces and plants
Morganella morganii	Unirary tract and nosocomial	Water, faeces and decaying animals

Table 3-1 Common pathogenic bacteria and viruses as well as associated diseases found in waste material entering water (after Sinton et al., 1999).

3.2.2.5.1 Indicator Organisms of water quality

Referring to indicator organisms means the possible organisms that can be used to detect the presence of many pathogens in water. It is unfeasible to monitor drinking water for all possible microbial pathogens that may exist in water due to contamination (WHO, 1984). The reasonable method for the determination of pathogens is to identify the organisms that are commonly found in the faeces of man and warm-blooded animals as indicators of excremental pollution (Boyd, 1984; Collins et al., 1989). As mentioned in section 3.2.2.4, the presence of indicator organisms reveals the existence of faecal material as well as intestinal pathogens in water. It can be said therefore, that intestinal organisms are more preferred as indicators of pollution than pathogens (WHO, 1984; Collins et al., 1989). The advantages of using indicator organisms over monitoring all pathogens existing in water is that (Collins et al., 1989):

- Indicator organisms are easily isolated and enumerated.
- They survive longer than pathogens in water and are known to be more resistant to disinfectants, i.e. the absence of the indicator organisms in water means that pathogens may also be absent.

Thus far, *E coli* is the only indicator organism that has all the above characteristics (Boyd, 1984). Therefore, it is important to detect it in water. The *E coli* is known to grow or divide very fast. Its division takes place through a lag phase where within 30 minutes a complete process of division occurs, depending on the physicochemical factors (Boyd, 1984). Other indicator organisms that have the above characteristics, although not all of them (e.g. *faecal streptococci*), can be used as supplementary indicators of faecal pollution. In simpler terms, these organisms can be used to confirm the tests or where there are doubtful results from coliform tests. Unlike the *E coli,* the division of this group of bacteria is very slow (Boyd, 1984). Other strains of faecal origin like *Klebsiella pneumonia* and *Enterobacter* can also be detected, but are not associated with faecal origin only, so care should be taken when using them (Sinton et al., 1999).

In general, the faecal coliform bacteria are suitable as indicator organisms of faecal pollution. Fermentation of lactose for total coliforms takes place at 37°C while the faecal coliforms ferment lactose at 44-45°C (thermo-tolerant coliforms) (Boyd, 1984, Collins et al., 1989). Therefore high temperatures for incubation of samples are required hence allowing easy enumeration of the bacteria. It should be noted that once a coliform bacteria is detected and treated, it is unlikely that it may be found after treatment unless post treatment contamination occurred.

The indicator organisms mentioned above are useful when detected in raw source water to predict the potential outbreaks of bacterial diseases. Detection of other pathogenic organisms (as in the case with treated water) may require sophisticated methods (Ford and Colwell, 1996).

In the case of detection of viruses, it is encouraged that the routine use of coliform limits for viral water quality examination be carried out (WHO, 1984).

3.2.2.5.2 Identification of micro-organisms

There are several methods to identify micro-organisms from a pollution origin in water (Boyd, 1984; WHO, 1984; Ford and Colwell, 1996; Sinton et al., 1999). These vary in terms of effectiveness as well as whether they can be operated on-site or in the laboratory. Thus far two categories exist, i.e. field methods and laboratory analyses. It should be noted that field methods could only be pursued where sampling of water is taking place in areas, with no electricity to carry out full analyses in order to assess the microbial quality of water. One of the requirements for bacteriological analyses is an immediate examination of bacteria within a pre-defined time (24 hours) so that meaningful results as well as reliable conclusions can be made. This means that even if the pre-test is done in the field, samples must be sent to laboratory to confirm the pre-test within 72 hours (WHO, 1984).

3.2.2.5.2.1 The Field Methods

One of the field methods includes *the delayed-incubation method*. The procedure on how to carry out this type of test is outlined in WHO (1984), although only the underlying principle for doing the test is described. As mentioned in section 3.2.2.4.2, the procedure is done just to allow the necessary time required for the transportation of the sample to the laboratory. The method is used where the field incubator is not available, thus delaying the process so that the bacteria can be kept viable. The method allows for the sample to be filtered and the filter with residue is kept in a pad saturated with the holding medium (i.e. selective culture medium). The culture media is a nutrient rich material that is used in most microbiological processes to produce bacteria under favourable conditions. Several forms of culture medium can be used i.e. solid, or semi- solid and liquid (Collins et al., 1989). The sample is then transported to the laboratory.

The other method that has shown promising results in the assessment of microbial water quality in remote areas is the H_2S Strip Method. The method allows the microbial assessment of drinking water without transportation costs of sending samples to the laboratory (Genthe and Franck, 2000). It can be used as a supplementary method especially in rural areas where water quality analyses is not normally carried out. It takes into consideration that (Dutka et al., 1998):

- Bacteria of faecal origin produce hydrogen sulphide through anaerobic catabolism of cysteine.

OR

- The bacteria of faecal origin use the elemental sulphur or oxidized sulphur compounds as terminal electron acceptors in their metabolic processes.

Using a medium with a sulphur source will allow the production of hydrogen sulphide, indicated by a black precipitate in the water sample. Caution needs to be taken when using the heavy metals as indicators of faecal contamination in a sulphur medium, because they tend to inhibit bacteria to produce hydrogen sulphide (Dutka et al., 1998). In nature, the H_2S Strip method is semiquantitative with its results presented in terms of the degree of blackness, i.e. you look at the colour of the precipitate and then identify whether the sample is contaminated by bacteria of faecal origin or not. The procedure for the H_2S strip method can be outlined as follows:

- The first step is the preparation of H_2S medium
- Impregnate strips of paper towel with H_2S medium and put them in sample bottle (note: sterilization of bottles as well as of papers is required).
- Fill in the bottle (usually 20ml, but this depends on concentration of H_2S medium used) with water and incubate at room temperature (±24°C) for 72 hours with examination of the bacteria after every 24 hours. Note: a black precipitate will indicate the presence of the bacteria.
- Colonies indicating H_2S production can be separated to an agar plate for single colony isolation (this step is optional).

On interpretation, the results obtained from this method can be compared with those of a multiple tube test method (MPN). These will be presented as correlated data, i.e. correlation between the degree of blackening versus the MPN.

The other methods are the *membrane filter method* and *the multiple tube method*. Both these methods are based on laboratory work and for them to be used in the field requires a portable laboratory kit.

3.2.2.5.2.2 The Laboratory Methods

Before discussing the laboratory methods it is of importance to mention that it is wise to use two different methods to indicate the presence of indicator organisms in water (Collins et al., 1989). The methods may not provide similar results, but the results produced can be compared. The laboratory techniques used for the detection and enumerations of indicator organisms in water are mainly those mentioned in section 3.2.2.4.2.2 i.e. the membrane filter method and the multiple tube method.

The membrane filter method measures the volume of water passing through the membrane filter. The filters mostly used have 0.45 μm pores and they retain coliform and other bacteria present in water. The membrane is then incubated in a medium (selective medium) for approximately 24 hours thus allowing bacteria to produce colonies. Counting of the colonies follows and the results obtained from this method can be compared to those of the multiple tube method discussed below. When testing for *faecal stretoptococci*, it is important to use a new membrane because such organisms are not easily removed when the membrane is cleaned (Collins et al., 1989).

The multiple-tube method measures volume of water added to duplicate tubes of a suitable liquid medium (WHO, 1984). It involves three stages during testing, i.e. the presumptive, the confirmed and the final or completed tests. These involve a protocol that allows proceedings to the following step provided the requirements of the first step are met. During the first test the method assumes the acid and gas produced may be from other organisms, hence the need for duplication of the tubes to confirm the tests. Inoculation of volumes of water into tubes containing the liquid medium allows an estimate of the number of presumptive coliform organisms present in a sample of water. A full explanation, the protocol mentioned and procedure for the application of these methods is outlined in WHO (1984).

3.2.2.5.3 Reporting results of bacteriological analyses

The well-known methods to report bacteriological analyses include colony counts, where the results are reported as colony forming units per millilitres (cfu/ml). In this method the size of the bacterial population per sample is considered (WHO, 1984). It assumes that a visible colony will develop from each organism. This method is associated with the membrane filter method. What is most important is the quantity of water that must be filtered; it should always be enough to result in the growth of colonies. Dilution using sterile water will be required when sampling highly polluted water (Collins et al., 1989). It is rare for bacteria to separate from their members (i.e. a cluster is normally observed).

Agitation during preparation of dilution may not necessarily break up the cluster (Collins et al., 1986). Furthermore, it is very seldom that bacteria may be evenly distributed throughout the sample since small sample are usually determined. It is clear from the above that the method is erroneous (Harley and Prescott, 1993).

The second method is the Most Probably Number (MPN) estimate that is related to the multiple-tube method. This method assumes that the bacteria are normally distributed in the liquid medium. Therefore, repeated samples of the same size from one sample or source are expected to have the same number of organisms on average (WHO, 1984). The combination of number of organisms obtained is then compared to MPN value. The MPN index table can be obtained from most microbiology literature, as well as from World Health Organization publications (WHO, 1984; Collins et al., 1989). The average number is the MPN from multiple tubes results. The number of organisms detected is reported as MPN/ ml (usually 100ml is used).

3.2.2.5.4 Bacteriological behaviour in water

The micro-organisms get into water in several ways (Senior, 1996). In some cases the bacteria are washed into water by overland flow to the streams as well through infiltration to groundwater. In the case of infiltration, the porosity and permeability will always determine the existence of bacteria (Engelbrecht and Tredoux, 2000). When the bacteria get into water, that is, from the host (i.e. leaving the body), they lose the capability to infect (WHO, 2001). It has been noted that the bacteria decays at a fast rate (exponentially) when in water and may ultimately be undetectable (Boyd, 1984; Senior, 1996; WHO, 2001). This mainly results from difference in temperatures, that is, the temperature of a living body is higher than that of atmosphere/ water. Moderate to warm temperatures allow a long life-span of bacteria in water. In contrast, accelerated temperatures accompanied by ultraviolet radiation of sunlight may result in the decay of bacteria in water (Sinton et al., 1999). It should be noted that the penetration of ultraviolet radiation in waters with large amounts of suspended material as well as in groundwater is insignificant; therefore this factor is non-effective in such cases. Furthermore, UV may result in injury and a non-culturable state of organisms in such that during counting, colonies may not be formed on the selective media (Ford and Colwell, 1996). Where inactivation of bacteria by sunlight is prevalent, the somatic coliphages tend to have a greater survival rate than faecal coliforms and *entoroccocci* (Sinton et al., 1999). This makes coliphages more favoured as faecal and viral indicators of pollution. Other factors that affect the decay or survival of micro-organisms in water include the soil type, moisture and its capacity to hold moisture, pH, presence of oxygen and nutrients (Engelbrecht and Tredoux, 2000; Gagliardi and Karns, 2000). Accelerated rates of nutrients in water mainly result from agricultural practices (manure applications). These (nutrients +pathogens) leach down to the subsurface and finally reach the groundwater while others are carried to surface water bodies. Gagliardi and Karns (2000) noted that the recycling of water by crop irrigation might infect humans and animals through drinking the water or through ingestion of crops. The factors mentioned above tend to have a significant influence in several disease outbreaks traced to livestock. Soils with high moisture holding capacity and acidic waters tend to enhance the survival time of micro-organisms (Sinton et al., 1999). The coliforms prefer anaerobic conditions for multiplication. As a result, the saturated zone is favoured.

3.2.2.6 Virological water quality

Although microbiological quality deals with the bacteriological water quality, it is also important to look at virological water quality. When examining water for the presence of viruses it is crucial to detect the existence of viruses from raw water resources as well as the water from the tap, i.e. water ready for drinking (WHO, 1984). This may help to understand the threat and health risks the population is exposed to as well as the trend of the micro-organisms. In some cases the spread of water-borne diseases can be confirmed by the detection of viruses in drinking water supplies (Grabow et al., 2000). The detection of viruses from water can be accomplished using bacteriophages. Bacteriophages are viruses that infect bacterial cells. Bacteriophages have served as useful models for the behaviour of human enteric viruses in water treatment processes because of their similarity to enteric viruses in structure, size and resistance to inactivation (Dutka et al., 1998; Grabow, 2001). Dutka et al. (1998) further noted, "there is also sufficient evidence to indicate that the coliphages test has many advantages over traditional bacteriological and possible virological hazards…" In that case the somatic coliphages as well as F-RNA coliphages are mostly used as the indicators for the presence of enteric viruses in water environment. Somatic coliphages, F-RNA coliphages are said to be easily detectable and the detection procedure is inexpensive (Dutka et al., 1998; Grabow, 2001).

Various factors account for the coliphages to be favoured for the detection of viruses in water. These include resistance to (Grabow, 2001);

- Sunlight
- Ultraviolet light
- Chlorination
- Water treatment

A vast number of studies looked at the bacteriological quality of water using standard methods that detect and count indicator organisms (Muyima and Ngcakani 1998; Nvondo and Cloete, 1999; Lehloesa and Muyima, 2000; Momba and Mnqumevu, 2000). The basic requirement as set in most water quality guidelines that water should not have bacteria incorporated virological water quality. Young (1996) as well as Ford and Colwell (1996) reported that indicator organisms (thermo-tolerant coliforms) offer no early warnings against viruses in water, therefore cannot be used as virus indicators in water. Furthermore, they don't correlate with pathogenic bacteria from environmental sources, e.g. *Vibrio cholerae*. It is therefore important to look at coliphages as indicators of faecal pollution with the interest of detecting viruses in water. Shortcomings on the use of bacteriophages as surrogates of enteric viruses are outlined (Grabow, 2001).

Nowadays, through technological advancement, the detection of viruses in water is possible through the use of molecular techniques based on reverse transcriptase polymerase chain reaction (RT-PCR) (Grabow et al., 2000). Within this context, Rose and Grimes (2000) not only focus on technological advancement for the detection of viruses but also encourage the improvement on microbiological risk assessment techniques. This does not mean that indicator organisms for bacteriological water quality analyses are not useful, but the methods on virological examination will assist on final water quality assurance (Young, 1996). It is noted that the bacteriophages/ bacterial indicator organisms can provide reliable results as surrogates of enteric viruses under controlled conditions (laboratory conditions when carrying out experiments) (Grabow, 2001).

3.2.2.7 Methods on the detection of coliphages

Coliphages or viruses in water can be detected using large volumes of the water sample (a litre of water can be enough), which are then passed through membrane filters (Collins et al., 1989). The filters can then be put in petri dishes with enrichment media and then incubated at particular temperatures (43°C). The host bacterium of choice can then be cultured over time intervals for 3-4 days. Advanced molecular techniques are being introduced, but they still need to be verified before applied to a meaningful extent in water quality monitoring (Grabow, 2001).

3.2.2.8 Sampling and handling water samples for microbiological water quality examination

When sampling water for microbiological analyses, care needs to be taken to avoid the contamination of samples as well as sampling point (WHO, 1984). In the case of a well or a borehole, purging needs to be done thereby removing the stagnant waters. Samples can be collected in plastic bottles (WHO (1984) suggests the use of autoclavable ones) as well as glass bottles. The bottles need to be sterilized first (i.e. sodium thiosulphate can be useful for this). It is preferred that the samples be kept in a cool place immediately after sampling and when transporting them to the laboratory. This is because increased temperatures affect the growth of micro-organisms. It is also important to sample water from storage tanks and taps for quality assurance of water supplied to people. Furthermore, risk of contamination is high during the distribution of water (WHO, 1984), therefore sampling of tap water is important to detect those risks people are susceptible to when drinking such waters.

3.2.2.9 Interpretation of the microbiological water quality results

The results of the microbiological water quality examination should, as suggested by WHO (1984), be interpreted with caution based on knowledge of the water supplies within the study area. Besides knowledge of the water supplies, geographical and engineering factors as well as laboratory reports should be considered. These, as for the engineering factors, tend to have a significant contribution to an understanding of the contamination of water resources. Most water quality guidelines indicate that the water suitable for drinking should not have bacteria of faecal origin. These guidelines should be consulted when interpreting the results. This means that the results obtained should be interpreted under the light of possible health risks the water is likely to pose to the public. The underlying geology will have to be given attention when interpreting the results of bacteriological water quality (Engelbrecht and Tredoux, 2000).

3.2.2.10 Microbial water quality monitoring- A South African context

Microbial quality monitoring is pursued on various scales in South Africa (DWAF, 2000a). It is pursued under human health requirements. The scales range from national to local scale. The Institute of Water Quality Studies (IWQS) of DWAF is conducting monitoring programmes at a national scale. This seems to focus more on the surface water resources. Much work has been conducted with maps showing the vulnerable areas. On a local scale, few studies have been conducted e.g. Momba and Mnqumevu (2000), Lehloesa and Muyima (2000), Nevondo and Cloete (1999) and Muyima and Ngcakani (1998). Some of these authors have recommended treating of the water prior to use. It is from the localized areas that most outbreaks of water-borne diseases are mostly reported.

A focus for bacteriological water quality assessment needs to be placed in such areas as most people in South Africa reside in rural communities.

In terms of the national scale the areas that seem to be vulnerable to water deterioration are limited parts of the Eastern Cape and to large extent KwaZulu-Natal. It is therefore important to revisit these areas and look at water quality on a local scale i.e. villages.

3.2.2.11 Protecting and controlling contamination of the water resources

Protection of the water resources from contamination can be achieved in several ways. These methods are mostly found in several books and articles, e.g. Spayd (2001), Vrba (2000), Water and Rivers Commission (1999, 2000), Xu et al. (2000), Scharp (1999), Mackay (1998) and Xu and Braune (1995). The literature focuses on the quality surveillance of water, water quality monitoring and wellhead protection as well as technical methods of upgrading treatment works, etc. Under water quality monitoring, a special attention was given to monitoring the water resource more than the sources of contamination. A paradigm shift is required, thus looking at both the sources of the contaminants and the water resource. This is because there are several factors that cannot be controlled such as floods and other natural phenomena. Such factors tend to have a great influence on water quality deterioration. It is therefore crucial to look at those factors that can be controlled to ensure the protection and development of the water resources. An example of the controlled factors may be proper sanitation. Proper sanitation is still lacking in most rural communities of South Africa and almost all reported water-borne disease outbreaks are related to this factor.

It should be noted that the quality of life in any country is always projected by the quality of its water resources. Therefore, working towards water quality resource protection, with all the issues related to encompassed, will not only mean the improvement of quality of the water resources but also the quality of life for all (Mackay, 1998).

3.2.3 Environmental issues

Resource Quality Objectives not only focus on groundwater protection, but also focus on surface water resources (Mackay, 1998; Xu et al., 2001b). The protection component targets specific objectives within the field of ecosystem management. The RQOs set within this field, ensure that the environment and ecosystem functioning is secured with developmental growth. The RQOs are based on incentives and measures discouraging over-exploitation of the resources.

Most studies in this field focused on the impacts of vegetation on groundwater recharge as well as potential impacts of groundwater abstraction to vegetation. Although these studies are of limited number in South Africa, their contribution is of significance. Vegetation is known to affect aquifers by extracting groundwater from the saturated zone, thus reducing the recharge amount. In such, the Department of Water Affairs and Forestry engaged itself on a project to clear vegetation (alien vegetation) from the catchments, which is known to consume a lot of water and affects groundwater recharge (Maclear and Kotze, 2000). Results from these studies proved groundwater levels increased significantly on clearing the alien vegetation.

More studies were initiated incorporating interactions between the vegetation and groundwater (Le Maitre et al., 1999, 2000). Such studies not only focussed on the groundwater component, but also on the mutual impacts both parameters have on each other. The ecological reserve from the NWA (1998) were considered, where groundwater users have to ensure that such reserves are not depleted and are maintained in desired state of the environment. The focus was more on the protection of the environmental resources for the benefit of current and future generations. The aim was the evaluation of dependent ecosystem to groundwater. Since the idea was based on the ecological reserve and functioning of the ecosystem, setting of groundwater reserve by Parsons and Mackay (1999, 2000) considered the geohydrological regions, which in turn considers the role played by groundwater to the environment.

3.2.4 Procedure for Water Resource Quality Monitoring

A simplified procedure for water resource quality monitoring is provided in Figure 3-1 to assist in the monitoring of water resources. The procedure specifies what to start with as well as the major steps to follow when conducting water resource quality monitoring. The procedure summarises what is discussed in this chapter.

Within water resource quality monitoring, focus will have to be given to water quantity, water levels as well as water quality as discussed in previous sections. This will serve as a tool to obtain information required to make decisions about the sustainable development and protection of the groundwater resource. The monitoring will be in compliance with the Resource Quality Objectives (RQOs) set for a particular water resource as well as with the maintenance of the ecological integrity (environmental issues) since RQOs incorporate this. The idea behind this proposed groundwater monitoring design is that at least there should be relation between the network of sample points and the sampling frequency.

