AN ASSESSMENT OF GROUNDWATER VULNERABILITY, QUALITY AND POLLUTION RISK IN GA-SEGONYANA MUNICIPALITY AREA, KURUMAN, NORTHERN CAPE IN SOUTH AFRICA

By

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DECLARATION

I, Saungweme Kuziwa Evans, do hereby declare that the dissertation, submitted in fulfillment of the requirements for awarding of a Master's Degree in Disaster Management from the Disaster Management Training and Education Centre for Africa (DiMTEC), is my own original work and has not been submitted by any other person to any other institution. The sources of borrowed knowledge have been appropriately acknowledged.

Signature………… …………

Saungweme Kuziwa Evans

Date 26 March 2019

DEDICATION

I dedicate this thesis firstly to God the creator and to all my family members for giving me unwavering support throughout this study.

RECOGNITION AND ACKNOWLEDGEMENT

Firstly, I would like to thank my supervisor, Dr Belle for his support and academic input during the research. I would also like to thank the DiMTEC lecturers at the University of Free State for building the knowledge that helped in carrying out this research.

I acknowledge the contribution of the personnel and institutions interviewed for data collection, these include Sedibeng Waters, Bothaville laboratory, Geoscience council and Ga-Sengonyana municipality. I appreciate their support in the form of resources and information that made the completion of this research possible.

Lastly, appreciation goes to Dr Maipisi and Dr Modreck for providing technical knowledge and guidance throughout the research.

LIST OF ACRONYMS

Acronym	Definition
NEMA	National Environmental Management Act
DRASTIC	**D**epth to water level; Net **R**echarge; **A**quifer media; **S**oil media; **T**opography; **I**mpact of vadose zone; and **C**onductivity
EC	Electric Conductivity
NTU	Nephelometric Turbidity Unit
WSA	Water Services Act
NWA	National Water Act
SANS	South African National Standards
PAR	Pressure and Release Model
TDS	Total Dissolved Solids
UNISDR	United Nations International Strategy for Disaster Reduction
WHO	World Health Organisation

ABSTRACT

An assessment of the quality of the groundwater supplied to the villages of Ga-Sengonyana municipality area of the Northern Cape Province was undertaken from March 2018 to February 2019. Water samples were collected from 17 boreholes during the wet season (summer) and dry season (winter) and tested at Sedibeng, Bothaville Laboratory. The samples were tested for physiochemical parameters pH, turbidity, TDS (measured by E.C), fluoride, nitrate, magnesium, calcium, sodium and biological parameters (total coliform count) and compared with the standards set by the South Africa National Standard on water quality (SANS 241:2006). These parameters were determined in the Laboratory by following standard analytical techniques (American Public Health Association (APHA), 1998).

The study adopted a exploratory research design that includes both quantitative and qualitative research approaches to explore groundwater quality and pollution risk. Microbial quality deterioration was observed in the dry and wet season samples in the year period 2018 to 2019 (range 0 - 45 cfu/100 ml). The results showed that 52% of boreholes tested positive for coliform bacteria and 0% for *Escherichia coli*. This could be attributed to the poor maintenance of the protection structure or sudden flow of pollutants in a highly vulnerable aquifer from pit latrines, sewage leaks and animal waste to subsurface water source. The seasonal variation revealed a significant change of variance in water quality parameters (46.721). The results revealed that all boreholes complied with the fluoride limit of SANS 241:2006 (0 to 1 mg/l). Four did not comply with the nitrates limit (0 to 6 mg/l as N), three did not comply with the magnesium limit (0 to 30 mg/l as Mg), eight did not comply with the calcium limit (0 to 32 mg/l as Ca), and two boreholes did not comply with the turbidity limit (<1 NTU).

The groundwater vulnerability assessment conducted using the DRASTIC index revealed a DRASTIC score of 140, implying that there is moderate to high vulnerability of aquifers in the Ga-Sengonyana district municipality. The unconsolidated material of sand, embedded dolomite and limestone that forms the vadose zone (unsaturated zone) and aquifer media contributes to high vulnerability of underground water sources to pollutants.

The identification and selection of management solutions for protecting shallow groundwater in Ga-Sengonyana municipality should not only be based on water quality problems and the causal physical characteristics as shown by this study, but also on institutional and socio-economic factors. The study also revealed the need for disaster management agencies and the local municipality to protect groundwater sources by integrating activities that promote development in local communities together with conservation of water resources. The findings of this study showed convincing evidence that some groundwater supplies in some areas of Ga-Sengonyana municipality pose a health risk to communities.

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DEFINITION OF TERMS

Groundwater quality: It is the physical, chemical, biological and aesthetic properties of water that determines its suitability for various uses including by human beings (Department of Water Affairs and Forestry, 1996)

Groundwater pollution risk: The interaction between the natural vulnerability of the aquifer and the pollution loading that is, or will be, applied on the subsurface environment because of human activity (U.S. Environmental Protection Agency (EPA), 1992).

Groundwater vulnerability: The relative ease with which a contaminant applied on or near the land surface can migrate to the aquifer of interest under a given set of its exposure, characteristics and hydrogeological sensitivity conditions (DWA, 2015; Ashton et al, 2001).

Aquifer pollution vulnerability: The intrinsic characteristics which determine the sensitivity of various parts of an aquifer to being adversely affected by an imposed contaminant load (Foster & Hirata, 1988; Wright, 2010)

Disaster: A disaster is a serious disruption of the functioning of the society that causes widespread human, material, or environmental losses and exceeds the ability of affected society to copy using only its own resources (UNISDR, 2005)

Water table: It is the upper surface of groundwater, in which below this surface, all the pore spaces and cracks in sediments and rocks are completely saturated with water (DWA, 2015)

Groundwater: It is the sub-surface water forming saturated layers in a phreatic zone. (DWA, 2015)

CHAPTER 1: GENERAL INTRODUCTION

1.0 Introduction

The chapter summarises the study of groundwater vulnerability, quality and pollution risk in Ga-Sengonyana municipality area in Northern Cape, South Africa. The chapter explores the background of the study, orientation, and statement of the problem, objectives of the study, ethical considerations, and chapter outline. The chapter outlines the research methodology that is discussed in detail in chapter 4. The study assessed the water samples of various boreholes in Ga-Sengonyana municipality to weigh the pollution risk of groundwater sources associated with natural factors and anthropogenic activities. In addition, the vulnerability existing in the municipality area was assessed (underground water saturated areas). The results of the assessment of groundwater quality, vulnerability, and pollution risk can help to put forward recommendations for the management of groundwater.