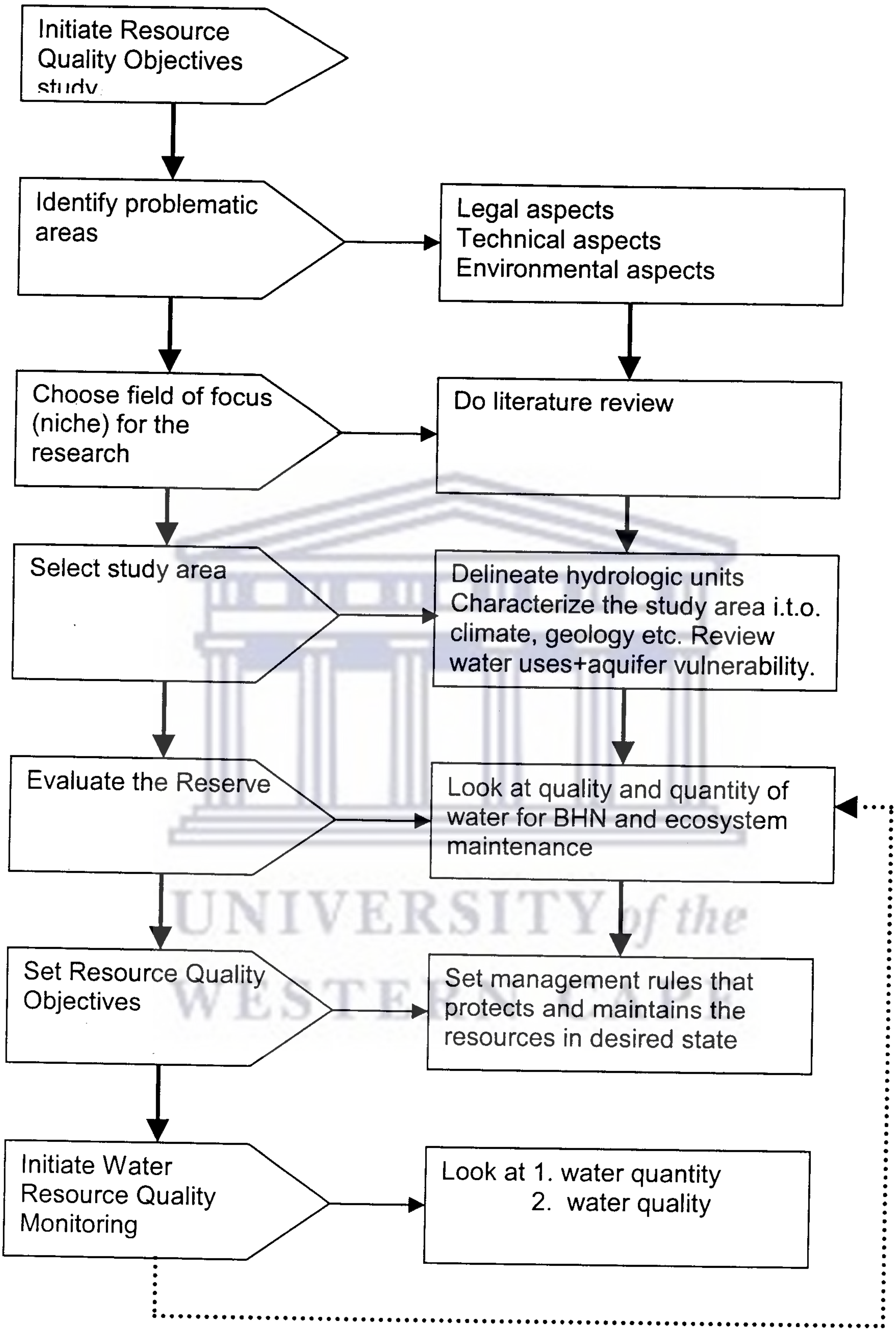


Figure 3-1 A procedure for Water Resource Quality Monitoring based on RQOs

If management of groundwater resources is the key point that needs to be fulfilled, then information about groundwater quantity and quality needs to be collected at the appropriate scale. Groundwater monitoring can be achieved by first identifying the functions and problems of the water resource and then take necessary steps and measures to control the problem. Depending on the objective of monitoring, *strategic monitoring* can be followed when reference conditions are required. *Operational monitoring* can only be followed for specific purposes such as compliance with legal aspects and protection. *Surveillance monitoring* is for an early warning on the response of water quality to hazards. The above monitoring types can always determine the parameters to be determined in water. These parameters are mentioned in section 3.2.2.2.

For water quality monitoring, the chemistry and microbial/ virological water quality will have to be given attention. These require frequent monitoring depending on type of aquifer being examined, (see section 4.1). This sampling frequency is applicable for microbial water quality assessment as the bacteria decays with time in water (± 30 days) (Xu and Braune, 1995). The sampling frequency also needs to be linked to the seasonal hydrological regime since groundwater recharge has a contribution to chemical signatures of water. Therefore, seasonal sampling will have to be endorsed to find out about seasonal changes of water quality. In the case of groundwater quantity, high frequency monitoring will have to be adopted depending on expected water level fluctuations. This can be done daily, weekly or monthly.

Well or borehole location and siting must be checked before the monitoring programme is initiated. Where boreholes/ wells need to be installed, the Department of Water Affairs and Forestry can assist as part of the National Monitoring System. The local people within a particular region, that requires monitoring, can assist although basic training on groundwater monitoring and sampling are required (Xu pers. comm, 2002).

4 METHODOLOGY

4.1 Introduction

This chapter considers the methodology for monitoring the water resources with the underlying aim of protecting water resources. Several scenarios are presented, from the type of aquifer and finally to data interpretation. This incorporates both the Resource Quality Objectives as a form of water resource protection as well as monitoring of the water resources as a continuing process towards the protection of water resources.

4.2 Classification of an aquifer system and the flow processes

When dealing with protection of the quality of water resources there are certain criteria proposed as well as there are important factors, relating to the resource that need to be considered. In such cases, the type of aquifer under investigation becomes important, particularly with regard to a procedure on how to plan to protect its water resources (Conrad and van de Voort, 2000). Therefore, in the list of criteria on how to protect water resources will also be governed by flow conditions for the particular aquifer. Under this topic three scenarios are considered;

- Primary aquifers with uniform recharge
- Fractured hard rock with preferential flow
- Basement aquifers with eventful recharge

4.2.1 Primary aquifers with uniform recharge

The material comprising these types of aquifers is mostly alluvium (Freeze and Cherry, 1979). Alluvium tends to filter the contaminants coming from the surface through its small particles and pore spaces. When groundwater recharge takes place, uniform flow (diffuse flow) conditions of water from the surface through the unsaturated zone and finally to groundwater exists (Figure 4-1a). Such uniform flow allows for a longer recharge resulting in the decay of the bacteria of faecal origin before it reaches groundwater. The latter depends on the thickness of unconsolidated material (Uil et al., 1999; Engelbrecht and Tredoux, 2000). These types of aquifers can be regarded as having natural protection as they can filter dirt from the surface. Consequently, protection measures can also be taken, i.e. monitoring of the resource, that can be pursued on a seasonal basis i.e. during dry and wet season to find out about potential contaminating agents.

4.2.2 Fractured hard rock with preferential flow

The fractured aquifers are mostly comprised of hard rock that has undergone fracturing (Freeze and Cherry, 1979). In this case the flow within the aquifer is mainly through the lineaments. When recharge takes place, preferential flow is mostly observed where water follows the existing channels through lineaments and finally recharge groundwater, (Figure 4-1b). This means that any contaminants from the surface has the potential of getting to groundwater since there is no filtering of the material/ contaminants as in the case of primary aquifers. Therefore, in terms of protection/ monitoring, these types of aquifers require high attention.

4.2.3 Basement aquifers with eventful recharge

Basement aquifers are mostly mixed aquifers comprised of fracture media as well as a weathered zone, (Figure 4-1c). When recharge takes place, which in most cases occur after a long dry season, the accumulated contaminants on the surface is flushed down to unsaturated zone. Unlike the fractured aquifers, the weathered zone serves to filter the contaminants to some extent, but the contaminants are likely to get to groundwater especially when they reach the fractured zone, which allows for preferential flow. In terms of protection and monitoring, the target to sample water from the aquifer should be after flooding or heavy rainfall events.

4.3 Groundwater Resource Quality Monitoring

4.3.1 Process and Aims

The aim of groundwater monitoring should coincide with the protection of water resources (Uil et al., 1999). Therefore, anyone considering this kind of monitoring should have aims in mind that will incorporate integrated protection at a specified scale. The process on how to monitor groundwater needs to be drafted so that there can be no deviations from the aims. This can be accompanied by a set of objectives for each step to ensure a flowing procedure.

4.3.2 Monitoring Criteria

On setting monitoring criteria, specification on the objectives for the monitoring to be pursued needs to be outlined. Specifying the objective means knowing exactly what will be determined from water samples to be collected. In the case of water resource protection, the objective behind monitoring will always be to ensure good water quality for Basic Human Needs (BHN) as well as integrated measures that ensure protection and conservation of the ecosystem at large as stipulated in NWA. Following the criteria set above, the data collected (i.e. water quality data) will have to be compared to reference conditions thus trying to find out any deviations from reference conditions. Since the aim is to ensure good quality of water for Basic Huma Needs, the drinking water quality standards of DWAF (1996) need to be considered, thus making a comparison with ideal conditions.

Still considering the aims set above, i.e. maintenance and conservation of the ecosystem, it means that water levels must be monitored as well (i.e. water quantity monitoring). This will ensure no over abstraction of water from the aquifer and no threats to the environment and ecosystem at large (Manathako et al., 1994).

Another criterion is the vulnerability of the water resource to contaminants. Once the word 'vulnerability' is used, it means that the underlying geology and aquifer properties need to be considered. This will narrow research to a specific niche that is governed by the type of contaminant that the water resource being monitored, is vulnerable to. This in turn goes back to what must be determined from the water samples to be collected.

4.3.3 Monitoring Network

In a monitoring network, the spatial distribution of the wells and the sampling procedure needs to be considered (Uil et al., 1999). This can either be the random sampling or the systematic sampling (sampling within a specific grid). The monitoring boreholes should at least spread all over the area intended to be monitored. In the case of monitoring based on protection of the water resources, the zoning recommended in chapter 6 will have to be followed. A number of boreholes need to be sited within the zone that has possible polluting activities and sources. Other boreholes may be sited further from the source of pollutant allowing monitoring of the dispersal of the contaminants with time. Ambient monitoring by DWAF can serve as the reference conditions to this type of monitoring. The ambient monitoring of DWAF occurs on a national scale as well as the regional (provincial scale) and local scale, where a specific borehole is monitored (Xu pers. comm., 2001).

4.3.3.1 Monitoring site

To choose a monitoring site mainly depends on the zone of contribution of surface or groundwater. Groundwater in alluvial sands and gravel deposits (i.e. primary aquifers) has been noted to exhibit a strong degree of hydraulic connection with streams or surface water (Xu et al., 2001a). The connection is also observed in fractured rocks, especially where groundwaters occur in mountainous areas and gets discharged in streams or where flow in mountain streams results in groundwater recharge. Therefore, if the aim is the protection of water resources, then an integrated delineation of the zone of groundwater contribution and surface water contribution is important (Xu pers. comm., 2001). The target when conducting monitoring will be the zones specified as they can easily tell if there are changes in water quality. The reasons to consider these zones are that contaminants in groundwater may be discharged to surface water or contaminated surface water may recharge groundwater. It is true that with flow, groundwater remediation is possible in terms of the contaminants it is carrying, and the zones of contribution are set for those purposes. Monitoring is required to ensure the status of water for health and drinking purposes.

4.3.3.2 Sampling frequency

Sampling frequency mainly depends on the vulnerability of the water resource to contamination (Uil et al., 1999). It can be said therefore, that it mainly depends on the monitoring team, thus based on their judgement in terms of how vulnerable the water resource is to contamination. Many factors have an input when deciding on the sampling frequency. These can even include the rainfall patterns of a certain area that may need monitoring. Sampling needs to be done twice a year during both rainy and dry seasons. Further, the type of aquifer investigated will influence the chosen sampling frequency. This means that the sampling frequency of primary aquifers will differ from hard rock aquifers or basement aquifers (Table 4-1).

4.3.4 Monitoring rules

Monitoring rules are mainly the procedure to be followed when sampling (Uil et al., 1999). These include the checklist of monitoring equipment and others. The manual on groundwater monitoring by Weaver (1992) can be useful i.e. on how to sample, handle and transport the samples to the laboratory. Quality assurance and control needs to be ensured and is also covered in the above cited manual.

AQUIFER TYPES	SAMPLING FREQUENCY
Primary aquifers	Twice a year during wet and dry season to monitor dirt the recharging waters flushes from the surface to groundwater.
Hard rock aquifers	Bi-monthly and immediately after flood events as these types of aquifers are highly vulnerable to contamination due to preferential flow they exhibit.
Basement aquifers with eventful recharge	Targeting time of monitoring may be after rainfall events.

Table 4-1 Sampling frequency for different hydrogeologic scenarios.

4.4 Fieldwork

The fieldwork for this study was conducted during November 2001. Wells used for domestic purposes were sampled and water quality analyses performed. Three types of wells seem to exist in the area i.e. tube wells, ring wells and open wells. These wells are spread all over Mbazwana, but in certain areas, the geology doesn't allow for their construction as their construction is based on hand auguring.

The field methodology followed was as follows: Firstly the rest water level was measured as well as the total depth of the well. Then the well volume was calculated based on the formula:

$$Q = (H - hr)\pi r^2$$

Where Q is the volume of water in the well (m^3)

H is the total depth of the well (m)

hr the rest water level (m)

r the radius of the well (m)

Disinfections or chlorination of the well was conducted with 20ml of Jik added to a 5L bucket of water, which was in turn poured into the well. Full buckets were plunged three times up and down the well. After well disinfections, bailing was performed, with two times the volume of water in the well bailed. Samples were only collected following bailing. For microbiology analyses, 0.5ml of sodium thiosulphate was added to 250ml of the water sampled. The water samples with added sodium thiosulphate, were used for the standard method of analysing microbial water quality. Sodium thiosulphate was added to neutralize the effect of chlorine (chlorine from Jik) in the sampled water. For the H_2S strip method, the sample bottles were filled with water (20 ml) in the field. For physico-chemical analyses, sample bottles were filled with water to prevent trapping of air bubbles, and then tightly sealed. The tube wells were favoured for sampling of groundwater because bailing and chlorination of the well could be done easily. Furthermore, the volume of water to be bailed could be calculated easily.

Chlorination was done to disinfect the well as well as to kill the bacteria that is likely to be in the well prior to bailing. Bailing was done to remove the stagnant water as well as to get a representative sample of groundwater. In open and ring wells the above procedure could not be done because the radius of these wells was too big and it meant that large volumes of water must be bailed out. Calculation of amount of water to be bailed was possible, but since bailing was done manually using buckets, continuing with it would be time-consuming. Sampling from these wells was done with no bailing prior to sampling. Furthermore, chlorination to disinfect the water was not performed.

The tube wells sampled were of two types i.e. the family tube wells (privately owned) and community tube wells. Differences in the way the tube wells are maintained and protected could be picked up easily. The family tube wells are protected with a fence around the wellhead to keep animals away from the well while community ones are not. In open wells each individual brings her own bucket to fetch water from the well. This on its own can result in contamination of the water due to poor personal hygiene. In the case of open wells vulnerability to contamination is very high since they are unprotected and uncovered.

For sampling, pre-sterilised polyethylene bottles were used (250ml). The bottles were rinsed three times prior to collecting the sample. The samples were collected for microbiology and chemistry analyses. On microbiology water quality, the analyses were based on the detection of possibly faecal organisms that may exist in the water. The detection of viruses using coliphages, as most of the authors recommend (Grabow 2001; Young, 1996), was not performed due to limited project funds. The physico-chemical parameters were measured in-situ using the Eutech Cyberscan pH 200 for pH and temperature measurements and Cyberscan Con. 300 for EC, TDS and temperature measurements. These meters were first calibrated using the pH buffer solutions prior measuring the parameters mentioned above. Issues relating to sample ID and site as well as activities taking place around the well were considered and recorded. Care with sampling and transportation of samples to the lab was followed as indicated by Weaver (1992).

All the wells in the villages around Mbazwana were sampled. At least five wells were sampled per village, depending on the number of the available wells. The wells were chosen in such that they represent the entire village being sampled. A total of nine villages were sampled with the total number of samples obtained amounting to fifty-two samples.

For microbiology analyses, two methods were followed i.e. the H_2S strip method, being the field method, and the full laboratory analyses of faecal coliforms using the colony counts method (standard method). The Mbazwana lab was used for this. Several problems seem to arise with the standard method of analysing bacteria in water due to lack of equipment in the laboratory. It was then decided to use the H_2S strip method as it worked successfully. At a later stage the colony counts method was tried again, and seemed to work successfully. Because of time constraints, only two villages could be sampled for standard method of analysing bacteria of faecal origin i.e. approximately eight samples were collected for this purpose. It should be noted that only those wells that were sampled for the H_2S strip method, were re-sampled for the full laboratory analyses of the bacteria of faecal origin.

4.5 Lab Analysis

4.5.1 Bacteriological Water Quality Analyses

As mentioned earlier, two methods were used for microbial water quality, i.e. H_2S strip method and the standard methods of analysing bacteria from water. For the H_2S strip method preparations were conducted in the microbiology lab at the CSIR. The procedure for the preparation was based on the modified method of Genthe and Franck (2000), which incorporates the work of Dutka et al. (1998). An H_2S medium was prepared based on the following reagents;

➢ Peptone	40g
➢ Dipotassium hydrogen phosphate	3g
➢ Ferric ammonium citrate	1.5g
➢ Sodium thiosulphate	2g
➢ Teepol	2ml
➢ L-cysteine	25mg
➢ Distilled water	100ml

The H_2S medium prepared based on the above chemicals was used to impregnate strips of folded paper towel. For each strip 1ml of H_2S medium was used. The strips were then placed in pre-sterilised 40ml plastic bottles.

The prepared bottles were filled with 20ml of water being sampled. The 20ml being measured is pre-marked on the bottle to make the procedure much easier in the field. After filling the bottles with sampled water, they were tightly closed and incubated at room temperatures (± 24^0C). These were examined for 72 hours. The samples were checked after every 24 hours for production of black precipitate, which indicates pollution of water by bacteria of faecal origin.

For the standard method (colony counts method) used in the laboratory, an mFC agar was prepared as suggested on the bottle of mFC agar, (i.e. as follows):
25g of mFC agar was suspended in 500ml of distilled water and heated to boil while stirring continuously. After boiling, the solution was cooled and poured in pre-sterilised petri dishes. These were then placed in a cool place to solidify. After solidification, 10ml and 100ml from each sample was used for analysis. The water used was first filtered. The filter paper was then placed on petri dishes with solidified mFC agar. Following this was the incubation of samples prepared for 24 hours at 44° C. After 24 hours, the samples that showed growth of organisms / colonies were counted. Only the bacteria of faecal origin, i.e. E. Coli, were considered.

On preparation of the samples for analyses, the filters and glass tubes to be used were first sterilized by boiling them for 5 minutes.

4.5.2 Physico-Chemical Analyses

The physico-chemical parameters examined were EC, pH, Dissolved Organic Carbon (DOC), nitrates, temperature and Total Dissolved Solids (TDS). The pH, EC, TDS and temperature were measured both in the field as well as in laboratory.

For the EC measurements, a dried KCl was prepared to an appropriate mass and dissolved to 500ml of reagent grade water and then diluted in 100ml of water. The conductivity was measured at 25^0 C using the conductivity meter.

The pH was measured using a Radiometer PHM82 STANDARD pH METER and GK2401C combined electrode. The meter was first calibrated prior measuring the pH. The nitrates, DOC and TDS were determined based on the standard methods for examination of the water and wastewater.

4.6 Sorting the data

The large number of data was sorted into a usable format using statistics (i.e. statistical sorting of data). This means that the average means, standard deviations etc. were considered. From these tables, figures and graphs trends in the data were observed.

For the presentation of results and generation of graphs for the thesis, the average mean rainfall data per month was used. The same procedure was followed for the temperature and chemistry data used (data obtained from Meyer et al., 2001). MICROSOFT EXCEL was very useful in generation of graphs as well in sorting of the data. Further, hydrochemistry based diagrams were generated by using MICROSOFT EXCEL based software i.e. Ham for the fingerprint and piper diagrams and Hydrogeomorphology based software. Both the cited software are available from the website www.science.uwc.ac.za/earthsience/index.htm.

4.7 Limitations

The condition of the pump/ well seemed to be the problem in few cases, where the bucket to collect water from the well was encountered to be stolen. Some buckets were leaking, as in the case of community wells, or reported to have fallen into the well. In such cases it was difficult to sample some of the wells, as a result few wells were not sampled. After frequently encountering this problem, a spare bucket was carried with to elude all the hassles encountered. Besides the problems mentioned, the equipment used during sampling was another problem, with few cases where it did not work. In this regard a reference is given to the Global Positioning System, EC and pH meters used. These problems were encountered during the early stages of sampling and were later resolved.

4.8 Excel based software Programme (GW_MONITOR)

A Microsoft Excel based programme, **GW_MONITOR**, is developed to assist in groundwater resource quality monitoring. It is developed specifically to help in monitoring of water resources for domestic purposes. The parameters indicating poor quality of domestic waters are specified. The programme, GW_MONITOR, compares the input data in relation to standard water quality guidelines and returns the output as ***Ideal,*** if it meets the target limits of the standards of water quality guidelines, ***Tolerable,*** if it falls within the range that can cause slight aesthetic problems and ***Crisis,*** if the value of the parameter is beyond the limits specified for domestic purposes as this can result in serious health risks. This is made easier in the programme through the colour change indication for each cell in relation to input parameter as one updates the data to the programme. The quality of domestic waters has been considered under three attributes i.e. for health purposes, aesthetics and food preparation. The macros used to design the programme as well as the output of GW_MONITOR are presented in appendix F.

The aim of the design/ development of this programme is to consider protection of water resources, specifically Resource Quality Objectives. If the quality of the resource needs to be evaluated first before the RQOs are set, then a programme that enables one to get the results quickly is required. The programme designed allows quick decision making regarding protection of the water reesources and set of RQOs based on the state of the results (output of the data collected) obtained.

For the water quantity, the procedure is similar to water quality, but the scope of the project does not allow to explore the point of considering water quantity.

5 CASE STUDY

5.1 Introduction

The monitoring and protection of water resources discussed in previous chapters was applied in Mbazwana, northen KwaZulu-Natal. The target period for this monitoring was the rainy season for this area. The monitoring (i.e.groundwater monitoring) was conducted over a month period and the results obtained are presented in this chapter. The methodology as presented in chapter 4 was followed strictly without any deviations.

5.1.1 Location

The study area comprises Mbazwana, a small town in the northern KwaZulu-Natal region (also known as Maputaland region). The area is about 300Km north of Durban and comprises an area of ±2589Km^2 (i.e. Quaternary Catchment). The upper boundary includes the Sibaya Lake, which is the largest fresh water lake in South Africa. Southwards, the flat plains of the northern Zululand comprise the study area, while the eastern side is bordered by the Indian Ocean, and the western side by the Lebombo Mountains, (see Figure 5-1 and 5-2). The Natal Parks Board protects the coastal area, including the Sibaya Lake as nature reserves. The entire northern Zululand region is well known as a tourist attraction. Due to this, development and improvement of the area is taking place.

5.1.2 Physiography

The northern KwaZulu-Natal comprises a flat terrain along the coast, which gently undulates to a ±300m altitude inland. The topography changes gradually inland as it attains the steep gradients towards the Lebombo Mountains. Along the coast, the remains of the prehistoric dunes can be observed, aligned with the present coastline. These dunes have been stabilised by vegetation in such that the winds do not have an effect on erosion.

Southwards is the Mkuze River, which emerges on the western part of the study area and flow eastwards to finally link with the St Lucia Lake. This river drains almost the entire southern part of the study area. This physiographic set up has an influence on the rainfall pattern of the area, with high rainfall occurring along the coastal plains and decreasing towards the escarpment.

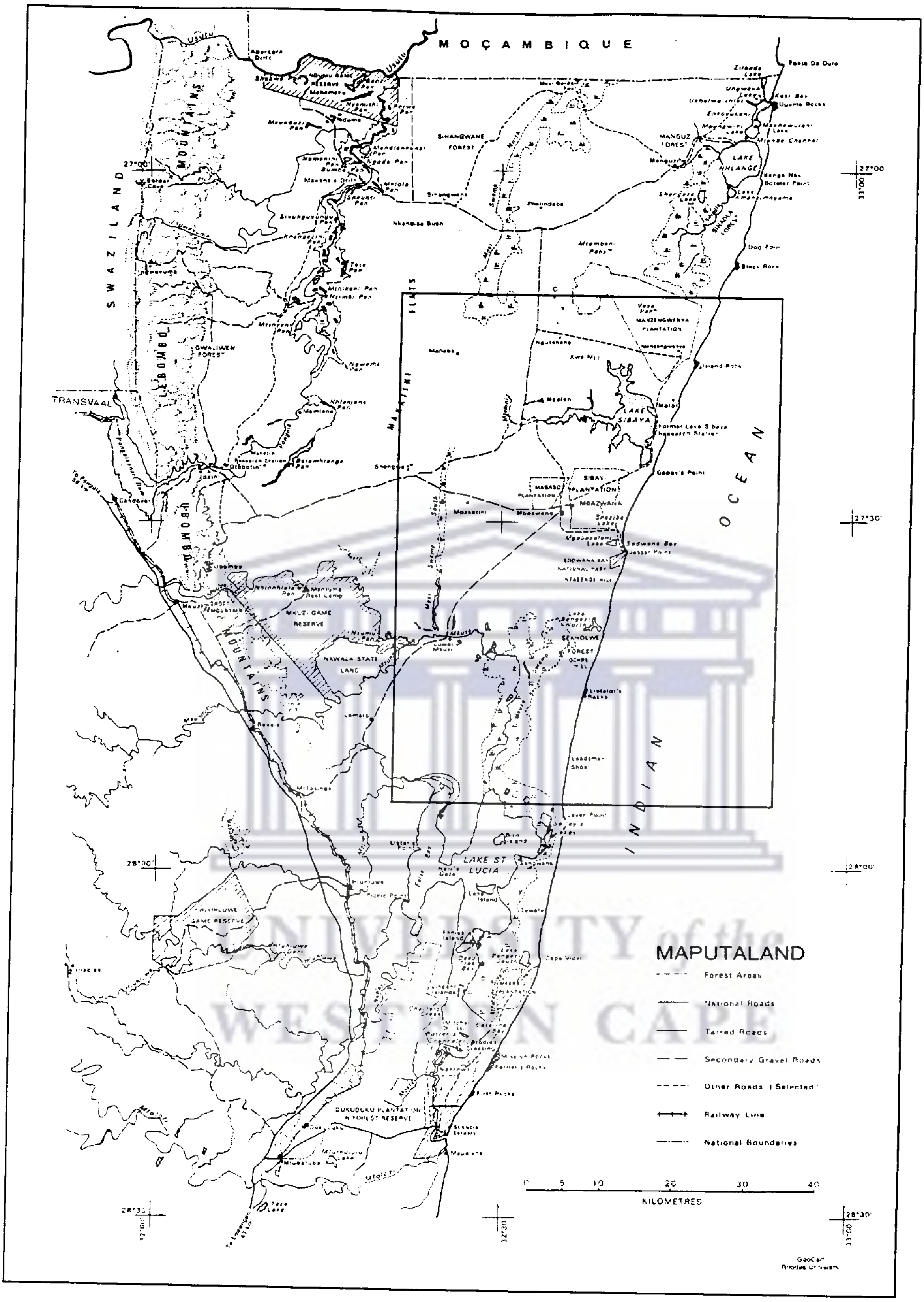


Figure 5-1 A Southern Maputaland map showing exact position of the area studied (map adapted and modified after Bruton and Cooper, 1980).

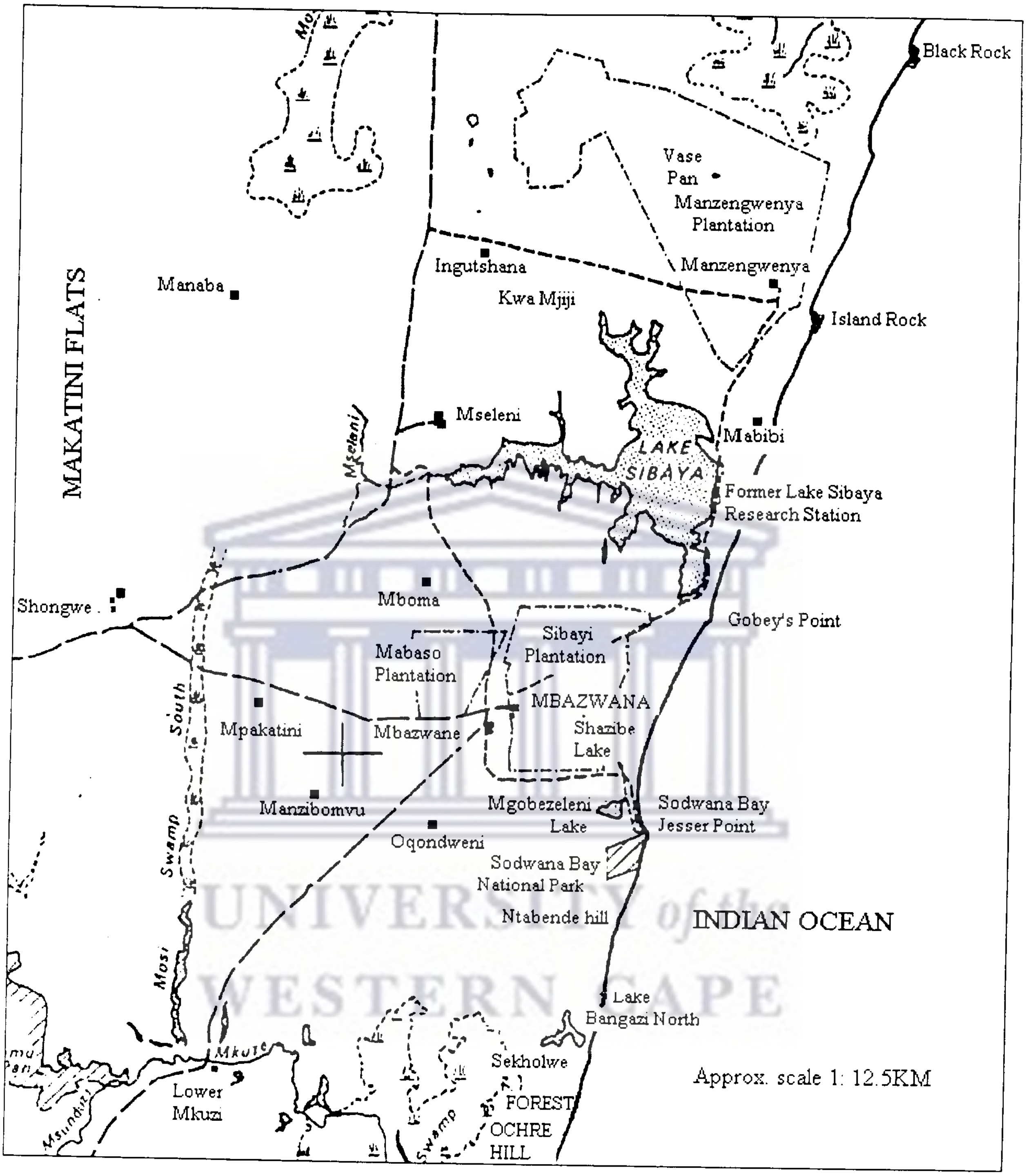


Figure 5-2 A zoom-in map showing the study area

5.1.3 Climate

The northern KwaZulu-Natal coast is characterised by the subtropical climates, with hot summers and warm winters. Its climatic zone is dominated by the southern subtropical high-pressure belt (Ramsay, 1996). The Agulhas current on the east coast affects the wind patterns within the study area. This enhances the convectional air circulation offshore.

The rainfall in northern kwaZulu-Natal region exceeds 1000mm per year along the coast and decreases inland to between 800- 1000mm/yr and finally to ±500mm towards the Lebombo Mountains, (Figure 5-1).

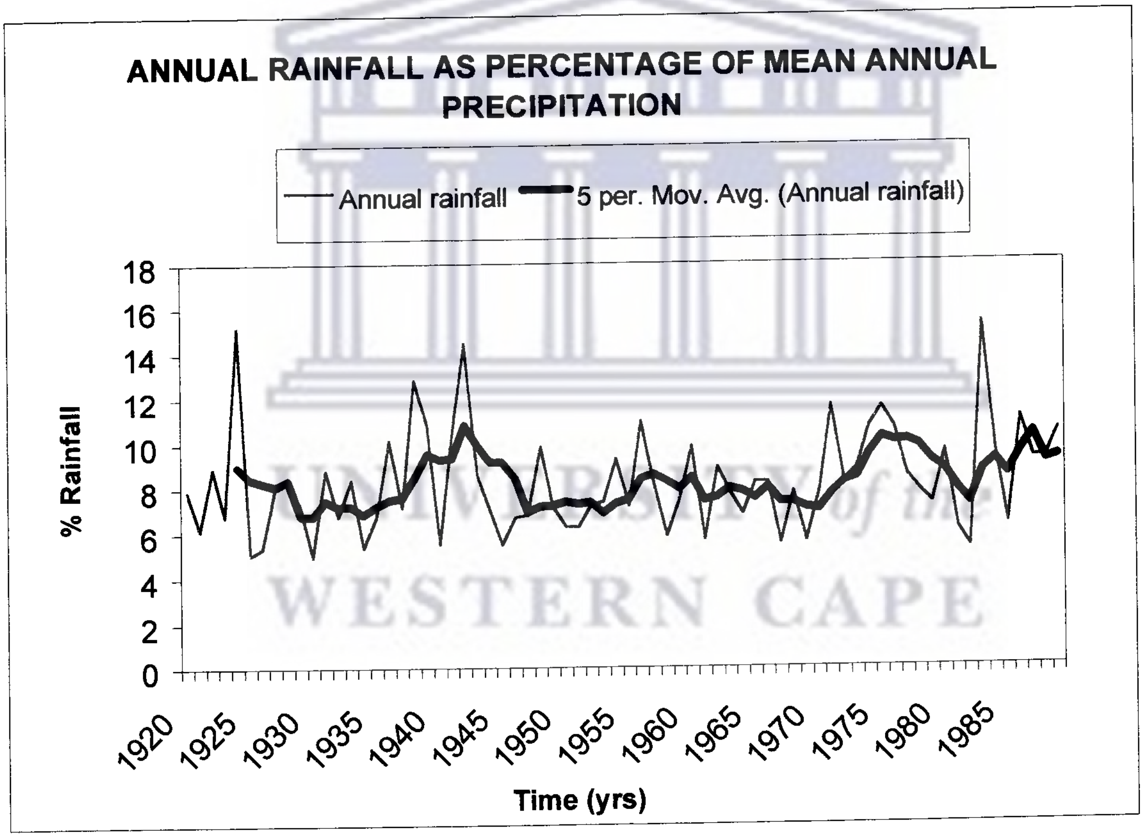


Figure 5-3 Percentage annual rainfall for the Zululand Coastal Plain (after Midgley et al., 1994)

Figure 5-3 shows annual rainfall variation measured on the Zululand Coastal plain over the years 1920-1989 (Midgley et al., 1994). From the figure a five-year moving average is provided. This mainly demonstrates the climatic changes within a five-year period. Regarding the chemistry, (extrapolation from rainfall-recharge), it can be said that the groundwater chemistry for the period 1940-50 and 1970-80s was almost the same, i.e. considering the diluting effect from rainfall recharge. This means that the concentration of different ions (expressed in weight) or the groundwater chemistry signature were almost the same since rainfall recharge dilutes the waters. Similar conclusions were drawn for flow conditions and the groundwater levels during the above-mentioned periods. These were the periods of floods for the Northern KwaZulu-Natal region, during which the Mkuze River was in flood. Unfortunately, the chemistry data for these periods is not available to allow accurate comparisons about the above deductions. From the diagram the historic climatic conditions and how it fluctuates with time can be observed.

The Relative Humidity for the area ranges between 56% and 84% and during winter months a decrease in the relative humidity by few percentages is mostly recorded (Midgley et al., 1994). Higher temperatures within the area have an effect on evaporation rates but the humid air circulation from the coast balances the effect. These high temperatures are mostly observed during summer and a decrease of temperatures to ±25^{0}C during winter can be observed (see Figure 5-4). This results in a potential mean annual evaporation of ±1500mm per annum in the region. Occasional storms and tropical cyclones, which are generated from the Indian Ocean, tend to have a disastrous effect during the summer months.

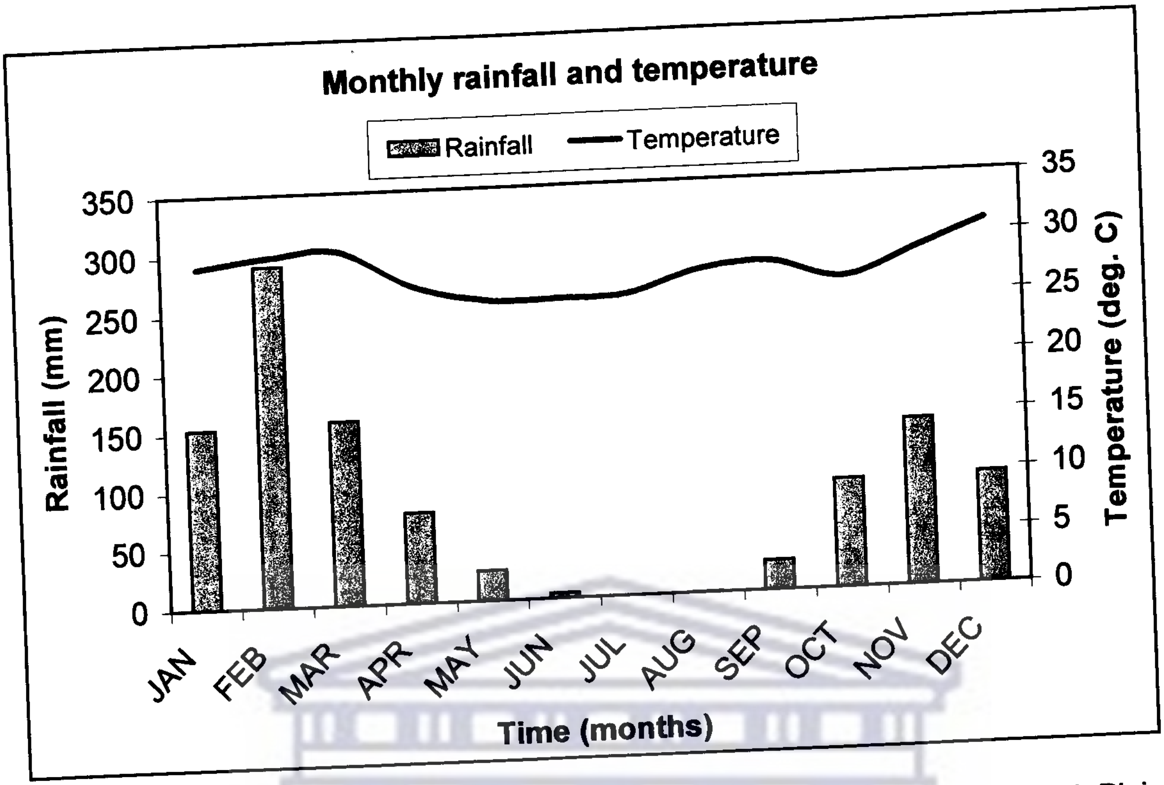


Figure 5-4 Average monthly weather parametrers for the Zululand Coastal Plain. (Weather Bureau Station 0411323, Makatini).

5.1.4 Vegetation

The vegetation typifying the study area is the coastal bushveld-grassland of the Savanna Biome (Low and Robelo, 1998). Its evolution results from the humid climates of the east coast accompanied by the relatively high temperatures recorded even during winter months. The forest patches as well as evergreen thicket and vegetation with shrubby appearance characterize the coastal bushveld-grassveld. Diagnostic of the evergreen thicket is the *Acacia gracornuta, Gardenia cornuta and Euphorbia grandicornis* (Moll, 1980). The coastal bushveld occupies the seaward dune slopes while the landward side comprises the Coastal grassland with dwarf woody plants (see Figure 5-5).

Figure 5-5 Typical vegetation of the Mbazwana area (inland section).

This coastal bushveld-grassveld covers the coastal area and the gently undulating slopes inland. The underlying soils influencing this type of vegetation are the sandy soils of the marine origin (Low and Robelo, 1998). Furthermore, the wetlands and swampy areas occurring along the coast have an effect in determining the type of vegetation growing there.

5.1.5 Geological Setting of the Northern KwaZulu-Natal region

The geology of the northern KwaZulu-Natal has evolved from the Cretaceous to Quaternary stage (Kelbe et al., 2001). In general, it can be said that the pre-Cretaceous rocks (basement rocks) and the recent deposits of the Quaternary age makes up the geology of KwaZulu-Natal. Forming the basement are the basaltic lavas of the Lebombo Group. These basaltic lavas have a thickness of ±1350m (SACS, 1980). The lavas erupted during the last stages of the

Phanerozoic eonotherm in a horizontal to sub-horizontal manner and have attained tilting of ± 15^0 in various directions along the coast, hence forming the Natal monocline (Visser, 1998). Eruption and deposition of the basaltic lavas in KwaZulu-Natal marked the last stages of the Karoo sedimentation.

5.1.5.1 The Cretaceous Geology

The Cretaceous geology comprises the three formations of the Zululand Group (Kelbe and Germishuyse, 2000). These include the St Lucia, the Mzinene and Makatini Formations. Characterizing the St Lucia Formation are the siltstones and shelly horizons. Underlying the St Lucia Formation is the Mzinene, with similar rock types to those of the St Lucia Formation (SACS, 1980). Both the Mzinene and St Lucia Formations consist of richly fossiliforus glauconites (glauconitic sandstones), which are attributed to shallow marine accumulations. The Makatini Formation underlies the Mzinene and is separated from it by a hiatus (SACS, 1980; Tankard et al., 1982). Comprising the Makatini Formation are siltstones and conglomerates, which are attributed to the progradation of braided fluvial deposits into shallow sea (Tankard et al., 1982).

During the Cretaceous period of sediment deposition in the Zululand-Natal, the coastal seaboard formed by shoreline regression and coastal dune formation (Tankard et al., 1982). Lowering of the sea level marked the deposition of sediments of marine origin on a seaward sloping platform. Because of the sea level withdrawal, the rivers southwards of the KwaZulu-Natal deposited extrabasinal pebbles that indicated transportation from different drainage systems. In general terms, the sedimentary deposits of the Cretaceous period can be said to be of marine and fluvial origin resulting from sea level regression and deposition of sediments by rivers.

5.1.5.2 Tertiary Geology

The final stages in the deposition of the Cretaceous sediments, ± 100 million years ago, were marked by the development of conglomerates along the coastal margin (Tankard et al., 1982). The clasts of these conglomerates are mainly of volcanic and quartzitic rock type derived from Lebombo. The deposition of the conglomerates was accompanied by the deposition of alluvial floodplain facies (i.e. deposition of Mkwelane Formation) on the proximal side of conglomerate (Tankard et al., 1982). This allowed for planar cross bedding, rich in fossils to develop and this planar bedding resembled a braided distributary. The deposition of conglomerates as well as the floodplain facies was initiated by a sea level regression during the Palaeocene. These conglomerates have been noted to outcrop as Uloa Formation and extend as far north as Kosi Bay (Meyer et al., 2001). Underlying the conglomerates is a sequence of limestones and coquinas. From the deposition of the Mkwelane Formation, deep weathering and erosion was observed. This was then followed by deposition of the calcarenites and coquina, which culminated towards the end of Miocene.