1.1 Background to the study

Groundwater quality is influenced by the water withdrawal and replenishment pattern, nature of rock hosting and surrounding rocks including exposure to contamination (Saidi, 2011). Groundwater quality depends on factors such as water depth, replenishment and land use. In this study, groundwater quality was evaluated to find out traces of the pollutants.

Although many aquifers possess natural capacity of attenuation of microbial contaminants of pollutant nature, this capacity should be capitalised to minimise adverse effects to groundwater (Morris et al 2003). Some pathogenic bacteria such as *Escherichia coli, Pseudomonas and Vibrio cholerae,* may persist in groundwater sources (Momba et al., 2006). Outbreaks of water borne diseases such as cholera and gastroenteritis reported from 2000 in South African provinces of KwaZulu-Natal, Eastern Cape and Mpumalanga, could be linked to drinking water contamination (Department of National Health and Population Development, 2001; Department of Health, 2005). Some studies showed that viruses move from the subsurface, through the unsaturated zone to the saturated zone to contaminate aquifers (Schijven, 2001).

South Africa is a water-scarce country with groundwater sources contributing 13% -15% of total fresh water (Van Vuuren, 2009). Even though groundwater only accounts for about 15% of total water use in South Africa, 65% of the population solely relies on this source (Woodford, 2005) with over 280 cities and towns having some dependence on groundwater (Van Tonder, 1999). Furthermore, groundwater is an important resource for socio-economic development and it buffers impacts of drought especially in arid and semi-arid regions (Custodio & Llamas, 2001).

Despite the ever-growing population in South Africa relying on groundwater, pollution is a challenge faced by communities who use groundwater. In certain areas, natural groundwater quality does not comply either with South Africa National Standards (SANS 241:2006) limits in minerals nor with portable standards for microbial indicators (Engelbrecht and Tredoux, 2000). Microbiological pollution in groundwater is caused by human activities that include waste disposal, feedlots, cemeteries, and pit latrines in some settlements (Engelbrecht and Tredoux, 2000).

Kuruman, the capital of the Ga-Segonyana municipality in Northern Cape is dry and is located at the eastern border of the Kalahari Desert. The town is experiencing rapid urbanisation with over 12,701 inhabitants relying entirely on groundwater. Population growth, farming and current land use changes affect groundwater sources negatively. The water basin of this area is typical Kalahari Basin, which is an endorheic basin, meaning that no water leaves the basin except through evaporation (Saayman et al., 2007). The surface water rapidly becomes groundwater and this poses a pollution risk to the community as contaminants can gradually increase in concentration. The continued use of pit latrines by some communities could be a potential source of contamination of groundwater.

The groundwater quality and pollution elements, which have been investigated during the last decades, include ambient groundwater quality on national scale (WRC project 841), geophysical techniques for identifying groundwater pollution (Meyer, 1994) and assessment of aquifer vulnerability in South Africa (Saayman, 2007). The area of study does not have perennial rivers as shown in Figure 1.3 below. The cost of extraction of water from the nearest Vaal perennial river that is 200 km to the southeast of Kuruman is prohibitive. Therefore, it is against this background that the assessment of groundwater quality and pollutant threats is carried out to help preserve groundwater sources.

1.2 Area of study

Ga-Sengonyana municipality area lies at the edge of Kalahari Desert to the east of Northern Cape. Ga-Sengonyana local municipality's area covers 4, 495 km² and has about 104 408 residents in Kuruman town, its surrounding villages and the farming area (Statistics South Africa, 2011). The major economic activity in the study area is agriculture, mainly ranching. The area falls within the summer rainfall region of South Africa. It is a relatively flat area with little topographical features. Locally the natural topography dips slightly towards the streambeds of the non- perennial Kuruman river. The area under study is shown in Figure 1.1, 1.2 and 1.3 below. Figure 1.3 shows the different places under the municipality in which the samples were obtained. From Kuruman weather station data, 85% of rainfall occurs during summer and an average annual rainfall of 266 mm is received per year.

According to Rutherford (2006), the vegetation of the area is Kalahari thorn veld in which trees such as; *Acacia erioloba* and *Acacia mellifera* are common. Underlying the area are 190 million year old volcanic dolomite dykes that thrust up forming dissolution channels in fractures, therefore allowing direct recharge and groundwater flow (Pavelic et al 2012). This is evidenced by the common 'eyes' (water springs) in the area, which serve as a tourist attraction. The aquifers are composed of dolomite with an average water level depth of 30m (Saayman, 2007).

Concretised sediments classified as the Kalahari group cover Kuruman area. It comprises unlithified sand, which unconformably overlies calcified sand, and gravel (Thomas & Shaw, 1991). Municipal and private boreholes are common in the urban area, villages, and surrounding farms.