5.1.5.3 Quaternary Geology

Aeolian deposits and coastal dunes comprise the Quaternary sediments (Kelbe et al., 2001). These deposits consist of unconsolidated material of silt, sands and clays. Along the coast, these coastal dune deposits lie parallel to the existing coastline, trending in a north-south direction, thus bordering Lake Sibaya and closing the link between the two. The sand dunes resulted from reworking of the Port Dunford Formation by wind action during the Pleistocene. This sediment reworking resulted in formation of the grey sands, which characterizes the sand dunes. The sand layer thins from east to west and northwards, covering the whole Zululand coastal plain. These aeolian deposits overlie the coarse gravely sands of alluvial and estuarine origin as well as the calcarenites of aeolian origin, thus resulting in an upward fining sequence. Since the basal gravels of these dunes rest on an erosional surface, they are regarded as resulting from transgression – regression couplets (Tankard et al., 1982). The transgressions and regressions during this period (Pleistocene) resulted in the incision of rivers of the Natal Province, which ultimately became lagoons (Kelbe et al., 2001). The incision led to the occurrence of sandy and clayey alluvium on the floodplain of the Pongolo and Mkuze rivers. Also associated with incision of rivers are the pans that result from agradational infilling of the main river courses during glacial periods of the Pleistocene (Maud, 1980). Generally, the palaeo-climates accompanied by sea level transgressions and regressions can account for the geology of the Zululand region. Table 5-1 shows the full stratigraphic succession for the Zululand region.

The sediments of the Quaternary as well as the Cretaceous stage mainly comprise the KwaZulu-Natal Coastal Aquifer.

5.1.6 Land-use practices

This section is included in this study because land-use and groundwater contamination are closely linked. This emphasizes land-use planning and practices when groundwater resources need protection. Understanding of land-use practices will assist with identifying possible polluting sources as well as the vulnerable areas that need protection. With regard to land-use planning, Scharp (1999) suggests that groundwater protection be incorporated and co-ordinated with other sectors of interests at an early stage in all land-use planning and urban development.

In terms of land-use practices nothing much is taking place in the Mbazwana, Northern Zululand area. Few communities practice agricultural farming, but even that rarely occupies a hectare of the land per household. Besides that, a huge area about $225km^2$ is taken by plantations, i.e. commercial plantations surrounding the Mbazwana and south and north of Sibaya Lake. The high growth rate of trees in this region seems to be influenced by high rainfall as well as the warm humid climates of this region. The underlying soils are noted to be infertile due to their physical and chemical properties (i.e. sandy soils exist) (Kyle, 1995). Furthermore, the high rainfall of this region results in leached soils, thus making them more infertile (Kyle, 1995). This may be the reason for limited agricultural practices in this area.

PERIOD	AGE (Ma)	GROUP	FORMATION	LITHOLOGY
QUATERNARY	0-2 Ma		Berea	Reddish brown and red sands, coastal dunes clayey sands and alluvium of recent deposits
			Bluff	Calcareous sandstone
TERTIARY	2-65Ma		Port Dunford	Calcarenites, coquina and fossilferous mudrocks
			Uloa	Coquina and conglomerates
CREATACEOUS	65-142Ma	Zululand	St Lucia	Siltstone and sandstone
			Mzinene	Siltstone and sandstone with glauconites
			Makatini	Siltstone and conglomerates
JURASSIC	142Ma	Lebombo	Mpilo	Rhyolites, dacites, andesites and pyroclasts
			Jozini	
			Letaba	

Table 5-1 Stratigraphic succession of the Zululand Coastal Plain (adapted and modified after Meyer et al., 2001).

5.1.7 Potential for contamination

The presence of groundwater varies with depth beneath the land surface (Todd, 1976). This makes it vulnerable to most contaminants, ranging from human activities taking place on land surface to discharges and infiltration of contaminated surface waters. This is a result of the underlying geology, the hydraulic properties and aquifer type (Uil et al., 1999). The Mbazwana area in the northern KwaZulu-Natal is not an exception as its underlying geology favours contamination. Activities taking place on land surface, e.g. construction and installation of pit latrines in the area, makes groundwater more vulnerable to contamination. Furthermore, the depth to the saturated zone is very shallow (water table can be encountered at ±4m depth below ground level) thus making the aquifer more vulnerable to contamination. High precipitation rates as well as high infiltration rates, the underlying soils (i.e. sands) also promote groundwater contamination of northern KwaZulu-Natal coastal aquifer. As a result of this high vulnerability, high threats and high health risk as the water is used for domestic purposes, adequate protection measures, proper monitoring, effective evaluation and implementation measures are required to assess the current status of groundwater as well as to protect the water resources to maintain a desired state, thus guaranteeing functioning and usage of groundwater.

5.2 Hydrogeology

5.2.1 General description of the aquifer

The characteristics and depositional history of the Cretaceous sediments in the Zululand coastal region suggest an ideal aquifer formed by these sediments (Kelbe et al., 2001; Meyer et al., 2001). This only considers the conglomerates of this period, but not the siltstones and shelly horizon. The siltstones have been noted to have a very low permeability with poor quality (TDS> 8000mg/L) and quantity (Meyer et al., 2001). This holds true if considering the depositional history of these sediments, which results from different marine environments and the transportation of fluvial material by palaeo drainage system.

The overlying Uloa Formation has been noted to be a good aquifer with a porosity of ±61% (Meyer et al., 2001). This Formation comprises the coquinas and calcareneous sandstones and does not occur everywhere (Meyer et al., 2001). This may be hindering sustainable yields in the zones where the highly porous coquinas and calcareneous sandstones are absent.

Overlying the Tertiary sediments are the widespread layers of clayey sands of Quaternary age. These sediments of marine origin as well as recent aeolian sands are highly permeable and promote quick recharge (Kelbe and Germishuyse, 2000).

In terms of groundwater flow, the groundwater mimics the topography as the water level map and the elevation maps in Appendix A show. From the map, the groundwater flow direction is eastwards i.e. the flow is towards the Indian Ocean.

With regard to groundwater interaction with surface water bodies, a study by Kelbe and Germishuyse (2000) showed that the groundwater feeds the fresh water lakes of the Zululand Coastal Plain. The study revealed that this interaction is encountered during dry seasons while reverse process is observed during the heavy rainfall periods.

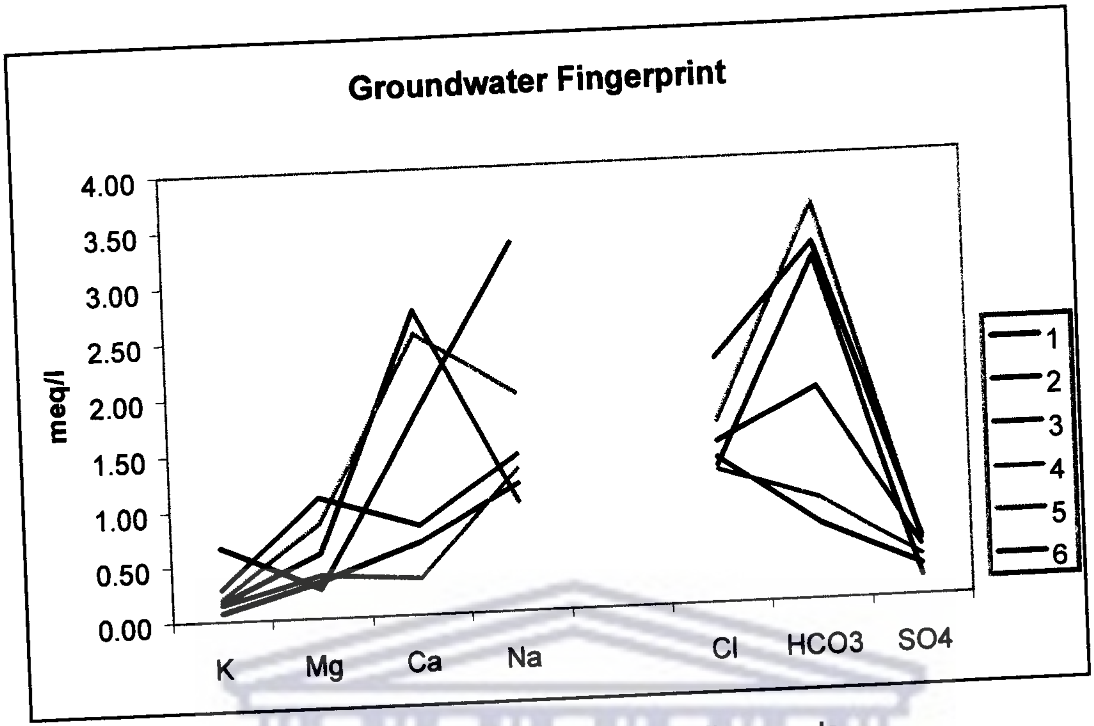
5.2.2 Hydrochemistry

The groundwater chemistry data for the Zululand region was obtained from the report of Meyer et al. (2001). The data is sorted according to the geological formations of the area. Only the average mean values of the data were used for the plots (Figures 5-6 and 5-7). The geological formations considered include the St Lucia mudstones, the Uloa, which is sub-divided into calcarenites and sands, the Lignite band and the Pleistocene Port Dunford (also sub-divided into Upper and Lower Port Dunford Formations). The average mean values used were based on four samples for the St Lucia Formation, twelve for the Uloa calcarenites and three for the Uloa sands, three for Lignite band, two for the Lower Port Dunford and seven for the Upper Port Dunford Formation.

A fingerprint diagram was used to present the data (Figure 5-6). A Fingerprint diagram is known to classify unknown unpolluted groundwater samples according to their origin (i.e. lithological character) (Meyer et al., 2001). The fingerprint diagram represents the major ions as ratios of cations against anions in milli-equivalents per litre. This allows one to read the water type based on the dominating cation and anion for the particular water.

Figure 5-6 presents the results obtained. From the diagram, it reveals that the groundwater of the Pleistocene Upper Port Dunford Formation is characterised by a NaCl type of water. This is also the case with Uloa sands. These waters resemble that of seawater.

The groundwaters of the Lignite band and the St Lucia Formation have similar trends in terms of their chemical character and origin. They both fall within the category of $NaHCO_3$ type of water. The Uloa calcarenites and Pleistocene Lower Port Dunford show $Ca(HCO_3)_2$ type groundwaters.

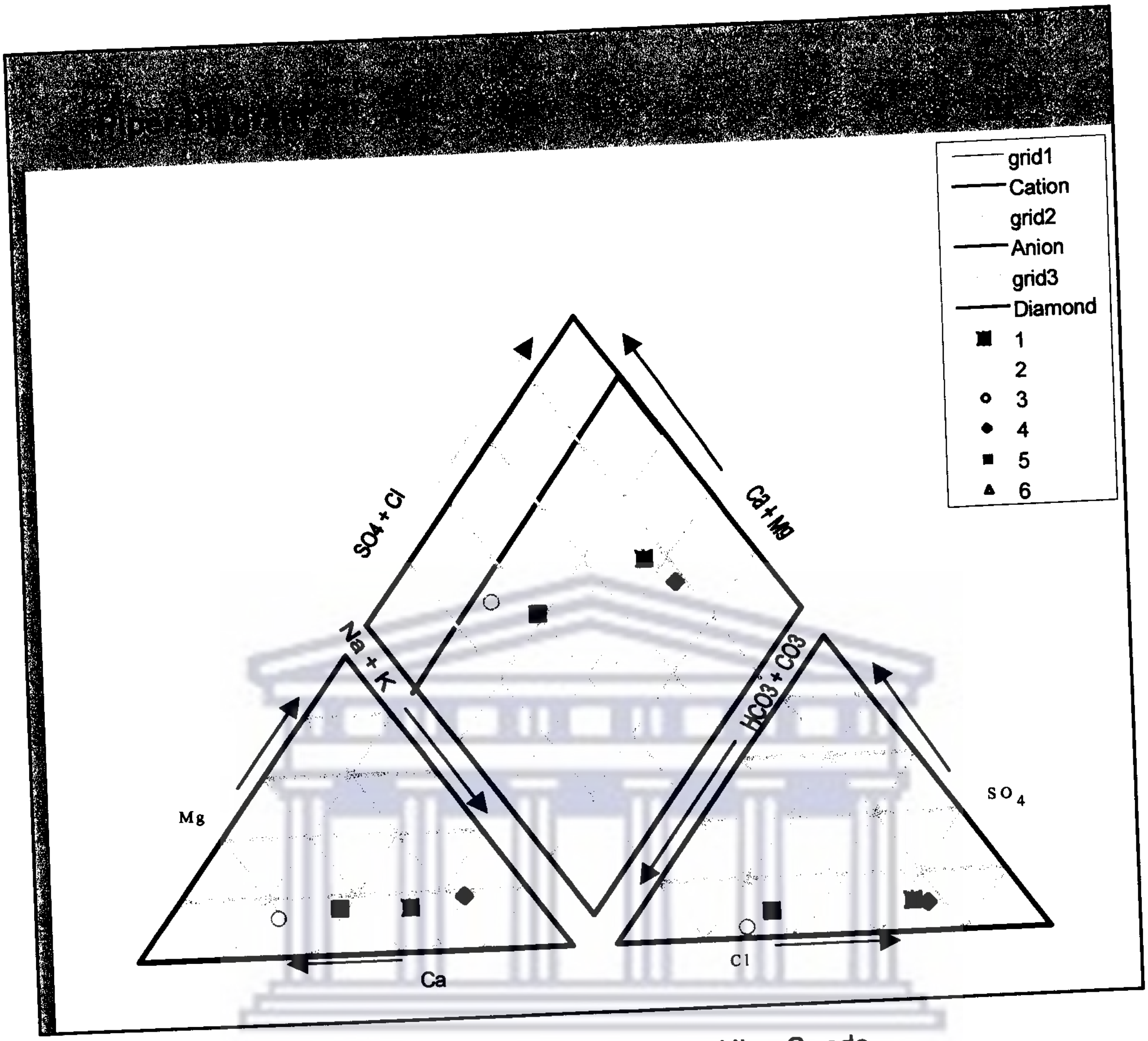


1. Pleistocene Upper Port Dunford
2. Lignite band
3. Pleistocene Lower Port Dunford
4. Uloa sands
5. Uloa calcarenites
6. St Lucia mudstones

Figure 5-6 A Fingerprint diagram showing the chemical composition of groundwater in Northern KwaZulu-Natal. Source of the data: Meyer et al. (2001)

Using the Piper diagram, the three distinct water types for the Zululand region can be easily recognized (see Figure 5-7). The groundwater types observed seem to resemble the lithological character for the formations mentioned above (see the section of geology). This holds true if the depositional environment of these formations is taken into consideration.

The groundwater chemistry of all the formations of the Zululand aquifer plot in the central zone of the Piper diagram (Figure 5-7). The zone where the groundwater plots (central part of the Piper diagram) can be considered as the mixing zone. Therefore, it can be said that the groundwater of the Zululand region is a mixture of fresh and saline water. This holds true if the water types for each formation are considered, i.e. these water types range from $Ca(HCO_3)_2$, $NaHCO_3$, to NaCl.



1. Pleistocene Upper Port Dunford
2. Lignite band
3. Pleistocene Lower Port Dunford
4. Uloa Sands
5. Uloa calcarenites
6. St Lucia (mudstones)

Figure 5-7 Piper diagram showing water types existing for the Zululand Coastal Aquifer
Source of the data: Meyer et al. (2001)

5.2.3 Baseflow separation

The inclusion of baseflow separation in this study was seen necessary since, during periods of droughts, the stream flow is mostly generated from groundwater. Furthermore, the aquifer under investigation is unconfined with shallow groundwater and shallow rooted vegetation, although commercial forests exist. Contribution of groundwater to stream flow is however, possible.

A base flow separation was conducted for the Mkuze River that emerges from the west, flows south-eastwards through the study area and finally links with the St Lucia Lake. The stream flow measurement values for the point W3H011 as well as the rainfall data zone W3E were obtained from WR90 (Midgley et al., 1994). The average values for the data mentioned above were used for each month.

The baseflow separation from run-off was made possible by the use of a hydrogeomorphologic based baseflow separation program available at www.science.uwc.ac.za/earthsience/index.htm. This program takes into account the hydrogeomorphologic classification of streams as well as the interaction type of the streams with groundwater. The parameters used to estimate the groundwater flux towards the river are based on the modified formula of Herold (1980).

The highest simulated/ observed run-off values are mostly encountered during the summer/autumn months, i.e. from October to March (Figure 5-7). This period represents the rainy seasons in the KwaZulu-Natal region.

This is the period, (i.e. October to March), that the unconfined aquifer gets recharged and subsequently loses its water through the rest of the year, (as Figure 5-8 suggests), with a fall in the run-off curve towards winter.

On the advancing limb of the hydrograph, the quick storm response from rainfall dominates the stream flow and attains its maximum with time as it reaches the inflexion point of the hydrograph curve. This mainly represents the drainage rate increase, responding to run-off.

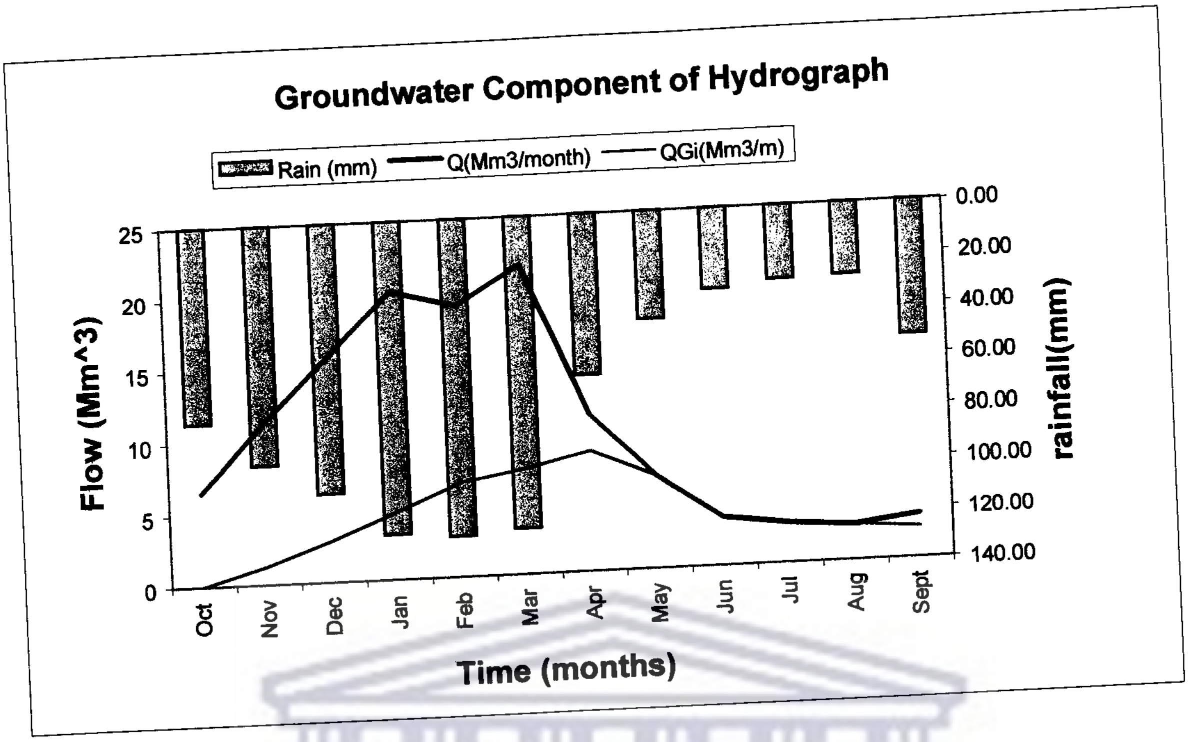


Figure 5-8 Baseflow separation from the rainfall hydrograph for the Mkuze River, Northern KwaZulu-Natal. Source of the data: Midgely et al. (1994).

The receding limb of the hydrograph mainly reflects the rate at which water gets depleted from the catchment (Figure 5-8). Since the response of groundwater and surface water levels to rainfall is not the same, the groundwater component seems to equate to the surface run-off as the surface water depletes on the receding limb of hydrograph. This shows a slow or delayed response of groundwater to recharge. Therefore in this region it can be said that the hydrograph comprises mainly groundwater i.e. baseflow.

To estimate the groundwater flux towards the river (Mkuze River) a decay factor of 0.75 and an increase in groundwater due to rainfall recharge (*I*) of 0.2 were used. The groundwater flux to the river (i.e. baseflow contribution) was calculated to be 294 m^3/d. The recharge value calculated for the area is 39.63% of total rainfall. This value of recharge considers the lower reaches of the stream. This means that groundwater quality will affect surface water and therefore quality monitoring becomes more meaningful to protect the aquatic ecosystem.

Classifying the stream (Mkuze River) in terms of its interaction with groundwater as proposed by Xu et al. (2001a), the Mkuze River is a gaining stream with bank storage due to the alluvial terrain over which the river flows, which serve as the storage buffer for groundwater.

5.2.4 Water Supply

The WHO (1984) recommends a thorough understanding and knowledge of the water supply of the area selected as well as the engineering factors prior the interpretation of the bacteriological water quality results. Mvula Trust, with *Partners in Development (PiD)*, initiated the water supply and sanitation programme in Mbazwana and its surroundings (Deverill et al., 1999a). The introduction of the programme takes place in phases, with only the pilot study undertaken currently (Deverill et. al., 1999a). During the pilot study, demonstration wells were built and these, at a later stage, were given to the community (Nash pers. comm., 2001). The demonstration wells comprised the ring wells and tube wells. It should be noted that not all communities have these demonstration wells as they were introduced in selected communities. Succeeding this phase was the introduction of family wells (i.e. privately owned wells). These were built specifically for each household.

Besides the wells mentioned, large amounts of water are required for recreational purposes and other purposes. The Sibaya Lake serves to provide water.

5.2.5 Sanitation programme in Mbazwana, northern KwaZulu-Natal

Sanitation is generally associated with pit latrines or maybe flush toilets, health implications and education, hygiene practises etc. (DWAF, 1994). The sanitation programme in Mbazwana is incorporated in the water supply programme. The sanitation programme is still in progress with few villages using pit latrines. Government subsidizes the programme and the community members pay a deposit to get the services (Nash pers. comm., 2001). Prior to this, the community members are encouraged to group themselves into ten households so that a limited number of pit latrines can be built for a particular village. The deposit is refunded to the community members after finishing the programme for a particular village (Nash pers. comm., 2001). This may seem as an easy and affordable way, but the people in Mbazwana often cannot afford it. As a result, some households are still using the open defecation system for sanitation practices. This, on its own has the potential of degrading the water quality. The programme is showing success as people are moving towards better sanitation practices. Still under investigation is whether the pit latrines are contributing to the deterioration of the groundwater quality.