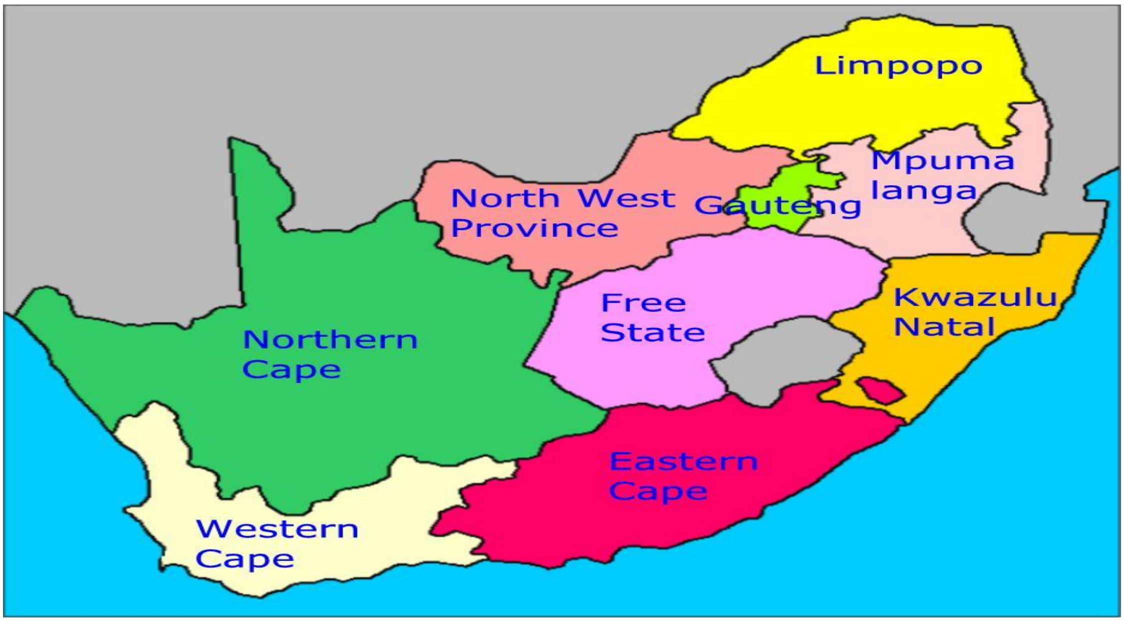

Figure 1:1: South African provincial map

Figure 1:2: Northern Cape district map

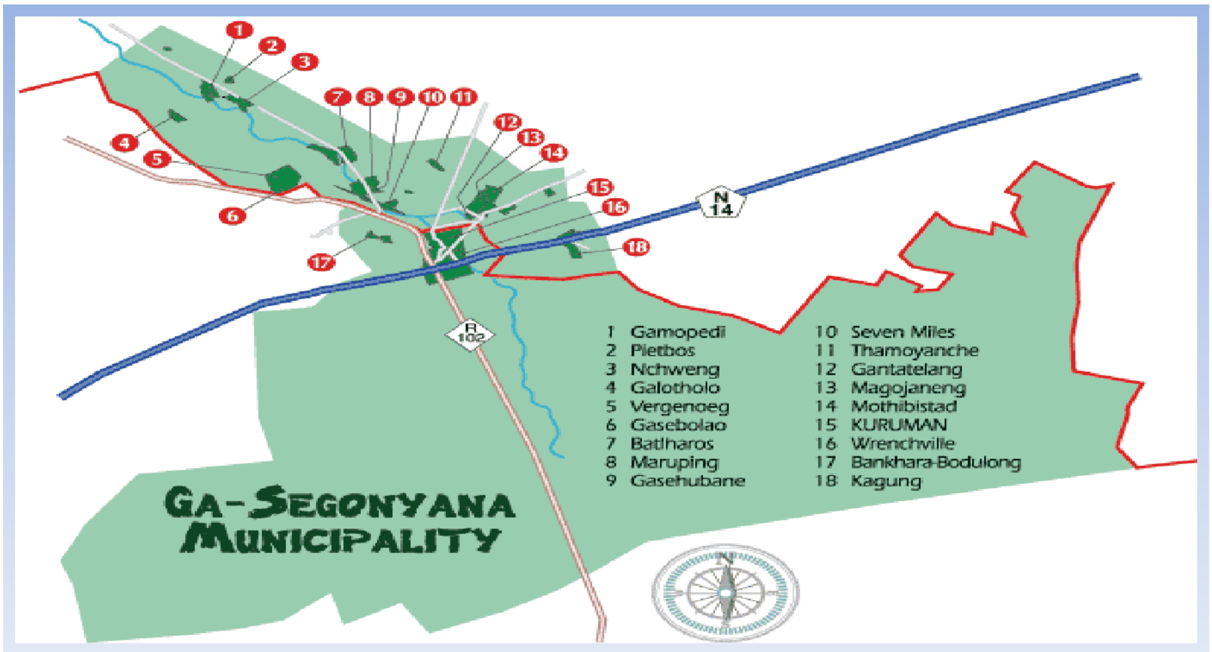

Figure 1.3: Ga-Segonyana municipality

Source: www. ewisa.za municipal profile

1.3 Orientation

South Africa has legislation governing water use including groundwater sources (National Water Act (Act 36 of 1998). However, there is lack of groundwater pollution risk research and its uses. This major handicap has often led to less recognition of groundwater issues in national water legislation (Knuppe, 2010).

The groundwater research was carried out in Ga-Sengonyana district municipality area. Pit latrines are still used in some clustered settlement of villages of the district. This research investigated the physical water parameters (pH, turbidity, temperature), chemical water parameters (total dissolved solids (TDS), chloride, nitrate, fluoride, sodium, magnesium and calcium concentration) and the biological water parameters (Total coliform bacteria count, faecal coliform bacteria count) of groundwater as well as aquifer vulnerability potentially contributing to pollution risk in Ga-Sengonyana municipality area.

Groundwater vulnerability assessment is a useful management concept for guiding decisions about groundwater protection and it demands crosscutting effort from different fields including regulatory policy makers, natural resource managers, educators, and technical experts. The local authorities and scientist are assisted in seeking solutions for managing groundwater better.

1.4 Statement of the problem

Research shows widespread deterioration of groundwater quality beneath cities (Learner, 1992). Leaner (1992), highlighted that in developing countries, the effects of settlements and the use of pit latrines on the environment, and in particular on groundwater, is relatively unknown. Gaining knowledge of local municipal groundwater vulnerability and degradation would be useful to compare the water quality with other areas and outcomes are used to raise public awareness (Morris et al., 2003).

Groundwater is the main source of water for Ga-Sengonyana municipality including for private use from the boreholes distributed directly to the communities and industries without prior purification. With the groundwater being the main source of water in the municipal area, there is a concern associated with its vulnerability. For instance, the groundwater aquifers are composed of dolomite rocks that are prone to fractures and caves and may provide an aggressive pathway for contaminants (Dochartaigh et al., 2005). There is a report from the Ga-Sengonyana local municipality health sector that points to an increase in groundwater contamination in the study area evidenced by more cases of diarrheal infection associated with bacterial contamination of groundwater. In some villages in the study area, substandard environment and sanitation facilities such as pit latrines, which have high-risk levels of polluting groundwater, are used. Therefore, the need for this study to investigate the exposure of the community to polluted groundwater hazard. This will lead to reduced reported cases of contaminated groundwater health related problems.

Currently, Ga-Sengonyana has an inadequate evaluation of groundwater quality in the municipality. Very few cases of groundwater contamination are recorded, largely due to the lack of systematic monitoring (Saidi, 2011). Groundwater is poorly understood in South Africa, yet it contributes 13% to 15% of total water supply in South Africa (Water Research Commission, 2005). The reason for the increasing incidence of water-related diseases and their complications often remains unknown in villages due to the lack of monitoring of the quality of their water supplies. Although groundwater is considered less prone to contamination, if it occurs the cost of remediation is prohibitively high therefore, groundwater quality should be protected from pollution (Morris et al., 2003).

This study seeks to find ways to preserve groundwater in the region. Land use is a problem that necessitates continuous thorough evaluation of groundwater vulnerability through quality and pollution potential monitoring. The aquifer characteristics also have the propensity to change over time, rendering it susceptible to pollution. Therefore, its close monitoring is necessary, especially given that hydrogeo-chemical evolution of groundwater is a dynamic process, which constantly changes (Tiwari, Dubey & Bharti, 2009).

1.5 Research objectives

1.5.1 Main objective

The aim of this research is to assess groundwater vulnerability, quality and pollution risk in Ga-Segonyana municipality in Northern Cape Province. The results will assist to prevent, or mitigate the groundwater pollution risk.

1.5.2 Sub-objectives

- To identify and assess groundwater pollutants and sources of the pollution risk in Ga-Segonyana municipality.
- To determine groundwater quality in Ga-Segonyana municipality using specific evaluation parameters.
- To evaluate vulnerability properties of the aquifer to pollution in Ga-Sengonyana municipality's local urban area of Kuruman and villages/ farming areas.
- To determine Ga-Segonyana municipality's seasonal groundwater quality variability (wet season and dry season).

1.6 Research questions

- What are the specific water quality parameter measurement levels in Ga-Segonyana municipality?
- Which are the groundwater pollutants and sources of contaminants threatening groundwater in Ga-Segonyana municipality area?
- How vulnerable to pollution is the aquifer under Ga-Segonyana municipality's urban and village jurisdiction areas?
- How does wet season water quality differ from that of the dry season?

1.7 Hypothesis

Groundwater quality has deteriorated due to anthropogenic activities and aquifer characteristics and these are the major causes of groundwater pollution risk.

1.8 Research methodology

Research methodology can be viewed as activities that a researcher does to explain ideas behind research methods and techniques (Welman and Kruger, 2001). Hussey and Hussey (1997) & Maree (2016) define research methodology as an approach that involves theoretical underpinning, collection of results and analysis of data.

The study determines present groundwater quality from water sample evaluation, aquifer vulnerability, and variation of groundwater quality with seasons (rainy summer and dry winter) and identifies and assesses the nature and scale of pollution risk.

1.8.1 Research design

An exploratory research design was adopted for this study. Both quantitative and qualitative approaches are used to achieve the study objectives. Maree (2016) and Leedy & Ormrod (2013) explain that an exploratory design is conducive to a research problem, which requires both quantitative and qualitative approaches.

The researcher opted to use the exploratory research design because it can use of both quantitative and qualitative techniques and for topics where there is little information about a phenomenon under investigation (Wright, 2010; Maree, 2016).

The qualitative approach captures opinions, statements and perceptions from the respondents while the quantitative approach caters for numerical observation or trends. These approaches are complementary (Maree, 2016).

A quantitative method was used to assess the water quality of collected borehole water samples. In-depth interviews were also done as part of the qualitative approach. Participants included water experts from Sedibeng Waters, council of Geoscience and Municipality health personnel to get technical and social aspects of groundwater use in the municipal area.

1.8.2 Sources of data and data collection techniques

Primary data and secondary data were utilized in the research. Primary data was gathered from the sample collected and measured on-site of the pH and temperature levels. The pH meter and thermometer were used respectively. In-depth interviews were used to collect primary data. Secondary data was collected from a review of existing literature on groundwater vulnerability.

The research questions are answered from the collected data (Allwright, 1998). A review of literature of **D**epth to water level; Net **R**echarge; **A**quifer media; **S**oil media; **T**opography; **I**mpact of vadose zone; and **C**onductivity (DRASTIC) studies were utilised in determining vulnerability of the aquifer in Ga-Sengonyana municipal area.

1.8.3 Target population

According to Bryman (2012) and LeCompte & Preissle (1993) a study population is a specified group of participants that are of interest to the researcher and useful in generating results in a research. The 45 functional boreholes scattered in Ga-Sengonyana municipality and belonging to the municipality were used as the population of boreholes of which 17 boreholes were sampled using stratified sampling method.

In instances where randomness is more important than the sample size, a sample of 5% of the total population or above is acceptable for generalisation of results (Swanepoel & De Beer, 1992). This study used a sample of 38% from the total borehole population.

Though there are also private boreholes in the study area the municipality boreholes were chosen for this study because the water is supplied to many people, hence its quality affects more people and is more significant to disaster management. A sample of 24 personnel was purposively selected from Sedibeng Water, Council of Geoscience personnel and Ga-Sengonyana district health personnel for the in–depth interviews in order to get information on the research problem.

1.8.4 Study samples and sampling procedures

A sample is a group that is selected from the entire population under review and is less than the population but remains a true representative of the population (Leedy & Ormrod, 2013). Sampling is the process by which a sample is obtained (Saunders et al., 2012).

Seventeen boreholes from seven different areas were selected from a population of 45 boreholes using stratified sampling method outlined in Figure 4.2 in Chapter 4. The 34 water samples were extracted two times (wet summer and dry winter) from the same 17 sampled boreholes for water quality parameters testing. The 17 borehole samples were partitioned between two (2) strata (10 from an area with sanitary services and 7 from an area without proper sanitary service but with pit latrines). The list of boreholes surveyed and their locations are shown in Table 4.1, Chapter 4. On-site testing for pH and temperature and turbidity was performed and the thirty-four (34) water samples were sent to Bothaville laboratory for chemical and further biological analysis.

The water quality parameters results were then compared to South African National Standards (SANS, 241: 2006) as shown in Table 4.4 in Chapter 4. Furthermore, the results were subjected to statistical analysis using statistical software (SPSS Windows 10).

1.8.5 Aquifer vulnerability assessments

DRASTIC vulnerability index (Aller et al., 1987) was used in this study to evaluate aquifer vulnerability. The DRASTIC index computes factors according to the following equation:

DRASTIC Index = DrDw + RrRW + ArAw + SrSw + TrTw+ IrIw + CrCw

Where D, R, A, S, T, I and C are seven parameters: **D**epth of the water level; Net **R**echarge; **A**quifer media; **S**oil media; **T**opography; **I**mpact of vadose zone; and **C**onductivity (Abdullahi, 2009). Conductivity refers to the volume of water that passes through the unsaturated zone to water table per unit time. The subscripts r and w are the corresponding rating and weights, respectively. The method is commonly used as a modeling process in assessing aquifer vulnerability (Armengol, Sanchez-Villa & Folch, 2014).

1.8.6 In-depth interviews

In-depth interviews were administered using broad questions to allow new questions to surface in discussions. Individuals with knowledge and experience on the topic were selected to answer open–ended questions (Appendix 1). It was administered to twenty-four (24) key respondents that were purposively selected in the Ga-Sengonyana municipal area to obtain information face-to-face. Interviews give a wealth of information regarding the qualitative aspects of a research (Denzin and Lincoln, 2003).

1.8.7 Data analysis

The water quality results of 34 boreholes water samples were analysed using SPSS windows 10 and the results were compared to the South Africa National standard of water (SANS 241) to assess the water quality. The two groups of water parameter tested results (wet and dry) were compared for seasonal variation with use of statistical analysis standard deviation and variance. Correlation was performed on data using

Excel and SPSS windows 10 for significant variations and inter-element relationships. Mouton (2006) defines data analysis as a process of seeking understanding of the various constitutive elements of data through examining the co-relations between concepts, isolated variables or point out repetitive themes.