5.2.6 Different scenarios on sanitation practices with regard to infrastructure in South Africa

In South Africa, the high unemployment rate as well as poverty determines the kind of lifestyle. This is demonstrated by the different sanitation practices existing in different areas, i.e. rural, peri-urban and urban areas of South Africa. These are not only influenced by the aforementioned factors, but also by the existing infrastructure within the divisions mentioned. These factors have been noted to include (Pearson and Morgan-Ramohatswa 19..):

- The type of settlement
- Sociological character and values
- Institutional structure in the community, and

- Health and environmental implications

In many instances it is relatively easy to change technology and hence improve the lifestyle of the public (Ford and Colwell, 1996). This mainly depends on cultural background as well as the values and behaviour of people. Willingness to pay also has a major effect on the technology options. Some of the problems encountered in Mbazwana were that the people have a tendency of resisting changes in addition to a loss of cultural values. At the same time it is difficult to prove and convince the public that latrines are beneficial to their health (Cotton et al., 1995). Measures to improve personal and domestic hygiene and provision of adequate water supply and sanitation practices are directly linked to health benefits for the public.

The rural set-up or situation does not allow the construction of sewage tanks, associated pipelines and flush toilets, mainly because the households are scattered. This problem is not only experienced with sanitation, but also with water supply and electrification. If the water quality for these three areas mentioned above is considered, it tends to deteriorate from rural to urban areas with the health risks highest in rural areas since the water is used for drinking purposes. In rural areas pit latrines are mostly used as well as open defecation systems. This has a high potential to contaminate groundwater especially in areas with shallow groundwater, e.g. the northern KwaZulu-Natal Coastal Aquifer. The open defecation system poses a serious threat to drinking water within rural areas as in most cases there is no proper infrastructure for water supply systems or sanitation systems.

Furthermore, public health in rural areas tends to be at stake due to waterborne diseases. The waterborne diseases are related to poor sanitation, poor water quality, poor domestic hygiene, improper waste disposal and improper water usage (Pearson and Morgan-Ramohatswa, 19..). This has been frequently encountered in KwaZulu-Natal and in the villages of the Eastern Cape province.

The aforementioned factors are driven by the fact that low-income people tend to be ignorant about the benefits of having proper sanitation (Cotton et al., 1995). Furthermore, the lack of understanding that health is directly linked to sanitation practices. The second reason may be associated with unsatisfactory value of pit latrines with regard to quality of water as well as long-term effects of public health, although the latrines mean an investment to low-income people.

Communities in rural areas use hand-dug wells for drinking water that are, in most instances, not protected from animals. In most cases such wells are not protected nor covered so that cattle drink there and the open water also attracts insects. This has a negative impact on the quality of water. A typical well that may be observed in the rural areas is shown in Figure 5-9.

Figure 5-9 A typical well used for drinking water purposes in rural areas (Photo taken from the Oqondweni Village, northern KwaZulu-Natal)

Open defecation is another serious health hazard in rural areas (Cotton et al., 1995), especially considering the water source. Due to this, water quality is noted to deteriorate immediately after heavy rains because of run-off that carries all the dirt and deposit it in the wells mentioned above (Kravitz et al., 1999). Reported cases of waterborne diseases encountered in rural villages are the result of the above-mentioned reasons. This liquid percolation into soil from the surface (i.e. latrines) means the flushing of micro-organisms of faecal origin into groundwater. It is for these reasons that well-head protection measures and minimum distances are set between a latrine and a well to elude the effects of water quality deterioration of drinking water drawn from the wells (Daly, 1995; Xu and Braune, 1995; Scharp, 1999 and Spayd, 2001).

In the case of peri-urban areas, including the informal settlements, bucket systems are mostly used although for the informal settlements open defecation systems are also used. In this case communal sanitation facilities (i.e. household latrine shared by several households living together in the same area/ plot) are used. The only drawback about these communal latrines is the unrestricted access and insufficient maintenance to keep them in a neat and tidy condition. Nuisance (unpleasant smell) and insects are some of the problems frequently encountered. Because of the Reconstruction and Development Programme (RDP), the water supplied to people in peri-urban areas can be regarded as of good quality since it is coming from taps. Reported cases of waterborne diseases are infrequent as compared to the rural areas. The situation is totally different for the informal sector where high levels of pollution are mostly encountered, mainly from domestic waste. Informal settlements are not considered as part of the municipal area, hence lack the provision of basic infrastructure, poor sanitary practices (open defecation frequently observed) with no storm-water run-off drains. Groundwater in these areas is highly contaminated due to the flushing of surface dirt to groundwater. Both the rural areas and the peri-urban areas experience similar problems like odour, which is coming from the pit latrines and insect nuisance, which are normally observed across the range of latrines.

In the urban areas, flush toilets are mostly used with no odour or insect nuisance encountered. Problems occur when sewage pipes bursts, but this is a rare case. Other instances are those of leaky sewage pipes, which may contaminate groundwater or when groundwater levels rise above the pipes. When the above situations arise groundwater pollution is a serious threat.

5.2.7 Children, latrines and water quality

It has been noted that when insanitary latrines are found in schools, children tend to acquire poor hygiene habits which may be difficult to break (Cotton et al., 1995). This is true when considering the results of the microbial water quality tests conducted for the schools in Mbazwana area. Pit latrines are available at these schools. Unlike other households, where the pit latrines would be encountered close to the well, it was not the case with school wells. These wells tested positive to microbial water quality tests due to the poor hygienic habits of people using the wells. This is true when thinking of school children coming with soiled hands and collect water from the well. Microbial contaminants are the most dangerous water contaminants to children (Cotton et al., 1995). Most authors, e.g. WHO (1984); Kravitz et al. (1999); Momba and Mnqumevu (2000) and Muyima and Lehloesa (2000) suggest regular water quality assessments of the wells used for drinking water purposes, especiallly in rural areas. This becomes difficult when dealing with an indirect source of contamination like that of poor hygienic behaviour of people.

Well-built latrines have been noted to reduce the possibilities of health risks to public (Cotton et. al, 1995). Such systems exist for the schools in Mbazwana. What is required and necessary now is the education on importance of washing hands after defecation and its relation to water quality. The soiled hands when in contact with water have a potential of degrading its quality hence posing health risks. This is not only the case with water quality, but also with the food the children may come into contact with. When this happens it becomes a problem since children are not resistant to diseases related to poor water quality.

5.2.8 A critical view on sanitation, public health and groundwater protection within a South African context

In South Africa sanitation is attached to water supply and that makes sanitation being less considered than water supply to people (DWAF, 1994). This is shown by the number of reported outbreaks of waterborne diseases in the rural areas of this country, which are frequently reported on television and newspapers, e.g. City Press (05/05/2002). Despite the good work on rural water supply presented to world countries, the question still remains 'Are we doing our level best on sanitation?' 'Is there any progress on the implementation of policy on the sanitation side?'. Several drawbacks can be outlined leading to poor progress on sanitation in comparison with water supply (DWAF, 1994). To mention a few; When defining sanitation many attributes are incorporated, in such that even the NGOs/ contractors helping on rural sanitation programmes cannot have an effective focus on all these attributes (i.e. education on hygienic practises, health education etc). As a result of this, outbreaks of waterborne diseases reported are not due to lack of proper sanitation but poor practices of sanitation. Poor in the sense that latrines may be found but other attributes of sanitation (as defined in section 5.2.5) are those poorly practised or not practised at all. This depends on the understanding of the people in the community and their willingness to accept technological advancement, although this does not mean modernised technology advancement. The policy principles on sanitation support the improvement on sanitation that is responsive to the demands of people as well as supporting the intensive health and hygiene programme (DWAF, 1994). A problem arises when it comes to implementation, as the contractors, especially in the rural areas, lack experience with health and hygiene programmes. As a result, the community members do not see the significance and importance of employing good hygienic practises. Besides that, a communication gap between the health workers and people responsible for construction of latrines always exist in such that the public do not get the clear message with regard to relationship between sanitation practices, hygienic practises and health benefits (Pearson and Morgan-Ramahotswa 19..). It has been noted that a holistic approach is required for any programme being implemented thus ensuring provision of services to people (DWAF, 1994). Such an approach for sanitation exists, but is associated with many problems that hinder its success in such that progress cannot be observed. Therefore, it is important to look for flaws and introduce corrective actions within any programme involving public health.

From the above, it can be said that protection of the water resources requires simple tools and innovative ways to be achieved. Protection of the water resources not only requires protection of the resource but the public health as well. When a sanitation programme encompassing all its attributes is implemented, protection of public health as well as of the water resources are considered.

5.2.9 Background on engineering and construction of the wells

The wells existing in the Mbazwana area are mostly tube wells constructed by hand auguring. This method is only applicable in areas with shallow groundwater and where there is unconsolidated material for easy auguring. A small diameter borehole is hand-augured until the water table is reached. Then PVC casing is installed, with bidim applied at the base of the well to avoid sandy material entering the well. A tripod is placed on the ground to allow the drilling rod to go straight down while the base plate safe-guards against incoming sands, as shown in Figure 5-10.

Figure 5-10 Construction of tube wells.

When the well is finished it will have two poles joined by a windlass, which is connected to a bucket (steel bucket) by a rope. The length of the rope depends on the depth of the well. When fetching water, the windlass allows the bucket to go down into the well until it reaches the water. Once the bucket reaches the water, the valve at the bottom of the bucket flips up to allow water to full the bucket.. When winding up the bucket, the valve flips back, thus closing the bucket for water to prevent leakage. The maximum volume of water that can be fetched per cycle is five litres. When the well is not in use there is a cap that closes the well to avoid contamination. The bucket is normally kept inside the well. Around the well an apron (like a drain) is built to drain wastewater away from the well (Appendix B).

In the case of ring wells, a difference is observed where these types of wells comprise a large diameter of approximately 1.5m. Instead of casing, large rings are used as the well is dug down until water table is reached. The rings are installed in such that they go approximately a meter below the water table. At the base of the well a bidim is placed to avoid accumulation of sand (Deverill et al., 1999a). On the surface a concrete cover is built to cover the well, but an opening of approximately 0.5m is left to allow a bucket to go down when fetching water. The windlass, concrete poles (i.e. these are built to ± meter up) and the bucket are connected together through a rope. When the well is not in use a wooden cover is used to protect the well. Unlike the tube wells, the bucket in ring wells is left hanging outside the well. From the groundwater monitoring conducted by Deverill et al. (1999b), it was found that the ring wells mostly test positive on microbial tests. The construction of these wells was terminated, with the result that there are very few in the Mbazwana.

Issues relating to the state of hygiene of the ropes used to connect the bucket are still under question. This was mostly encountered in community wells where the ropes were found torn and worn off or joined with tiny untidy pieces of ropes. Very few cases like the ones mentioned above were encountered in family owned wells. In the case of chains used instead of ropes, rusting seemed to be a problem. Furthermore, in the case of community tube wells, wastewater was in most cases found damming around the well. The apron that drains water away from the well was found damaged in many instances, and the buckets were not working properly in some cases. Problems such as buckets not working properly or the bucket reported have fallen in the well were the hindering factors to sampling of the wells.

5.3 Results and discussion

5.3.1 Introduction

Sanitation as well as safe drinking water have been noted to be the problem in most developing countries (Kravitz et al., 1999). South Africa is not an exception. Here these problems are addressed, but solutions to one (i.e. sanitation) tend to have negative effect on the other (i.e. water supply). This is the case in Mbazwana, a small town in northern KwaZulu-Natal, where Mvula Trust is assisting with the water supply and sanitation requirements of this area. The sanitation programme is based on the development of pit latrines for the community (families) while water supply is based on the construction of wells in the area. A growing concern has arisen about the pit latrines used in this area and their effect on groundwater pollution as the area has shallow groundwater (i.e. water levels range between 4-20m below ground level). Due to varying amounts of rainfall, people in Mbazwana mainly rely on groundwater as water supply.

The Water Services Act (1997) has acknowledged the provision of safe drinking water and sanitation as important for well-being. Furthermore, public health is one of the major points of concern in this country. It is for these reasons that legal steps towards water resource management, i.e. the protection, conservation and management of water resources from quality deterioration as well as depletion are followed.

5.3.2 Results

5.3.2.1 Microbial water quality

A total of 52 samples mainly from domestic sources in the Mbazwana villages were collected during November 2000. A total of nine villages were considered and the number of available wells per village determined the sampling protocol, with a minimum of 5 wells sampled per village. As mentioned earlier, sampling was done for both microbiology and physico-chemical analyses. For microbiology analyses, the H_2S strip method was mainly used, although the standard method was considered at a later stage. The samples for microbiology analyses (H_2S strips) were incubated at room temperatures (i.e. $\pm 24^0$ C). After every 24 hours, for the period of 72 hours, the samples were checked for any colour change, i.e. production of black precipitate[2] within this period. The samples that showed blackening over the specified period are presented in Appendix C. The table shows all the tube wells sampled as well as those tested negatively. From the results almost all community tube wells tested positive from the experiments of bacteriological water quality assessment. Ring wells and open wells tested positive for the bacteria of faecal origin. In the case of ring wells and open wells, it was expected that they might test positive to microbial or H_2S strip tests since well disinfection prior to sampling was not done. This means that bailing was not considered and therefore only stagnant waters were sampled.

In the case of samples collected from the nine villages shown in appendix C, only samples from Manaba, Oqondweni and Manzibomvu villages were analysed using the standard methods of microbial water quality analyses. The results of the analyses for samples from these three villages are shown in Table 5-2. In Oqondweni and Manzibomvu villages, the standard method of microbial water quality analyses was used as a follow up to the H_2S strip method. This follow up was only considered for the wells that were sampled for H_2S strip method. The few wells that did not show positive tests for H_2S strip method showed growth of micro-organisms of faecal origin during the second round sampling. This sampling followed after heavy rains in the area.

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[2] Black precipitate indicates pollution of water by bacteria of faecal origin.

DATE	LOCATION VILLAGE	SITE	WELL TYPE	E. COLI STRAINS (CFU/10ML)	E. COLI STRAINS (CFU/100ML)
24/11/01	Manaba	Manaba 2	CTW	17	60
24/11/01	Manaba	Dlamini B	FTW	0	0
24/11/01	Manaba	Manaba 1	CTW	0	8
24/11/01	Manaba	Manaba P. school	CTW	70	>500
24/11/01	Manaba	Ndlazi EM	FTW	2	11
27/11/01	Oqondweni	Oqondweni	OW	1	6
27/11/01	Oqondweni	Oqondweni	CTW	3	21
27/11/01	Oqondweni	Nxumalo	FTW	5	45
27/11/01	Oqondweni	Zabalaza	FRW	33	>100
27/11/01	Oqondweni	Izikhali	FTW	0	0
27/11/01	Manzibomvu	Manzibomvu	CTW	10	17
27/11/01	Manzibomvu	Manzibomvu	CRW	ND	ND
27/11/01	Manzibomvu	Nsele	FTW	ND	ND
27/11/01	Manzibomvu	Siphizikhali	FTW	1	4

Table 5-2 Results of faecal coliform tests conducted for selected villages in Mbazwana.

OW – Open well	FTW – Family tube well
CTW – Community tube well	FRW – family ring well
CRW – Community ring well	cfu –Coliform forming unit
ND – Not determined	

Since public health is one of the critical and important issues of concern in South Africa, it was also given consideration in relation to water supplied to people. The local health centre at Mbazwana was visited to find out if there are any reported cases of waterborne diseases where the communities complain of poor water quality. In this regard, the diseases that were given attention include cholera, diarrhoea and typhoid fever. The cases for reported diarrhoea for the Mbazwana area for the year 2001 are presented in Table 5-3. Only the statistics for the months shown was available. The statistics shown is for children (≤ 5yrs) and adults (>5yrs)[3].

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[3] These are the classes existing in Mbazwana health centre with these age divisions, therefore the data could not allow for the third class.

MONTH	CHILDREN <5YRS	ADULTS >5YRS
January	36	52
February	12	32
March	45	77
April	23	30
May	31	29
June	33	40
July	43	43
August	17	33
September	13	46
October	16	19

Table 5-3 Cases of reported diarrhoea in Mbazwana for the portion of 2001.

The data presented in Table 5-3 includes the number of HIV/AIDS cases, which have been observed to increase the number of those suffering from diarrhoea (Ntsele and Zikhali pers. comm., 2001). Cases of dysentery have, however, been encountered in children. Therefore, conclusions about the degree of health risk the water of the Mbazwana area is posing to the people could not be reached.

Regarding the other diseases, i.e. cholera and typhoid fever, few cases have been reported with an average of one in six months, while for typhoid fever no cases have been reported.

5.3.2.2 Physico-Chemical water quality

The physico-chemical parameters of groundwater samples from the Mbazwana villages are presented in Appendix C. In terms of the general characteristics of the samples collected, the water has a good taste and is odourless. Most of the samples were clear although in few instances a light brown colour was observed. The pH of water (all samples) range between 5 and 6.5, i.e. the pH is slightly acid (Figure 5.11).

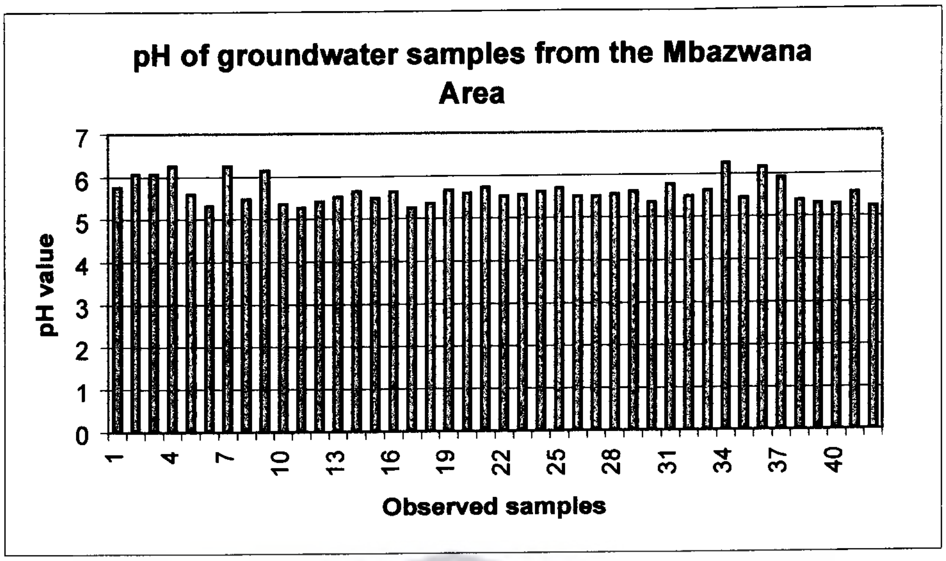

Figure 5-11The observed pH values from the groundwater samples of Mbazwana

The electrical conductance (EC) range between 11.5 and 42 mS/m and these values comply favourably with the standards for drinking water quality (Figure 5-12).

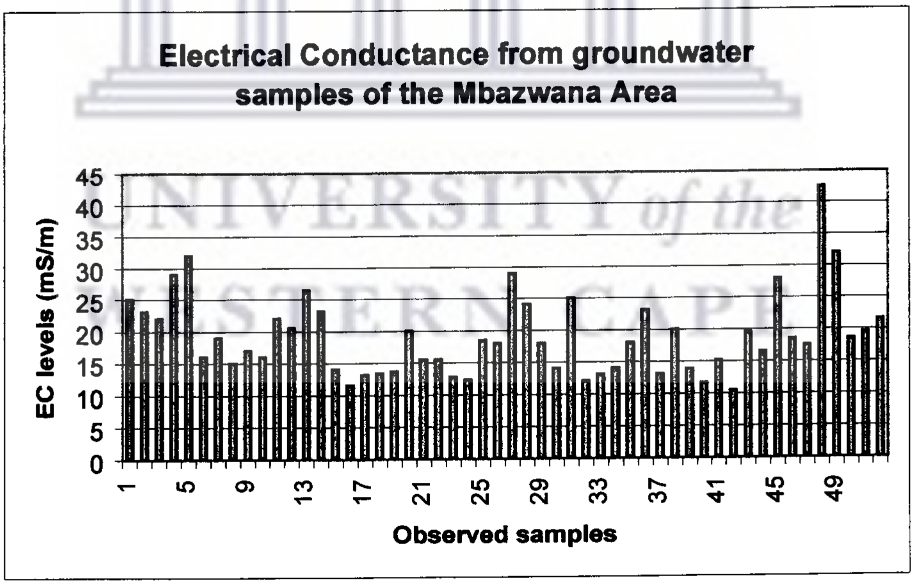

Figure 5-12 EC values from the groundwater samples of Mbazwana

The Total Dissolved Solids (TDS) values fall within the specified standards of drinking water quality, i.e. less than 450mg/L (DWAF, 1996) as illustrated in Figure 5-13.