1.8.8 Ethical considerations

The water samples were collected from municipal boreholes after seeking permission from the municipal authority. The confidentiality of the participants was respected during the research (Leedy and Omrod, 2001). As a guide the following principles were adhered to:

- No financial benefit was promised or given to the personnel interviewed.
- All data and information collected and processed for the research was treated confidentially and used for academic purposes only, unless otherwise authorised.

The University of the Free State granted ethical clearance to carry out the research.

1.9 Limitation and delimitation of the study

Limitations of the study include the short duration of water sample collection and testing. The contaminants may take longer to move from the earth surface to the saturated zone underneath. Therefore, the results may be given on basis of short duration assessment while some contaminants might still be in transition through the unsaturated zone of aquifer. Another limitation is that only a small sample of Ga-Sengonyana municipality was studied out of many municipalities around Northern Cape and that may not help to give a conclusive decision on groundwater quality and pollution risk of the whole province. This was due to the limited study period and budget.

The study focused on the evaluation of groundwater vulnerability in Ga-Sengonyana municipality area with the aim of preventing or mitigating pollution risk. The study made use of participants whose duties are involved in water supply to the municipality.

1.10 Theoretical concepts of the study

1.10.1 Groundwater pollution risk

Groundwater pollution risk is defined as the probability of contamination of groundwater aquifer, which deteriorates the water quality to concentrates above World Health

Organisation (WHO) standard for drinking water quality (World Health Organisation, 1993). In South Africa, the international standards are observed in collaboration with SANS 241. Groundwater pollution risk is considered as the interaction between the natural vulnerability of the aquifer, and the pollution loading that is, or will be, applied on the subsurface environment because of human activity (U.S General Accounting Office, 1991). Pollution risk adapted from conventional risk expression can be interpolated as follows:

$$R = \frac{V \times H}{C \times M}$$

Where R= Pollution Risk, V = Vulnerability of Aquifer ,H = Hazard of nature contaminant load, C = Coping capacity of aquifer influenced by aquifer natural characteristics and anthropogenic activities, M = Manageability by local authority

Pollution risk is therefore an interaction of all the factors of pollution risk, which determines the water quality of the aquifer. A combination of vulnerability assessments methods are used to determine the consequence of contamination event (Saidi et al, 2011).

1.10.2 Groundwater quality

Water quality is defined as the physical, chemical, biological and aesthetic water properties determining its fitness for use and its ability to maintain the health or farmed organisms (U.S. Environmental Protection Agency (EPA), 1992); Department of Water and Forestry, 1996). The water properties are influenced by the constituents, which are either dissolved or suspended within the system.

1.10.3 Groundwater contaminants

Groundwater contaminants are composed of natural occurring inorganic pollutants and manmade pollutants. While natural pollutants are fluoride, nitrates, mercury, arsenic, aluminum lead and iron, the manmade pollutants are composed of chlorinated solvents, pesticides and plasticisers (Gosh, 2009)

Groundwater pollution is the introduction of certain pollutants into the groundwater, which reduces the quality of the groundwater, making its use very limited, or in some cases impossible. In a detailed assessment done by Mishra & Tiwari (2012), around Dabhaura area in India concerning quality and pollution potential of groundwater using water quality parameters the results showed higher pH values on groundwater samples, indicating the presence of carbon dioxide and carbonate- bicarbonate.

1.10.4 Vulnerability of an aquifer to pollution

Vulnerability is the extent to which an individual, household, community or area may be adversely affected by a disaster (South Africa Disaster Management Act, 2002). The aquifer vulnerability to pollution is determined by contaminant characteristics and hydro-geological sensitivity conditions (U.S. Environmental Protection Agency, 1993).

Some areas are more vulnerable to contamination by pollutants than other areas. The nature of the aquifer influences the susceptibility to contamination problem (Morris et al., 2003). An aquifer, which is highly fractured, allows easier infiltration of water at a relatively rapid rate and widespread contamination may occur. The soil thickness and extent of strata consolidation coupled with fracture nature and rock types influences the aquifer's vulnerability in relation to pathogens (Morris et al., 2003). Therefore, the groundwater in a mature karst aquifer system or a shallow sand and gravel alluvial aquifer is highly vulnerable to contamination.

1.10.5 Aquifer sensitivity

Aquifer sensitivity is the relative ease with which a contaminant on or near the land surface can migrate to the aquifer. Aquifer sensitivity is a function of the intrinsic characteristics of the geologic materials of interest, any overlying saturated materials, and the overlying unsaturated zone (U.S. Environmental Protection Agency, 1993).

1.10.6 Land degradation and groundwater pollution risk

Anthropogenic activities in expansion of urban areas and clearance of land for agricultural purpose in rural areas increases pollution risk of groundwater. Ecosystems are altered and their ability to retain the protection services of both surface and groundwater is immensely compromised. Reduction of groundwater consequently harms the quality and quantity of groundwater sources (British Red Cross et al. 2014). Natural composition of groundwater can be altered through the chemicals and microbial matter disposal at the land surface and into soils, or through contamination of surface water by wastes, which eventually infiltrates into the aquifers.

1.11 Chapter outline

The research is organised into sections/chapters to provide for a logic debate. Chapter 1 identifies the research problem giving the background and introductory framework of the study. In this chapter, theoretical concepts underlying the study were defined. The chapter also highlights the employed research methods and approaches, orientation, ethical considerations, and challenges encountered during the data gathering, analysis and dissemination processes.

Chapter 2 covers the theoretical basis of the research. The Pressure and Release (PAR) model is discussed in relation to disasters and water pollution. In chapter 3, literature on groundwater vulnerability, quality, pollutants and their sources is reviewed. Chapter 4 gives a detailed analysis of the methodology used in conducting the research. Chapter 5 provides a summary of the results and analysis of the findings. Lastly, chapter 6 draws conclusions to highlight if the objectives of the study were achieved. Recommendations are given for future research and adoption in the water pollution field and disaster risk reduction (DRR) policy making.

1.12 Chapter summary

The chapter provided background information of the study to the reader; the problem statement and array of approaches used in information collection in order to answer the research questions and fulfill the study objectives. The final section of this chapter outlined the rest of the research. The following chapter provides a literature review of information regarding disaster risk reduction and the vulnerability of groundwater in the community under study. The legislation governing disaster management as a whole and related to groundwater in South Africa is also discussed.

CHAPTER 2: THEORETICAL AND LEGISLATIVE FRAMEWORK

2.0 Introduction

The chapter gives an overview of disaster theory and the concepts guiding this study. Theoretical frameworks are important as they help to put the study in the right empirical context (Kombo & Tromp, 2006). A conceptual framework is defined as a broad set of principles and ideas taken from appropriate fields of inquiry for use in constructing a given theoretical presentation (Dickson, Emad & Adu-Agyem, 2018). The Pressure and Release model developed by Wisner (1994) guides this research. The model was used as a research tool to identify the progression of vulnerability towards disasters and in particular, groundwater pollution risk. Addressing some root causes leading to a disaster would help build safe conditions that reduce vulnerability. The chapter also defines groundwater pollution hazard, explores its impacts and the justification as to why there is need for measures towards preventing and or reducing pollution risk. The chapter also gives an overview of the legislative framework guiding disaster management systems or approaches in South Africa.

2.1 Disaster theory

The Pressure and Release model is utilised in this study to review the progression of groundwater pollution risk among other disasters facing the municipal area.

2.1.1 Pressure and Release (Crunch) Model

The PAR model presented in Figure 2.1 below helps to understand risk in terms of assessed vulnerability in specific hazard situations. The model provides an outline of root causes that can lead to progression of vulnerability of groundwater leading to pollution and health risk. This results in increased pressure on people due to underlying vulnerability and growing hazard risk (Wisner, 2003).

The release incorporated in the model helps conceptualise the reduction of disasters. The relieving of the pressure and vulnerability brings safe conditions. The PAR model looks at two opposing forces interacting with underlying causes of disasters. On one end, there is increased creation of a vulnerable situation whilst on the other end the hazard itself. Vulnerability is defined as the degree to which the system or subsystem components are likely to experience harm due to exposure to the hazard, which can either be a perturbation or a stress/stressors (Turner, 2003).

The PAR model shows how unsafe conditions can lead to a disaster and how the conditions can be traced back to socio-economic dynamic root causes (the political and economic systems). In order to avert the risk of disaster, the whole chain of causation needs to be addressed at all three levels of vulnerability progression. The PAR model consists of four major components namely underlying or root causes, dynamic pressures and unsafe conditions as well as the hazards.

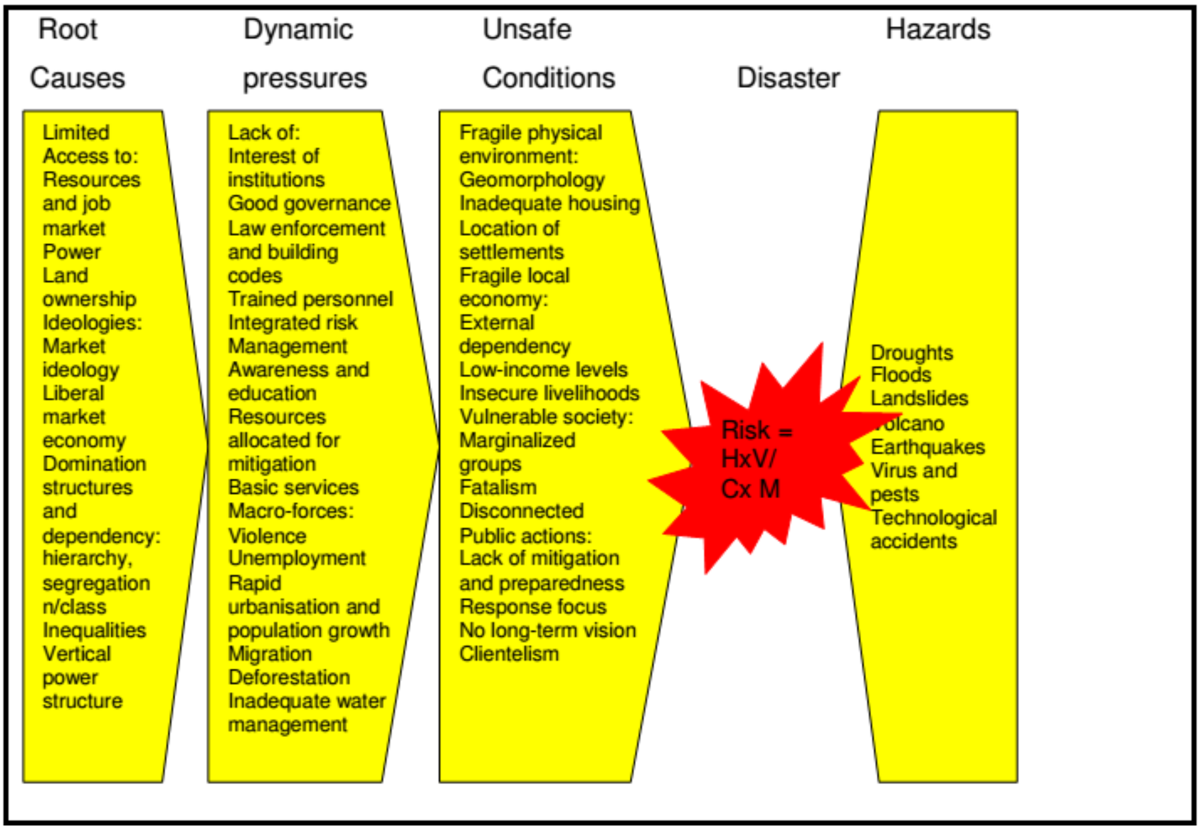

Figure 2.1: Progression of vulnerability

Source: Blakie et al, 2004

2.1.1.1 Root causes

Theoretically, the root causes are formed of a matrix of deep-rooted factors created by limited access to power and resources, which leads to vulnerability. For instance, a political system may create limited access to power to marginalised groups. Many governments often overlook such factors that may be distant from the disaster itself, as they appear more cumbersome to solve. The factors are usually left out in processes of drawing disaster management plans (Blaikie et al., 2004).

2.1.1.2 Dynamic processes

The negative macro-forces are usually transformed into unsafe conditions of physical and social environments of groups of people susceptible to vulnerability and risk (Wisner, 2003). These processes may be created by a lack of basic services e.g. lack of sanitation. In the context of this study, the result is the use of pit latrines that risk groundwater pollution. Other macro-forces such as a lack of adequate water management facilities in the face of rapid urbanisation can also lead to deforestation where applicable.

2.1.1.3 Unsafe conditions

Unsafe conditions expose property and people to disaster risks (Wisner, 2003). The unsafe conditions affect vulnerable people for example, by inadequacies in disaster preparedness measures, inadequate sanitation, fragile local economy and lack of long term vision. Unsafe conditions may include the use of pit latrines and use of pesticides that can contaminate groundwater among others.