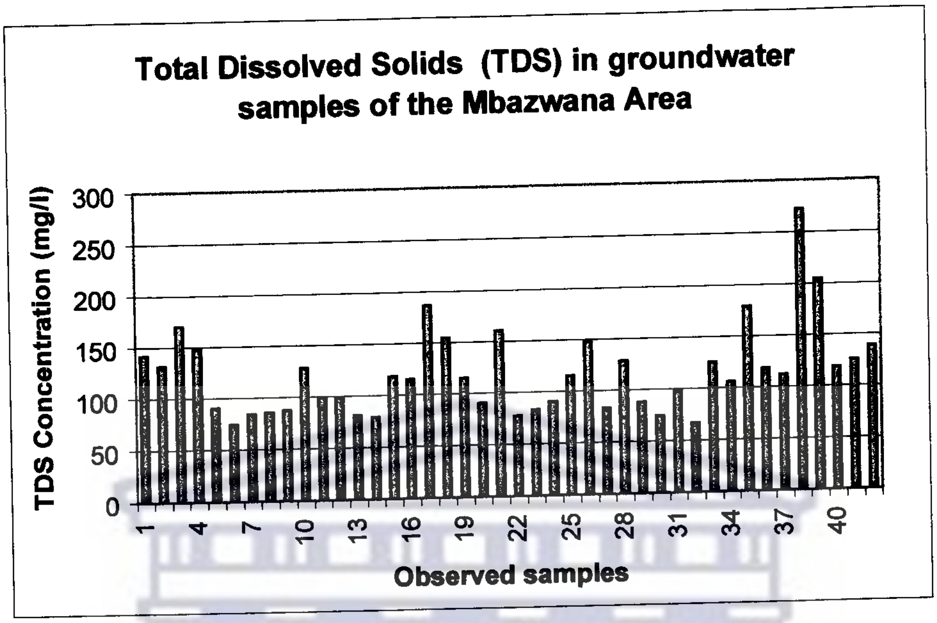

Figure 5-13 The observed concentration of Total Dissolved solids from groundwater samples of the Mbazwana Area

The Dissolved Organic Carbon (DOC) content from the analysed samples fall within target limit i.e. less than 5mg/L (Figure 5-14). Only one sample exceeded the limit value by 1.2 mg/L, which cannot pose serious health risks. The temperatures of the sampled water in the Mbazwana area range between 24^0C and 27^0 C, which is still an acceptable range for drinking water.

The nitrate concentrations were very erratic with average concentration of 1.6 mg/L (Figure 5-15). The concentration values of nitrates were below the limit value (6mg/L) of South Africa water quality guidelines, with few wells exceeding the limit (Figure 5-15). Generally, the nitrate levels observed probably do not pose health risks to people as they still fall within the tolerable limits, i.e. 6 – 10mg/L (DWAF, 1996).

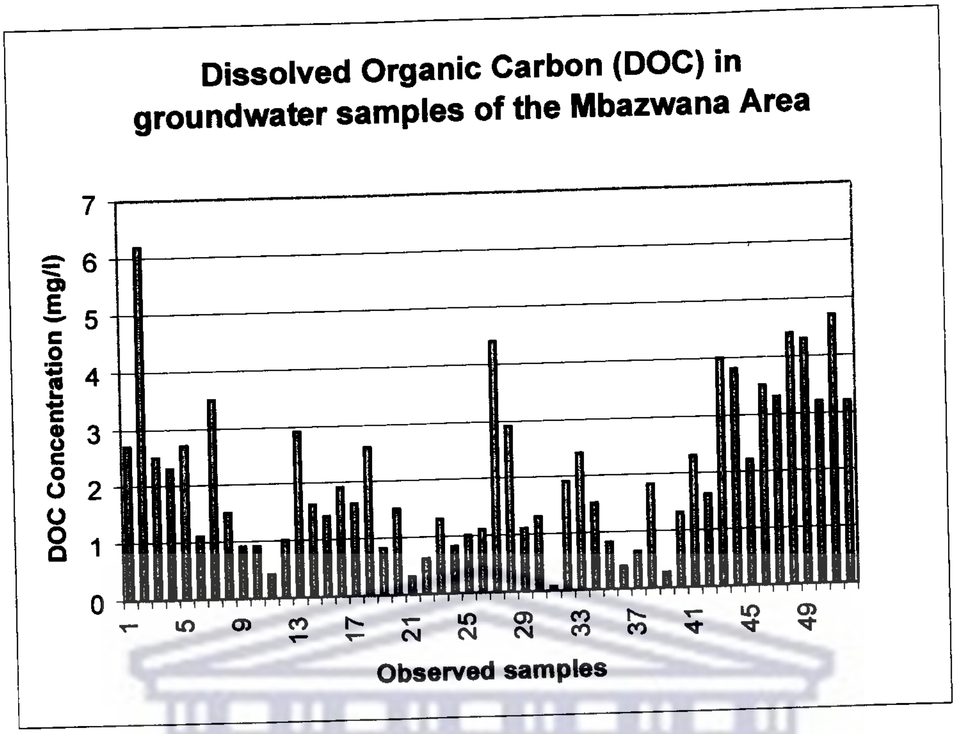

Figure 5-14 The content of Dissolved Organic Carbon in groundwater samples of the Mbazwana Area

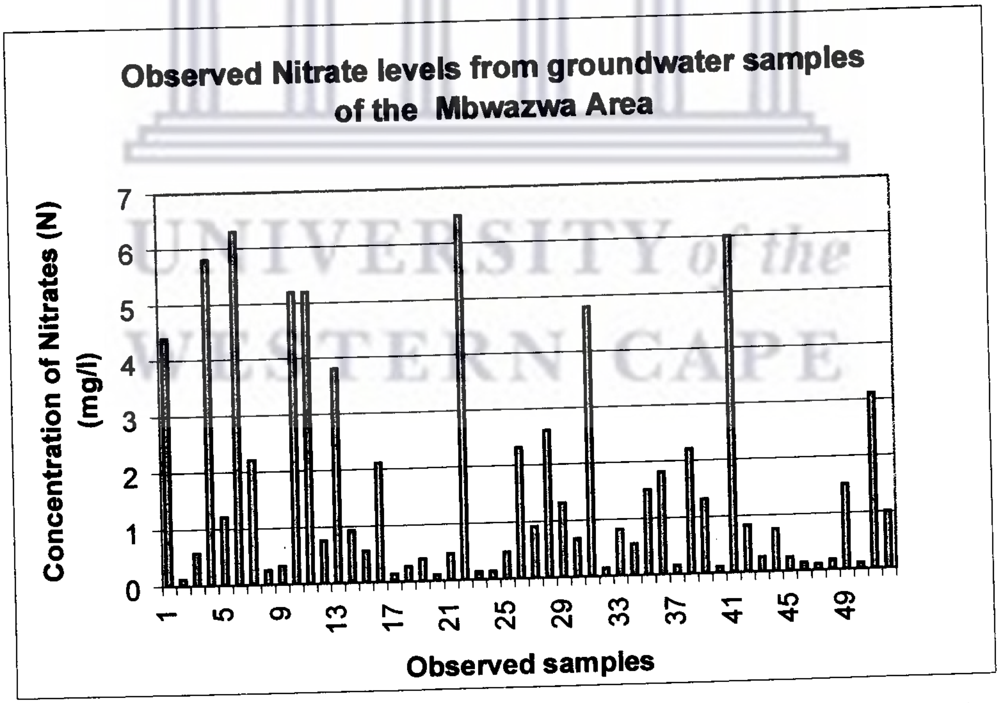

Figure 5-15 The observed nitrate levels from groundwater samples of the Mbazwana Area

5.3.3 Discussion

From the results presented above, quantification of the degree of pollution of groundwater in the Mbazwana area is achieved. Blackening of the water samples collected from various villages in Mbazwana reveal contamination of groundwater by bacteria of faecal origin. From the results, a total of 61% of the sampled drinking water showed to be contaminated. Domestic water supplies in the Mbazwana appear to be severely contaminated and pose a significant health risk to the communities.

The community tube wells are the wells mostly testing positive to the experiments conducted (i.e. H_2S strip method). This may be related to poor hygienic status of the equipment used to collect water from the well. In this regard, a reference is given to ropes used to link the bucket to a windlass as well as the bucket itself (i.e. equipment used at well site to collect water). Furthermore, the wasted water around the well has a potential of infiltrating back thus polluting the resource, particularly considering the fact that this is a shallow groundwater system (i.e. ±4m below ground level). In some cases, livestock watering (i.e. specifically cattle) results in damaging of the apron that drains the wasted water away from the well hence inducing spillage around the well. In general, it can be said that inadequate protection of water resources (i.e. lack of well head protection) results in groundwater contamination.

Ring wells and open wells they all tested positive to H_2S strip tests conducted. This may be a result of not purging the well prior to sampling. Further, the open wells are not covered in such that they attract locusts and other insects to float on water. In addition, when collecting water from the well, each community member comes with her own collection vessel to drop down the well. The collection vessel is placed on the ground prior to being dipped into well. This results in contamination of the water as these buckets differ in its hygiene state.

Furthermore, soiled hands may have a great contribution to contamination of the water as was encountered when children collected the water.

Considering the results of the standard method of microbial water quality analyses obtained from these types of wells (i.e. open wells and ring wells), the number of micro-organisms of faecal origin (i.e. E.Coli) that showed growth was less than expected. The high number of micro-organisms that showed growth was that of total coliforms. This confirms the various sources of contamination of water in these wells, since they are not protected nor covered.

When re-sampling was done in Oqondweni and Manzibomvu for the standard method of microbial water quality analyses, some of the tube wells that tested negative on the H_2S strip method showed growth of micro-organisms of faecal origin. This re-sampling followed after heavy rains in the area. Kravitz et al. (1999) noticed that the potability of water tends to deteriorate during rainy months because bacterial contamination increases. Such heavy rains results in a high infiltration of water that carries all the dirt from the surface to groundwater. The case in the Oqondweni and Manzibomvu villages confirms the findings of Kravitz et al. (1999).

The standard method of microbial water quality analyses (although it was only conducted in few villages) allowed the comparison of the results with drinking water quality standards. The samples analysed proved to be unsuitable for drinking as the micro-organisms counted exceeded the specified value (0cfu/100ml) for safe drinking water (Table 5-2).

In the case of privately owned (i.e. family owned wells), those that tested positive to the H_2S strip method were mostly found close to the pit latrines (i.e. ±60m). The pit latrines induce contamination of groundwater while the shallow groundwater system permits short-circuiting of natural attenuation process to remove faecal micro-organisms hence resulting in groundwater contamination.

Furthermore, point source pollutants (in this case pit latrines) have been noted to have a high risk of contaminating groundwater (Cotton et al., 1995). This has been confirmed by the H_2S strip method used to assess the microbial contamination of water in Mbazwana where water samples collected from wells close to the pit latrines showed blackening within 24 hours of incubation (room temperatures used) thus indicating faecal contamination.

Groundwater in the Mboma village (where all samples collected tested negative on H_2S strip method) is protected through adequate filtration of the dissolved substances by the sandy soils of this region since the water table in this village is very deep (±17m below ground level), as compared to other villages with water table ranging between 4 and 12m bgl. The decay of bacteria of faecal origin during its travel time to groundwater is possible especially if the water tables are deep. The unconsolidated material has been noted to provide an effective attenuation buffer that removes faecal micro-organisms and induce the decay of chemical compounds (Engelbrecht and Tredoux 2000, Xu and Braune 1995). This might be the case in Mboma where there is thick unconsolidated material.

Studies by Deverill et al. (1999a) on soil analysie of the Mbazwana area revealed that the grain sizes of the soils range between 0.14 and 0.18mm and are rounded. In their study a flow rate of 0.18m per day was postulated with an average gradient of 0.012 (calculations based on Darcy's Law). Considering these flow rates, the depth to water table and the grain size of the sands for the study area, it means it can take longer period for pollutants to reach groundwater as in the case of Mboma. In other villages shallow depths to groundwater allows for the relatively short travel times of contaminants hence leading to groundwater contamination.

5.3.4 Standardization on land use practices

Contaminants in their natural state can occur in many forms (Todd, 1976). They may be diffuse or point sources, diluted or immiscible. The contaminants require restrictions and monitoring from their source in order to avoid resource degradation. Such restrictions need collaboration work from the environmental perspective to ensure the water resource protection. The following is proposed:

- Protection in terms of environmental legislation as with case of urban development.
- Incorporation of legal environmental aspects with development and water supply programmes for the area of concern, e.g. Inter-institutional cooperation where the institutions define common goals with the aim of protecting groundwater in terms of development (Scharp, 1999). This should take into account the vulnerability of water resources within an area. Therefore, evaluation and assessment of contamination loads are required. In this regard, DWAF outlined the main sources of pollution that needs attention including agricultural, industrial, mining, urban development and waste disposal or effluent discharge. The aforementioned sources of contamination need restrictions in terms of zones assigned for protection.
- The strictest regulation in the vicinity of the abstraction point (i.e. fencing can be the option to prohibit unauthorized entry). The onus lies with the owner of the well.

When regulating land-use practices, difficulties with current land-use practices are encountered (Scharp, 1999) that is difficult to prohibit through legal means. Therefore willingness of the parties involved to undertake mitigation measures can lead to great awareness about resource protection, hence complying with regulations. Future planned activities can be easily regulated and probihited within a zone assigned for protection. In such, the methodology to be followed during development should show a layout that takes into account protection of groundwater. Further, the involvement of people interested in groundwater protection and management who in future can be the protection planners will need to be ensured (NWA, 1998).

5.3.5 Resource Quality Objectives for the Zululand Coastal Aquifer

Having pursued the study in the Zululand region, a set of guidelines on how to manage, conserve, preserve in a desired state, as well as to utilize the groundwater resources need to be set. This cannot just be set based on expert judgement, but needs practical assessment, as the study is conducted to assess current conditions of the area. Since the study is based on water quality issues, the RQOs set will be stringent in order to maintain and improve the groundwater resources of this region (Zululand region). Based on research the following can be set to be as guiding rules to maintain the groundwater resource in a desired state.

- In terms of chemical reference conditions; chemistry data used to plot the piper and fingerprint diagrams revealed that $Ca(HCO3)_2$, $NaHCO_3$ and NaCl water types exist in the northern KwaZulu-Natal region (these water types considers different hydrogeological formations in northern KZN). The quality objectives (i.e. guiding rules) set for this is that there should be no change from the reference conditions, i.e. no deviations from reference conditions, that would mean a change in water quality.
- With regard to the microbial water quality; the guidelines for drinking water quality will still be useful thus ensuring that the water is suitable for drinking without posing health risks. This means that at least the target should be zero micro-organism of faecal origin in water. With respect to total coliforms, a value of less than 5cfu/100ml will be tolerable.
- According to the categories of modification for water resource units by Xu et al. (2001b); the groundwater resource of the northern KwaZulu-Natal region can be classified to fall within category C. This means that the water resource is moderately modified, with moderate changes apparent.

These modifications are mainly on the microbial water quality side. The target should at least be category B, where natural conditions are maintained, with few localized modification observed, but no negative effects apparent. This will at least ensure that water supplied to public is unlikely to pose health complications.

- Based on the groundwater flux to the river; the water levels should not vary more than 50% of annual rainfall, or else that would mean a change in aquatic ecosystem, since groundwater contribution to stream flow would be insignificant. If there is understanding that groundwater has an important contribution to the ecological value, then an increasingly importance on functioning of the resource is required, hence allowing the ability of the groundwater resource to buffer and bridge the periods of droughts.

6 CONCLUSIONS AND RECOMMENDATIONS

This thesis focuses on the protection of groundwater resources based on water resource monitoring. The procedure on how and why to conduct monitoring is provided as well as the necessary steps that incorporate the protection of water resources. A comprehensive methodology that accommodates several hydrogeologic scenarios as provided in chapter 4 is proposed. The methodology designed ensures a continuing process for resource protection and allows for potential polluting agents to be pinpointed. The methodology can be verified and improved through more case studies in future.

Regarding the case study, it is noted that the bacteria of faecal origin contaminate the drinking water in the Mbazwana area. The factors leading to this are noted in the preceding chapter (I.e. chapter 5). These are related to development taking place as well as improper household (i.e. community sanitation) and poor hygienic behaviour of people. This can be improved by educating and engaging women and children, since they are involved in water collecting activities, in primary health education programmes as well as teaching them about the importance of clean drinking water for health purposes. The programme should be practical-based with a cost-effective approach, thus ensuring prevention of risks associated with waterborne diseases. This can reduce the number of diarrhoeal sufferers, especially among children, as well as the diseases associated with poor drinking water quality.

Sanitation is another problem resulting in groundwater contamination in Mbazwana. This needs consideration regarding the minimum distances between the pit latrines and the wells. The guidelines on water supply and sanitation by Xu and Braune (1995) can be useful in this instance. Having conducted the study and fieldwork in the Zululand Coastal aquifer, the minimum distance between a pit latrine and the well can be set at 180m, considering the fact that the area has shallow groundwater (±4m bgl) and groundwater flow velocities of 0.18m/d (Deverill et al., 1999). This will mean that a 30-day travel- time is calculated for contaminants to reach groundwater (i.e. water table). Within this period, the decay of bacteria of faecal origin is possible. Furthermore, considering the filtering effect of the sands of the Zululand Coastal region, the decay of bacteria within the unsaturated zone is possible. This zone is regarded as sensitive and therefore land-use practices should be managed strictly.

Thickness of 2 -3m of soil or fine sand is adequate as an effective filter especially for pollution from micro-organism of faecal origin (Engelbrecht and Tredoux, 2000). The situation differs when there is pit latrines built in areas of shallow groundwater, e.g. KwaZulu-Natal, where groundwater levels may be encountered at ±4m bgl. In instances like these, the depth of pit latrine may be approximated to be 2 -3m, meaning that only a metre of soil is left to filter material that is flushing downwards. This may not be enough as it is difficult to estimate the load of polluting material being flushed.

Rivett –Carnac (1989) proposed a minimum distance of 30m for a well from the pit latrine for Natal. His results were based on experiments conducted upstream of the source of pollutant. The proposed distance considers both the low-lying areas and downstream reaches where groundwater is relatively shallow. What should be noted about the distance is that it only considers protection against microbial water contamination. Other sources of contamination like oil spillages that can persist for a quite longer periods and are non-biodegradable are not considered (Todd, 1976). In this case, only the soil properties and velocity at which the contaminants move is given attention. The distance set also assumes that the area is homogeneous in terms geology and fairly vulnerable (considering land-use practices of the Mbazwana area).

Poor hygienic practices and improper sanitation practices, as mentioned earlier, are the underlying cause for contamination in the Zululand region. Resource Quality Objectives are set to correct for the latter. The question is 'Is this enough to ensure non-degradation of water quality resources for this region?' RQOs are defined as guiding rules that protect resources at large by setting them to be stringent towards the resource being protected. Still problematic is how to ensure that these guiding rules are met. This requires practical based methods thus ensuring that water resources are protected. An example is the delineation and setting of wellhead protection areas or zoning (WHPA). This mainly proposes the distances between the well and possible polluting sources as proposed above. The underlying principle is to look at time of travel of contaminants that are likely to pollute groundwater. The WHPA does not only consider the time of travel of contaminants, but the activities taking place around the well and the condition of the pump (well), i.e. first and second tier protection concept as proposed by Xu and Braune (1995) or the source site and inner protection area as proposed by Daly (1995). Therefore, the minimum distance set above for the KwaZulu-Natal Coastal region is a basic protection method to avoid contamination as well as land-use practices in the vicinity of the abstraction point. It is preferred to issue stringent restrictions on land-use practices taking place around the well or well zone to avoid contaminants entering the subsurface and finally reaching the well. In this regard, the wellhead protection area as well as the time of travel of contaminants set will serve as effective tools that ensure that the RQOs are met. This zoning (or protection area) takes into consideration the land-use planning and practices discussed in section 5.1.6 thus ensuring prevention of conflicts between incompatible land-use and overcrowding (Daly, 1995).

With regard to open defecation system, which is seen as another problem, homeowners, especially in rural areas, should be encouraged to move towards better sanitation practices, such as pit latrines. On the technical side, advice and support on the treatment of water in wells (e.g. use of jik once in two weeks) should be the aim towards improving public health. The steps to do this can be outlined as follows:

- Add 10ml of Jik in a 5L bucket of water

- Plunge the solution into the well. Do this two to three times to allow mixing of Jik with the water.
- Cover the well for 30 minutes to an hour to allow reaction of Jik with water as well as allowing bacteria to get destroyed.

Other than that, boiling of drinking water prior to use can be effective in elimination of bacteria.

The H_2S strip method has proven to be a reliable technique in terms of to surveying the quality of water for domestic use in remote areas. The method proved its accuracy by detecting organisms of faecal origin in small volumes of water (i.e. 20ml). This has been tested in the rural areas of the northern KwaZulu-Natal region, where it proved successful, providing qualitative results on drinking water quality assessments. The results of chemical water analyses revealed that water is suitable for drinking.

Setting of the Resource Quality Objectives is important for the protection of not only groundwater resources, but also for protection of water resources at large. Establishing the water quality, allows for the background guiding rules to be set thus ensuring the proper management of water resources as well the long-term sustainability of water resources. The H_2S strip method is a powerful tool when used on raw water source (Dutka et al., 1998). Powerful techniques on viral detection are being developed (Ford and Colwell, 1996). These may assist in final water quality assurance, supplementing the methods used in this study. The current methods employed assisted in the protection of the water resources, thus ensuring that the water supplied to people is of a desired state through the detection and elimination of possible contaminants.

Based on the study conducted the RQOs set can be useful to:

- Environmental maintenance and ecosystem functioning
- Holistic management of water resources
- Proper utilization of the water resources, without deterioration and degradation in their quality and quantity.

- Resource sustainability for future generation.

From the above points, it can be said that implementation of Resource Quality Objectives and groundwater resource quality monitoring means a closure of the gap between utilization of the resources and its sustainability.

7 GLOSSARY

Autoclavable bottles: Certain type of bottles that can allow chemical reaction at high pressures and temperatures.

Bacteria: Single-cell microorganisms lacking complex cellular structures.

Bacteriophage: A form of virus, which attacks bacteria

Bidim: A form of cloth that is used as filter (i.e. filtering) when constructing wells. It is normally applied at the base of the casing so that when pumping water, sand does not come out.

Biochemical oxygen demand (BOD): Amount of dissolved oxygen consumed in five days by biological processes breaking down organic matter.

Biodegradable: Substance capable of being decomposed by biological processes.

Biofilm: Microbial cells encased in an adhesive, usually a polysaccharide material, and attached to a surface.