2.1.1.4 Hazards

A hazard is a process, phenomenon or human activity that may cause loss of life, injury or other health issues, property damage, social and economic disruption or environmental degradation (UNISDR, 2009). Furthermore, a hazard poses a threat to humans and property. Hazards can be classified as natural or man-made. Natural hazards can be biological, climatological and geological whilst man-made hazards consist of famine, conflicts and industrial accidents among others. The impact of hazards to a given population depends on how vulnerable the population is to such hazards.

According Wisner (2003), a hazard refers to natural phenomenon that may affect different places singly or as a combination, at the same or different times. A hazard can be understood by identifying its causes; geographical distribution and frequency; elements and activities mostly vulnerable to destruction as well as; the possible economic and social consequences it causes.

2.1.1.5 Disaster

A disaster is referred to as a serious disruption of the functioning of a society that causes widespread human, material, or environmental losses and, exceeds the ability of the affected society to cope using only its own resources (UNISDR, 2005). Disasters can be classified according to cause (human–induced or natural and speed of occurrence (sudden or slow onset). Sudden-onset disasters are triggered by a quick or unexpected hazardous event, slow-onset disasters emerge gradually over time (UNISDR, 2009).

Disasters affect societies differently as some societies are more vulnerable to given disasters than others. The damage to property and casualty numbers is often used to measure the magnitude of a disaster. A disaster's increased impact is caused by factors such as poverty and environmental degradation (Blaikie et al., 2004).

2.1.2 Progression to safety

While the PAR model seeks to answer why there is development of unsafe conditions, the progression to safety model shows the reversal of unsafe conditions by addressing dynamic pressures and root causes. Progression to safety is depicted in Figure 2.2 below and development of appropriate skills in a society could upgrade their economic status and reduce their vulnerability.

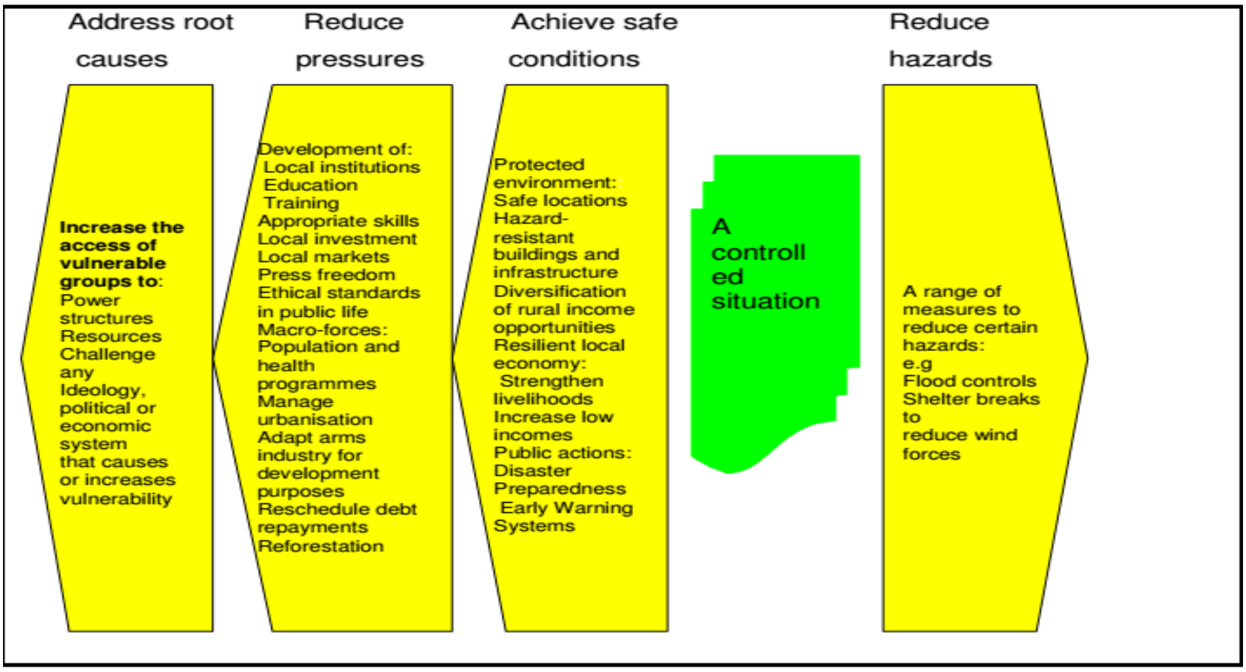

Figure 2.2: Progression to safety

Source: Blaikie et al, 2004

The main idea of progression to safety is to reduce vulnerability of the society through planning and implementation of measures that reduce the impact of hazards. The pursuit of favourable conditions reduces pressure and addresses root causes (Blaikie et al., 2004).

2.2 Application of the PAR model to Ga-Sengonyana municipality

Ga-Sengonyana municipality area is faced with increasing groundwater pollution risk caused by climate change as well as other political, socio-economic and land use factors. The application of the PAR model in this study will result in acquiring in-depth knowledge about groundwater pollution and ways to achieve progression to safety and more sustainable community livelihoods.

The Ga-Sengonyana district municipality area under study was mandated to prevent, reduce and mitigate disaster risks in its area of jurisdiction as is with all municipalities in South Africa (NDMF, 2005). Ga-Sengonyana community is not spared from the progression of vulnerability reflected in the PAR model. There are many known hazards, which affect Ga-Sengonyana municipality, and these include droughts, fires and groundwater pollution. Groundwater pollution risk is closely associated with land use changes that lead to environmental degradation.

Ga-Sengonyana municipality can however, create an environment that progresses towards safe groundwater quality. This can be achieved through reducing groundwater vulnerability by creating appropriate infrastructure, groundwater research, and good governance. This research assesses groundwater in Ga-Sengonyana municipality with the aim of investigating groundwater vulnerability to contamination. The results will inform measures for reducing the risk of ground water pollution.

Although the PAR model provides general information on most disasters (Wisner, 2003), some disasters do not necessarily follow the prescribed progression of vulnerability as shown in the model. Some natural disasters do not emanate from a political or political ideological standpoint. However, the approaches to mitigate their impact can be imbedded in power structures and ideologies. For instance, a hazard such as a cyclone, may affect the given population without regard to prevailing safe or unsafe conditions. In the same vein, groundwater pollution can occur instantly; immediately presenting its impacts despite existing dynamic pressures such as state of governance and prevailing economic situation.

Mitigation measures that can be implemented depend on preparedness of the local authority to disasters, which is in turn influenced by governance and economic state of populations before the disaster strikes. In some societies, good governance and better livelihood security enables a community to build ‘back’ better than before. In addition, in the wake of climate change, groundwater vulnerability in one nation may not lie in its own progression of vulnerability, but on other distant nation's activities. For instance, developed nations are highly industrialised and contribute to high pollution levels that can trigger climate change disasters even in areas where there is less pollution.