CFU (Colony forming unit): The single cell or clump of cells which gives rise to one colony. This term is used to indicate that not all cells manage to survive plating, and also that when cells tend to clump together (be in physical contact), a single colony will arise even though many cells may have been initially at the site of the colony.

Coliform: Gram-negative, non-spore forming rods which produce gas and lactose during fermentation.

Coliform bacteria: Non-pathogenic microbes found in faecal matter that indicate the presence of water pollution; are thereby a guide to the suitability for potable use.

Colony: The cells arising on a plate (solid growth medium) from a single cell (or a collection of cells which were stuck together). Usually grows as a slightly raised circle.

Culture: A liquid suspension of cells. Usually means the cells, which grow in a given piece of glassware containing medium; sometimes is also used to mean cells growing on a solid medium.

Diarrhoea: A gastrointestinal disorder in which one has frequent liquid bowel movements.

Dielectric: A measure for the effect of a medium on the potential energy of interaction between two charges. It is measured by comparing the capacity of a capacitor with and without the sample present.

Dysentery: In simple terms it can be referred to as type of diarrhoea containing blood.

E. coli: The most commonly studied bacterium. Why? Because it grows very rapidly at 37 degrees Celsius (body temperature) and because it is of interest for sanitation studies.

Ecosystem: Groupings of various organisms interacting with each other and their environment

Fermentation: A reaction, occurring in the absence of oxygen or when very little oxygen is present, causing complex organic molecules to split into simpler molecules especially, in production of alcohol from sugars.

Inoculation: To seed something; the introduction of a substance which results in a biological response

Lag phase: The initial growth phase, immediately after inoculation, in which the bacterial population is growing at less than an exponential rate, because they are adjusting to the culture, are sparse in number, and are not multiplying at their maximum rate.

Latrine: A place/ building not normally within a house or other buildings for deposition, retention and decomposition of excreta/ human waste.

NWA: A Water Act passed in 1998 to ensure protection, management, conservation and usage of water resources thus ensuring that water resources are maintained in a desired state of the environment and the ecosystem is not degraded.

Microorganisms or **Microbes**: Living organisms too small to be seen by the naked eye with three exceptions: viruses, which are not really alive, but microscopic; helminth worms, which are not always microscopic in size and some insects, which, although visible, carry microscopic agents of disease.

MPN index: Most Probable Number of coliform-group organisms per unit volume of sample water. Expressed as a density or population of organisms per 100 mL of sample water

Open defecation: A form of sanitation practice where one deposits the human excreta in an open bare space.

On-plot sanitation: Sanitation systems, which are contained with the plot occupied by the dwellings. On plot sanitation is associated with household latrine, but also includes facilities shared by several households living together at the same plot (Cotton et al, 1995)

Pathogen: A microorganism associated with disease in man.

Pollution: An action that would lead to quality deterioration of a resource.

Potable water: Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking.

Reserve: According to NWA (1998) it is defined as quality and quantity of water required to satisfy basic human needs and to protect aquatic ecosystem

Resource Quality Objectives: Rules and regulations set so to maintain, manage and conserve resources in desired state and sustainable manner thus ensuring that the current and future generations benefit.

Sanitation: Collection and disposition of excreta and community liquid waste in hygienic way so as to not endanger the health of individuals or the community as whole.

Source Directed Measures: incentives aiming at protection of water resources by controlling both the point and non-point pollution by means of authorization.

Water quality: The chemical, physical, biological, and radiological condition of a surface or ground water body.

Water quality degradation: The impairment (reduction) of water quality by agriculture, domestic or industrial wastes (including thermal and radioactive wastes) to such a degree as to hinder any beneficial use of the water or render it offensive to the senses of sight, taste, or smell or when sufficient amounts of waste creates or poses a potential threat to human health or the environment.

Water resources: A term referring to watercourse, surface water estuary or an aquifer (NWA, 1998)

Water Services Act: A water policy set in 1997 that entitles people to adequate supply and equitable share of water that is unlikely to pose health risks and proper sanitation.

Water well: An artificial excavation constructed for the purposes of exploring for or producing groundwater (Glossary of Water resource Terms).

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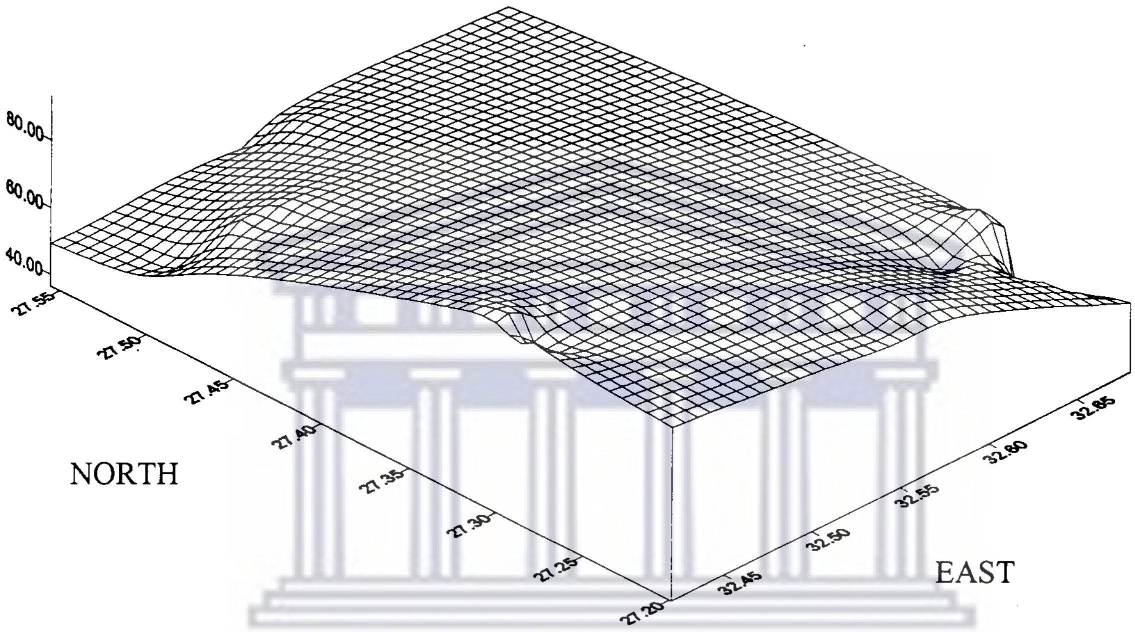
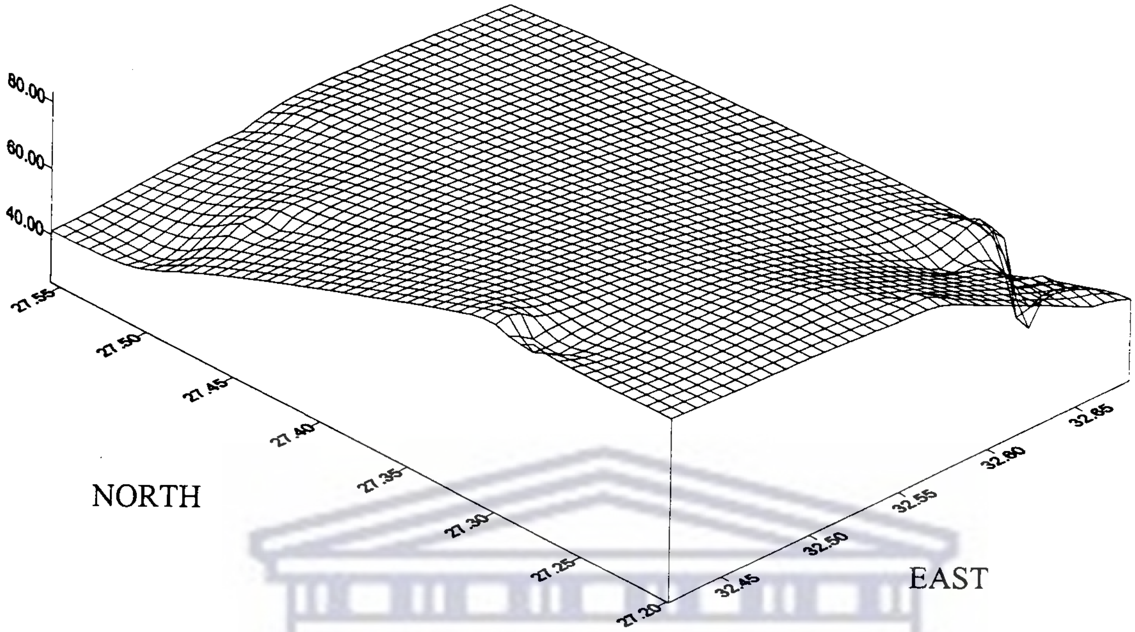
9 APPENDICE

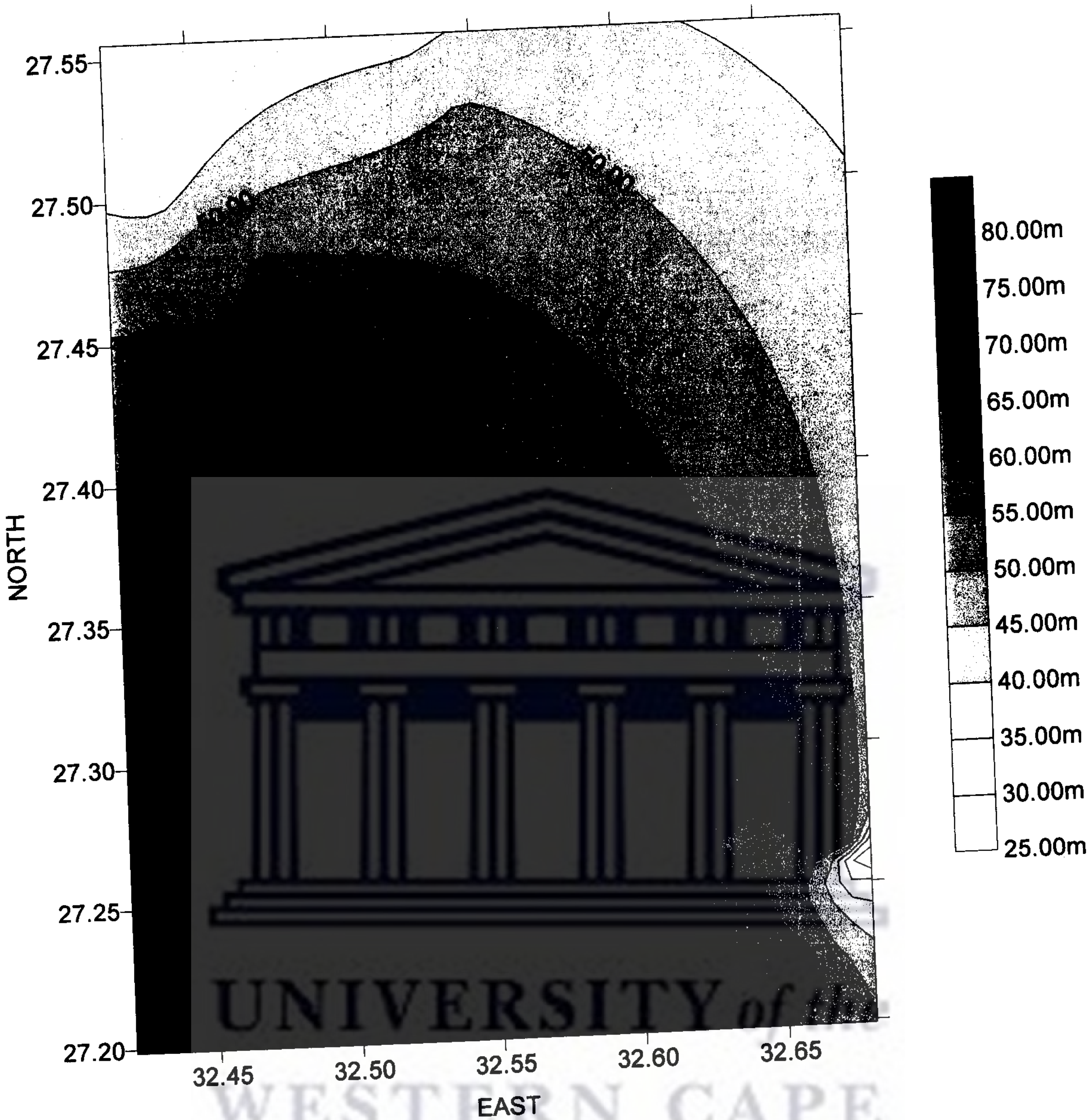
APPENDIX A



A topographical plot of the Mbazwana Area, Northern Zululand. The information is obtained from the Topo- maps of the Mbazwana Area.



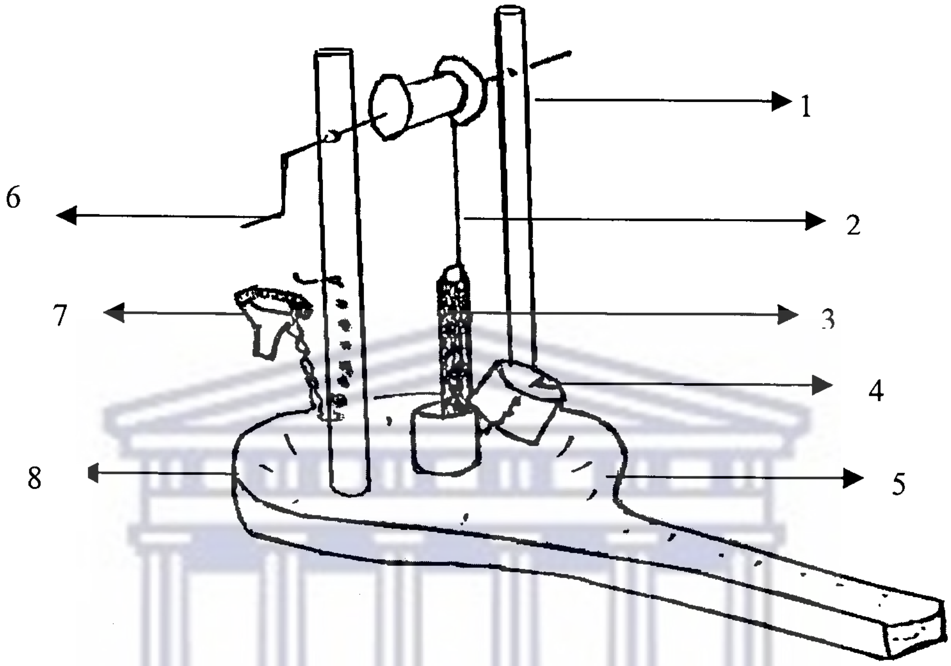
A 3D plot depicting groundwater levels (measured in relation to mean sea level) for the Mbazwana Area, Northern Zululand coastal region.



Graphical representation of groundwater levels, above mean sea level for the Mbazwana Area, Northern Zululand.

The above three diagrams show the relationship between the water levels and the topography. The groundwater levels are measured in relation to mean sea level. From the diagrams it can be clearly seen that the groundwater flow mimics the topography. The flow of groundwater is towards the east i.e. towards the sea. The regional flow of groundwater can be explained as from the Lebombo Mountains then flow towards the sea (Indian Ocean).

APPENDIX B



Condition of the well / pump (after Deverill et al., 1999b).

1. Poles
2. Rope
3. Bucket
4. Lid
5. Drain
6. Windlass
7. Funnel
8. Apron

Appendix B shows one of the tube wells used for water supply in Mbazwana. During the monitoring period (November, 2001), the above-labelled parts were given attention, i.e. to check if they are not damaged and are still in good condition. Most of the community tube wells were found not to have funnels, lids etc. The ropes were mostly worn out, the drain and the apron damaged. From these, conclusions about the requirements for wellhead protection were considered.

APPENDIX C: Microbial water quality results from the H2S strip method

Location/Village	Site	Well type	Temperature (deg C.)	pH
Oqondweni	Oqondweni	OW	26.7	5.7
Oqondweni	Oqondweni	CTW	26.6	6.0
Oqondweni	Nxumalo	FTW	25.8	6.0
Oqondweni	Zabalaza	FRW	24.8	6.2
Oqondweni	Izikhali	FTW	24.8	5.5
Manzibomvu	Manzibomvu	CTW	ND	ND
Manzibomvu	Manzibomvu	CRW	ND	ND
Manzibomvu	Nsele	FTW	ND	ND
Manzibomvu	Siphizikhali	FTW	ND	ND
Manzibomvu	Mntanenkosi	FTW	ND	ND
Mboma	Ntuli	FTW	ND	5.
Mboma	Nxumalo Mabuto	FTW	ND	6.
Mboma	Zikhali Samson	FTW	ND	6.
Mboma	Ngubane	FTW	ND	5.
Mboma	Thwala	FTW	ND	5.
Siphahleni	Zikhali Sonto	CTW	24.1	5.
Siphahleni	Mthembu	FRW	24.7	6.
Siphahleni	Ncube	FTW	24.9	
Siphahleni	John Zikhali	FTW	25.4	5.
Mthunzini	Qwabe Samuel	FTW	25.6	5.
Mthunzini	Mtembu Lindiwe	FRW	25.5	5.
Mthunzini	Qwabe Lindiwe	FTW	26.2	5.
Mthunzini	Ntembe Amos	FTW	25.3	5.
Mthunzini	Mthunzini	CTW	24	5.
Mphakathini	Ntuli M	FTW	25.7	5.
Mphakathini	Mphakathini	CTW	26.1	5.
Mphakathini	Mphakathini School	TW	27.4	6.
Mphakathini	Nxumalo Nelson	FTW	26.4	5.
Mphakathini	Nsukwini Mkhonto	FTW	25.6	4.
Chith'umzi	Ntuli Mazondo	TW	27.4	5.
Chith'umzi	Manzengweya School	TW	27.2	5.
Chith'umzi	Twala Thokozani	FTW	25.3	5.
Chith'umzi	Twala Amros	FTW	25.5	5.
Chith'umzi	Ngubane SS	FTW	25.5	5.
Chith'umzi	Ntuli Sipho	FTW	26.5	5.
Chith'umzi	Ndlozi Masheshe	FTW	26.4	5.
Chith'umzi	Ntomb'emhlophe School	TW	26.5	5.4
Ngutshane	Zikhali Kenneth	FTW	27.7	5.
Ngutshane	Mdletye	FTW	26.8	5.
Ngutshane	Mthembu Sanele	FTW	26.4	
Ngutshane	Ndlovu Thembisile	FTW	27.3	5.
Ngutshane	Ingutshane	CTW	25.3	5.
Manaba	Mashunguzane High School	TW	25.9	5.
Manaba	Gumede N K	FTW	26.6	5.
Manaba	Ndlovu J	FTW	25.6	5.1
Manaba	Linda T	FTW	25.5	5.
Manaba	Ndlovu N	FTW	24.7	5.
Manaba	Manaba 2	CTW	25	5.1
Manaba	Dlamini B	FTW	25.4	5.2
Manaba	Manaba 1	CTW	25.4	5.1
Manaba	Manaba Primary school	TW	25.5	5.5
Manaba	Ndlazi EM	FTW	24.8	5.4

CTW: Community tube well CRW: Community ring well FTW: Family tube well FRW: Family ring

APPENDIX D

Appendix D shows the wells sampled in Mbazwana (see the table marked Appendix D), Zululand region are included. Also included are the activities taking place around the well and possible underlying reasons for the results obtained. From the results it can be noticed that distance between the pit latrines for particular households and the wells have an effect on results obtained. Furthermore, noticing the results obtained for the Ngutshane and Manaba villages, they mostly tested positive to the tests conducted. The sampling on these villages followed after heavy rainfalls in the Zululand region. The possibility is that the rain carried all the dirt from the surface and flushed it to groundwater. This is true for the Mbazwana area where open defecation system of sanitation is still used. Agricultural practices are unlikely to have an effect on contamination of water since the fertilizers are not used. Further, the nitrate levels, as shown in Appendix C, do not correlate with contamination, i.e. nitrate levels fall within the limits of drinking water quality standards of South Africa.

APPENDIX D: Microbial water quality results from the H2S strip method

Location/Village	Site	Well typ	24hrs	48hrs	72hrs	Activities taking place aro
Oqondweni	Oqondweni	OW	Clear	Clear	**Black**	Well uncovered, grass and
Oqondweni	Oqondweni	CTW	Clear	Clear	**Black**	Condition of the well/pump
Oqondweni	Nxumalo	FTW	Clear	Clear	**Black**	The well is fenced. A kraal i
Oqondweni	Zabalaza	FRW	**Black**	**Black**	**Black**	No bailing of the well done,
Oqondweni	Izikhali	FTW	Clear	Clear	Clear	Kraal situated 45m from the
Manzibomvu	Manzibomvu	CTW	Clear	Clear	Clear	Pitlatrine situated at 250m a
Manzibomvu	Manzibomvu	CRW	**Black**	**Black**	**Black**	No bailing of the well done,
Manzibomvu	Nsele	FTW	Clear	Clear	**Black**	No polluting activities identif
Manzibomvu	Siphizikhali	FTW	Clear	Clear	**Black**	No possible activities that m
Manzibomvu	Mntanenkosi	FTW	Clear	Clear	**Black**	Well located far from the ho
Mboma	Ntuli	FTW	Clear	Clear	Clear	Agric practices 150m upslop
Mboma	Nxumalo Mabuto	FTW	Clear	Clear	Clear	Agric practices 200m upslop
Mboma	Zikhali Samson	FTW	Clear	Clear	Clear	Pitlatrine about 250m from t
Mboma	Ngubane	FTW	Clear	Clear	Clear	Litering around the well obs
Mboma	Thwala	FTW	Clear	Clear	Clear	Pitlatrine located at 400m ar
Siphahleni	Zikhali Sonto	CTW	Clear	**Black**	**Black**	Agric practices 200m from t
Siphahleni	Mthembu	FRW	**Black**	**Black**	**Black**	No possible polluting agents
Siphahleni	Ncube	FTW	Clear	Clear	Clear	Pitlatrine approximately 100
Siphahleni	John Zikhali	FTW	Clear	Clear	**Black**	Pitlatrine 250m from the wel
Mthunzini	Qwabe Samuel	FTW	Clear	Clear	Clear	Agric practices 3m from the
Mthunzini	Mtembu Lindiwe	FRW	Clear	Clear	Clear	Agric practices 1m downslop
Mthunzini	Qwabe Lindiwe	FTW	Clear	Clear	Clear	Pitlatrine approximately 400
Mthunzini	Ntembe Amos	FTW	Clear	**Black**	**Black**	Agric practices 7m from the
Mthunzini	Mthunzini	CTW	Clear	Clear	Clear	Wasted water collects aroun
Mphakathini	Ntuli M	FTW	Clear	Clear	Clear	Kraal located 150m from the
Mphakathini	Mphakathini	CTW	**Black**	**Black**	**Black**	Agric practices 300m from t
Mphakathini	Mphakathini School	TW	Clear	**Black**	**Black**	Pitlatrine approximately 300
Mphakathini	Nxumalo Nelson	FTW	**Black**	**Black**	**Black**	Kraal located 200m from the
Mphakathini	Nsukwini Mkhonto	FTW	Clear	Clear	**Black**	Nothing can be regarded as
Chith'umzi	Ntuli Mazondo	TW	Clear	Clear	**Black**	Agric practices 200m from t
Chith'umzi	Manzengweya School	TW	Clear	Clear	**Black**	Nothing can be regarded as
Chith'umzi	Twala Thokozani	FTW	Clear	Clear	Clear	Agric practices approx. 250
Chith'umzi	Twala Amros	FTW	**Black**	**Black**	**Black**	Domestic waste 5m from the
Chith'umzi	Ngubane SS	FTW	Clear	Clear	Clear	Agric practices 300m from t
Chith'umzi	Ntuli Sipho	FTW	Clear	Clear	Clear	Agric practices 8m from the
Chith'umzi	Ndlozi Masheshe	FTW	Clear	Clear	Clear	Agric practices 10m from the
Chith'umzi	Ntomb'emhlophe School	TW	Clear	Clear	**Black**	Rope connecting the bucket
Ngutshane	Zikhali Kenneth	FTW	Clear	Clear	Clear	Agric practices 25m from the

Ngutshane	Mdletye	
Ngutshane	Mthembu Sane	
Ngutshane	Ndlovu Thembi	
Ngutshane	Ingutshane	around the well
Manaba	Mashunguzane	
Manaba	Gumede N K	
Manaba	Ndlovu J	
Manaba	Linda T	
Manaba	Ndlovu N	
Manaba	Manaba 2	. Wasted water collects around the well
Manaba	Dlamini B	
Manaba	Manaba 1	
Manaba	Manaba Primar	
Manaba	Ndlazi EM	

APPENDIX E

Appendix E, shows a closer look to the various villages visited as well as the types of wells sampled in the Mbazwana area. This accompanies the data showed in Appendix C and D. From the map it can be noticed that the wells sampled are close to each other. Availability of wells per village was the determining factor hence others are very close to each other. In the case of the samples representing the entire groundwaters of the Mbazwana area, the target can be said to have been reached, since the villages are far (scattered) from each other.

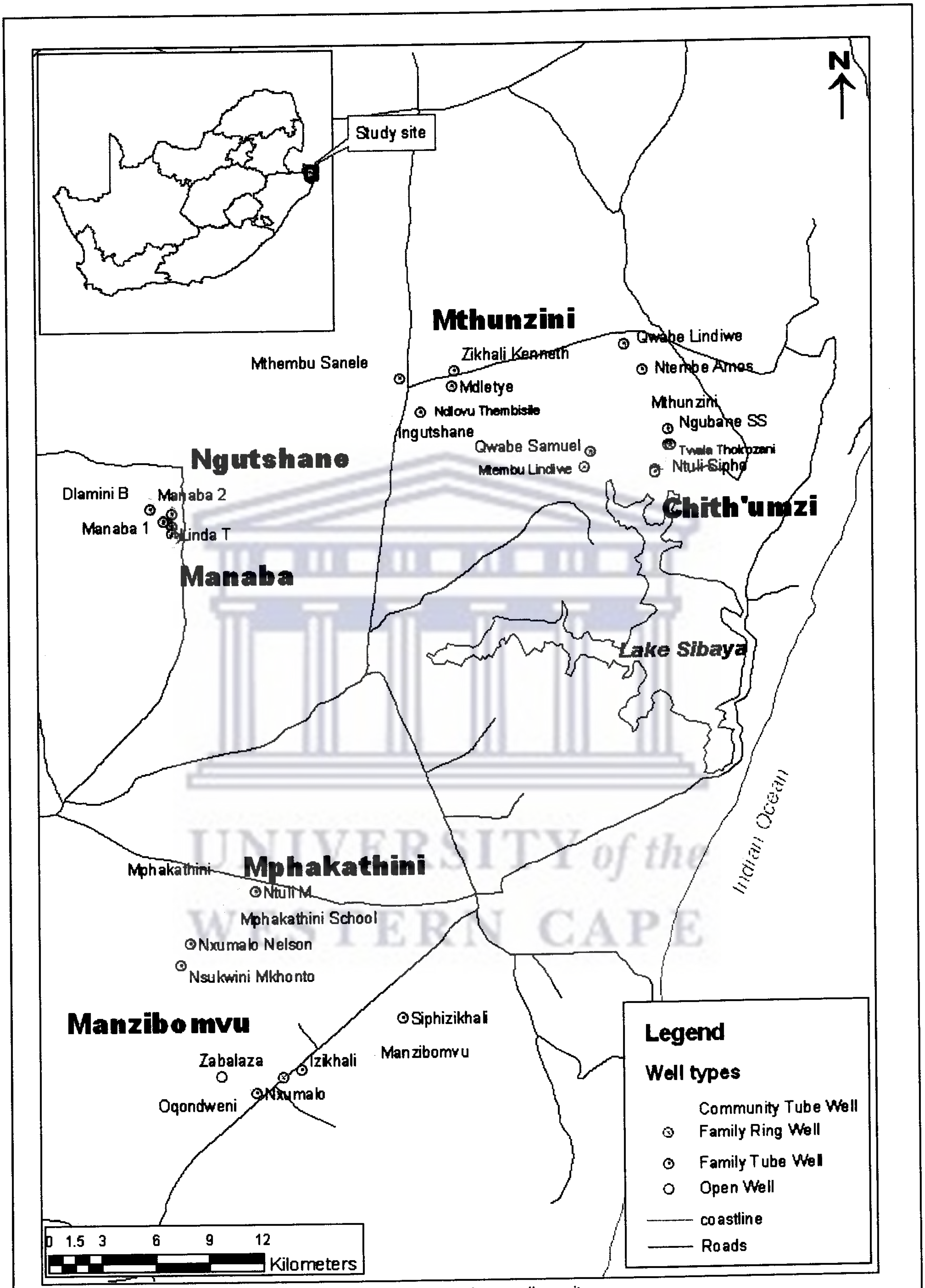


Figure 1 Location of the Mbazwana study area and sampling sites

APPENDIX F

Appendix F presents the outline of the program used to evaluate the quality of water sampled in Mbazwana, northern KwaZulu-Natal. All the necessary steps followed are shown as well as the macros generated. Also presented is the output of the program GW_MONITOR, that is, the worksheet that provides results after data input.

Macros generated during the design of the programme GW_MONITOR

```
Sub Macro1()
'
' Macro1 Macro
' Macro recorded 4/16/2002 by Tholeka Mafanya
'

'
    Range("A2").Select
    ActiveCell.FormulaR1C1 = "pH"
    Range("A3").Select
    ActiveCell.FormulaR1C1 = "EC"
    Range("A4").Select
    ActiveCell.FormulaR1C1 = "TDS"
    Range("A5").Select
    ActiveCell.FormulaR1C1 = "DOC"
    Range("A6").Select
    ActiveCell.FormulaR1C1 = "Nitrate as N mg/L"
    Range("A7").Select
    ActiveCell.FormulaR1C1 = "Fluoride mg?L"
    Range("A7").Select
    ActiveCell.FormulaR1C1 = "Fluoride mg/L"
    Range("A8").Select
    ActiveCell.FormulaR1C1 = "Feacal Coliforms no/100ml"
    Range("A3").Select
    ActiveCell.FormulaR1C1 = "EC mS/m"
    Range("A4").Select
    ActiveCell.FormulaR1C1 = "TDS mg/L"
    Range("A5").Select
    ActiveCell.FormulaR1C1 = "DOC mg/L"
    Range("B3").Select
    ActiveCell.FormulaR1C1 = "70"
    Range("B4").Select
    ActiveCell.FormulaR1C1 = "450"
    Range("B5").Select
    ActiveCell.FormulaR1C1 = "5"
    Range("B6").Select
    ActiveCell.FormulaR1C1 = "1"
    Range("B6").Select
    ActiveCell.FormulaR1C1 = "6"
    Range("B7").Select
    ActiveCell.FormulaR1C1 = "1"
    Range("B8").Select
    ActiveCell.FormulaR1C1 = "0"
    Range("B1").Select
```

```
    ActiveCell.FormulaR1C1 = "value"
    Range("B1").Select
    ActiveCell.FormulaR1C1 = "Acceptable value"
    Range("C8").Select
    ActiveCell.FormulaR1C1 = "=OR(RC=RC[-1], RC[-1]>0 )"
    Selection.ShowPrecedents
    Application.CommandBars("Circular Reference").Visible = False
    Range("C11").Select
    Application.Goto Reference:="R8C2"
    ActiveCell.NavigateArrow TowardPrecedent:=False, ArrowNumber:=1, _
        LinkNumber:=1
    Range("C8").Select
    ChDir "C:\WINDOWS\Desktop"
    ActiveWorkbook.SaveAs Filename:="C:\WINDOWS\Desktop\Book1.xls",
FileFormat _
        :=xlNormal, Password:="", WriteResPassword:="",
ReadOnlyRecommended:= _
        False, CreateBackup:=False
End Sub
Sub Macro2()
'
' Macro2 Macro
' Macro recorded 4/16/2002 by Tholeka Mafanya
'

'
    Range("D15").Select
    Sheets("Sheet3").Select
    Range("A1:C19").Select
    Selection.Copy
    Sheets("Sheet2").Select
    Range("A1").Select
    ActiveSheet.Paste
    Range("F23").Select
    Columns("A:A").ColumnWidth = 20.14
    Range("E29").Select
    Sheets("Sheet1").Select
    Application.CutCopyMode = False
    ActiveWindow.SelectedSheets.Delete
    Range("A30").Select
    ActiveWorkbook.SaveAs Filename:="C:\WINDOWS\Desktop\Thole.xls",
FileFormat _
        :=xlNormal, Password:="", WriteResPassword:="",
ReadOnlyRecommended:= _
        False, CreateBackup:=False
    Range("I22").Select
```

```
    Columns("B:B").ColumnWidth = 12.57
    Range("B9").Select
    ActiveCell.FormulaR1C1 = "0"
    Range("B1").Select
    ActiveCell.FormulaR1C1 = "Water quality guideline for domestic use"
    Range("E12").Select
    Columns("A:A").ColumnWidth = 25.29
    Range("E23").Select
End Sub
Sub datainput()
'
' datainput Macro
' Macro recorded 4/16/2002 by Tholeka Mafanya
'

'
    Dim IDNo As Integer
    Dim PH_value As Single
    'this is to copy PH value
    Range("B2").Select
    IDNo = ActiveCell.Value
    Sheets("Data").Select
    Range("G" & IDNo + 2).Select
    PH_value = ActiveCell.Value
    Sheets("Eva").Select
    Range("B4").Select
    ActiveCell.Value = PH_value


    Dim EC_value As Single
    'this is to copy EC value
    Range("B2").Select
    IDNo = ActiveCell.Value
    Sheets("Data").Select
    Range("H" & IDNo + 2).Select
    EC_value = ActiveCell.Value
    Sheets("Eva").Select
    Range("B5").Select
    ActiveCell.Value = EC_value

    Dim Nitrates_value As Single
    'this is to copy Nitrates value
    Range("B2").Select
    IDNo = ActiveCell.Value
    Sheets("Data").Select
    Range("S" & IDNo + 2).Select
```

```
Nitrates_value = ActiveCell.Value
Sheets("Eva").Select
Range("B6").Select
ActiveCell.Value = Nitrates_value

Dim Flouride_value As Single
'this is to copy Flouride value
Range("B2").Select
IDNo = ActiveCell.Value
Sheets("Data").Select
Range("Z" & IDNo + 2).Select
Flouride_value = ActiveCell.Value
Sheets("Eva").Select
Range("B9").Select
ActiveCell.Value = Flouride_value

Dim Iron_value As Single
'this is to copy Iron value
Range("B2").Select
IDNo = ActiveCell.Value
Sheets("Data").Select
Range("AL" & IDNo + 2).Select
Iron_value = ActiveCell.Value
Sheets("Eva").Select
Range("B12").Select
ActiveCell.Value = Iron_value


Dim Feacalcoliform_value As Single
'this is to copy Feacalcoliform value
Range("B2").Select
IDNo = ActiveCell.Value
Sheets("Data").Select
Range("AS" & IDNo + 2).Select
Feacalcoliform_value = ActiveCell.Value
Sheets("Eva").Select
Range("B13").Select
ActiveCell.Value = Feacalcoliform_value

Dim Arsenic_value As Single
'this is to copy Arsenic value
Range("B2").Select
IDNo = ActiveCell.Value
Sheets("Data").Select
Range("Y" & IDNo + 2).Select
```

```
Arsenic_value = ActiveCell.Value
Sheets("Eva").Select
Range("B14").Select
ActiveCell.Value = Arsenic_value

Dim Coliphages_value As Single
'this is to copy Coliphages value
Range("B2").Select
IDNo = ActiveCell.Value
Sheets("Data").Select
Range("AU" & IDNo + 2).Select
Coliphages_value = ActiveCell.Value
Sheets("Eva").Select
Range("B15").Select
ActiveCell.Value = Coliphages_value

Dim Entericviruses_value As Single
'this is to copy Entericviuses value
Range("B2").Select
IDNo = ActiveCell.Value
Sheets("Data").Select
Range("AV" & IDNo + 2).Select
Entericviruses_value = ActiveCell.Value
Sheets("Eva").Select
Range("B16").Select
ActiveCell.Value = Entericviruses_value


Dim TDS_value As Single
'this is to copy TDS value
Range("B2").Select
IDNo = ActiveCell.Value
Sheets("Data").Select
Range("I" & IDNo + 2).Select
TDS_value = ActiveCell.Value
Sheets("Eva").Select
Range("B7").Select
ActiveCell.Value = TDS_value

Dim DOC_value As Single
'this is to copy DOC value
Range("B2").Select
IDNo = ActiveCell.Value
Sheets("Data").Select
Range("J" & IDNo + 2).Select
DOC_value = ActiveCell.Value
```

```
    Sheets("Eva").Select
    Range("B8").Select
    ActiveCell.Value = DOC_value



    Dim Aluminium_value As Single
    'this is to copy Aluminium value
    Range("B2").Select
    IDNo = ActiveCell.Value
    Sheets("Data").Select
    Range("AG" & IDNo + 2).Select
    Aluminium_value = ActiveCell.Value
    Sheets("Eva").Select
    Range("B10").Select
    ActiveCell.Value = Aluminium_value

    Dim Mecury_value As Single
    'this is to copy DOC value
    Range("B2").Select
    IDNo = ActiveCell.Value
    Sheets("Data").Select
    Range("AQ" & IDNo + 2).Select
    Mercury_value = ActiveCell.Value
    Sheets("Eva").Select
    Range("B11").Select
    ActiveCell.Value = Mercury_value

    Call colour

End Sub
Sub colour()
'
' Macro4 Macro
' Macro recorded 4/17/2002 by Tholeka Mafanya
'

'
   'color cell called c4
   Range("c4", [e4]).Select
   If Cells(4, 2) > 6 Then
      With Selection.Interior
      .ColorIndex = 10
      .Pattern = xlSolid
   End With
   Else
```

```
With Selection.Interior
   .ColorIndex = 3
   .Pattern = xlSolid
End With
Range("c4").Select
End If

'color cell called c5
Range("c5", [e5]).Select
If Cells(5, 2) < 70 Then
   With Selection.Interior
   .ColorIndex = 10
   .Pattern = xlSolid
End With
Else
With Selection.Interior
   .ColorIndex = 3
   .Pattern = xlSolid
End With
Range("c5").Select
End.If


'color cell called c6
Range("c6", [e6]).Select
If Cells(6, 2) < 6 Then
   With Selection.Interior
   .ColorIndex = 10
   .Pattern = xlSolid
End With
Range("c6", [e6]).Select
ElseIf Cells(6, 2) > 6 And Cells(6, 2) < 20 Then
   With Selection.Interior
   .ColorIndex = 7
   .Pattern = xlSolid
End With
Else
With Selection.Interior
   .ColorIndex = 3
   .Pattern = xlSolid
End With
Range("c6").Select
End If


'color cell called c7
```

```
Range("c7", [e7]).Select
If Cells(7, 2) < 450 Then
   With Selection.Interior
   .ColorIndex = 10
   .Pattern = xlSolid
End With
Else
With Selection.Interior
   .ColorIndex = 3
   .Pattern = xlSolid
End With
Range("c7").Select
End If

'color cell called c8
Range("c8", [e8]).Select
If Cells(8, 2) < 5 Then
   With Selection.Interior
   .ColorIndex = 10
   .Pattern = xlSolid
End With
Else
With Selection.Interior
   .ColorIndex = 3
   .Pattern = xlSolid
End With
Range("c8").Select
End If


'color cell called c9
Range("c9", [e9]).Select
If Cells(9, 2) < 1 Then
   With Selection.Interior
   .ColorIndex = 10
   .Pattern = xlSolid
End With
Range("c9", [e9]).Select
ElseIf Cells(9, 2) > 1.5 And Cells(9, 2) < 3.5 Then
   With Selection.Interior
   .ColorIndex = 7
   .Pattern = xlSolid
End With
Else
With Selection.Interior
   .ColorIndex = 3
```

```
    .Pattern = xlSolid
End With
Range("c9").Select
End If



'color cell called c10
Range("c10", [e10]).Select
If Cells(10, 2) < 0.15 Then
    With Selection.Interior
    .ColorIndex = 10
    .Pattern = xlSolid
End With
Range("c10", [e10]).Select
ElseIf Cells(10, 2) > 0.15 And Cells(10, 2) < 0.5 Then
    With Selection.Interior
    .ColorIndex = 7
    .Pattern = xlSolid
End With
Else
With Selection.Interior
    .ColorIndex = 3
    .Pattern = xlSolid
End With
Range("c10").Select
End If



'color cell called c11
Range("c11", [e11]).Select
If Cells(11, 2) < 1 Then
    With Selection.Interior
    .ColorIndex = 10
    .Pattern = xlSolid
End With
Range("c11", [e11]).Select
ElseIf Cells(11, 2) > 1 And Cells(11, 2) < 10 Then
    With Selection.Interior
    .ColorIndex = 7
    .Pattern = xlSolid
End With
Else
With Selection.Interior
    .ColorIndex = 3
```

```
     .Pattern = xlSolid
 End With
 Range("c11").Select
 End If


 'color cell called c12
 Range("c12", [e12]).Select
 If Cells(12, 2) < 0.1 Then
     With Selection.Interior
     .ColorIndex = 10
     .Pattern = xlSolid
 End With
 Range("c12", [e12]).Select
 ElseIf Cells(12, 2) > 0.1 And Cells(12, 2) < 0.3 Then
     With Selection.Interior
     .ColorIndex = 7
     .Pattern = xlSolid
 End With
 Else
 With Selection.Interior
     .ColorIndex = 3
     .Pattern = xlSolid
 End With
 Range("c12").Select
 End If


 'color cell called c13
 Range("c13", [e13]).Select
 If Cells(13, 2) = 0 Then
     With Selection.Interior
     .ColorIndex = 10
     .Pattern = xlSolid
 End With
 Else
 With Selection.Interior
     .ColorIndex = 3
     .Pattern = xlSolid
 End With
 Range("c13").Select
 End If


 'color cell called c14
```

```
Range("c14", [e14]).Select
If Cells(14, 2) < 10 Then
   With Selection.Interior
   .ColorIndex = 10
   .Pattern = xlSolid
End With
Range("c14", [e14]).Select
ElseIf Cells(14, 2) > 10 And Cells(14, 2) < 200 Then
   With Selection.Interior
   .ColorIndex = 7
   .Pattern = xlSolid
End With
Else
With Selection.Interior
   .ColorIndex = 3
   .Pattern = xlSolid
End With
Range("c14").Select
End If


'color cell called c15
Range("c15", [e15]).Select
If Cells(15, 2) < 1 Then
   With Selection.Interior
   .ColorIndex = 10
   .Pattern = xlSolid
End With
Range("c15", [e15]).Select
ElseIf Cells(15, 2) > 1 And Cells(15, 2) < 10 Then
   With Selection.Interior
   .ColorIndex = 7
   .Pattern = xlSolid
End With
Else
With Selection.Interior
   .ColorIndex = 3
   .Pattern = xlSolid
End With
Range("c15").Select
End If


'color cell called c16
Range("c16", [e16]).Select
If Cells(16, 2) = 0 Then
```

```
   With Selection.Interior
   .ColorIndex = 10
   .Pattern = xlSolid
End With
Range("c16", [e16]).Select
ElseIf Cells(16, 2) > 0 And Cells(16, 2) < 2 Then
   With Selection.Interior
   .ColorIndex = 7
   .Pattern = xlSolid
End With
Else
With Selection.Interior
   .ColorIndex = 3
   .Pattern = xlSolid
End With
Range("c16").Select
End If


End Sub
```