The vulnerabilities in groundwater pollution create unsustainable livelihood in the municipal area as discussed in the PAR model. For instance, the politics and ideologies such as economy in Ga-Sengonyana municipality have impact on the groundwater vulnerability and pollution risk. Socio-economic factors in the municipal area need to improve to enhance groundwater protection. The provision of sanitary services and houses in formal areas could reduce the risk of water pollution.

The efforts in the municipality to improve water governance should not be done in isolation, but should be integrated with community development projects and other disaster risk reduction measures aimed at reducing disaster impacts from other disasters such as drought. The municipal disaster management in South Africa can effectively manage disasters by working with other stakeholders such as police services and fire department during emergencies. Working together with other stakeholders can provide solutions to groundwater management problems.

The municipal disaster management office can also advocate for the declaration of a local disaster if the disaster impact exceeds the capacity of the local authority to handle it, though the declaration powers vest with COGTA minister (DMA, 2002). Funds can also be mobilised from local municipalities. The municipality mayor in this regard can release funds for handling disaster impacts such as water pollution.

With these measures in place, the vulnerabilities noted in the PAR model and sustainable livelihoods should be addressed. Funding is a challenge for disaster management centres because the cost of some disasters such as groundwater pollution is prohibitively high. The emphasis should be placed on integrating measures that are less costly and aimed at promoting sustainable livelihood and at the same time preventing groundwater pollution.

2.2.1 Root causes: power, politics and resources

The major challenges which Ga-Sengonyana municipality and the nation at large is facing against preventing, reducing and mitigating disasters are institutional, political and resource limitations (Council of Canadian Academies, 2009). Vulnerability in the PAR model's root causes cannot be fully debated without considering the historical political background of the apartheid era. The remnants of apartheid are still proving to be a hurdle in the new dispensation of democracy that dawned in 1994. During apartheid, the political system in the nation was skewed in favour of the predominantly white minority that ended up amassing more resources than the black majority. Effects of the political and economic resources distribution imbalance are still evident among the majority of blacks in South Africa. The access to resources among blacks' remains limited which leads to increased vulnerability during disasters.

Water management was privatised during apartheid. Water only became a public commodity in 1998 (RSA, 1998). Regardless of the time that has passed since the dawn of the democratic era in South Africa, inequality is still common. The root causes of vulnerability including groundwater tend to vary among different areas divided by race. However, the past apartheid system cannot be solely blamed for water management issues, as new dispensation policies emphasise equal distribution of resources in the country.

The existing institutions for disaster management have been primarily implementing policies in the vertical top-down approach causing major disaster management challenges in South Africa. For example, disaster management plans were being created at national level and then just being delegated to municipalities (South Africa, 2005). On the other hand, the economic system follows the pattern of resource allocation in South Africa. The lack of land ownership in Ga-Sengonyana has led to forceful occupation of land and establishment of informal settlements that usually lack basic sanitary services. Furthermore, pit latrines commonly erected in these areas are becoming a threat to existing groundwater resources.

2.2.2 Dynamic pressures in Ga-Sengonyana

Though the disaster management institutions are fairly well established from national level (with National Disaster Management centres) to the municipal level (Municipal Disaster Management Centres) in South Africa, implementation of policies in a top-down approach remains a big challenge (South Africa, 2005). Fragmented and overlapping jurisdiction as well as competing priorities facing the local Ga-Sengonyana municipality may be resulting in poor governance that has been leading to the prevailing unsafe environment. Governance is defined as an informed decision making process that enables trade-offs between competing users of available resources to balance protection and use in a way that ensures sustainability, enhances security, mitigate conflict and hold entrusted government officials accountable for their conduct during execution of their delegated mandate (Turton, Godfrey & Hattingh, 2006). Good governance forms the basis of effective municipalities (Department of Cooperative Governance (DCOGTA), 2014).

Poor governance manifests itself in the lack of financial and human resources needed to adequately research about water resource characteristics and functions, which at times lead to shortcomings of suitable legal provisions. Accessibility to resources on its own is also considered as a key factor to vulnerability in populations (Coppola, 2012). In some cases, the local municipality may lack incentives to prevent, reduce or mitigate groundwater risks.

Lack of integration of activities between the district municipal disaster management centers and local municipalities, further hampers disaster management effectiveness in South Africa (Sithole, 2014). As a result, capacity disjuncture between local and district municipalities can be partially blamed for such lack of integration. Besides lack of integration within the local spheres of government, the challenge also extends horizontally between different government administration spheres. According to Van Niekerk (2002), the distrust and conflicts between different spheres further undermines collaboration against overcoming obstacles.

Lack of skilled personnel in the municipal area compromises the creation of safe environments. In general, South Africa has skills shortage in fields that are more scientific and that hinder effective water resources management (Knuppe, 2010). For instance, lack of knowledge on geo-physical characteristics (recharge rate, discharge and vulnerability) of the underlying aquifer system in the jurisdiction area could have led to uninformed land use decisions that further jeopardise the water resource. Steward (2010) noted that novel policies on water governance were actually impeding sound implementation of pertinent water risk management strategies. This is expected to persist unless applicable simple concepts are created and easily communicated to stakeholders so that they change their approaches.

Rapid urbanisation, rural urban migration and population growth in Ga-Sengonyana could also be putting pressure on groundwater resources. Although groundwater resources are still being underutilised in many areas of South Africa, pressure still exists in terms of avoiding contamination of this resource (Knuppe, 2010). Yet clearance of existing vegetation to give way to urban sprawls in the municipal area can alter the natural hydro-geological process and that can lead to water contamination. Besides altering of the hydro-geological system, concentration of domestic waste in highly populated areas threatens surface and groundwater resources with pollution. The rapid population growth being witnessed in Kuruman a town under Ga-Sengonyana municipality also has a multiplier effect. There is expansion of industries and intensification of agriculture in areas around Kuruman. With these developments in place, there is a threat of infiltration of toxins, for example, through leached agro-chemicals and ever-increasing waste from booming populations. Figure 2.3 below shows an image of sewage ponds that serve Mothibistad location area.

Figure 2.3: Sewage ponds serving sewage system of Mothibistad residential area

2.2.3 Unsafe conditions in Ga-Sengonyana

Poor governance in the local municipality as an institution usually manifests itself by its response mode approach to disasters. In most areas where groundwater governance is lacking, resources may only be mobilised once the water quality is affecting stakeholders and available services are at risk (Tuinhof et al., 2003). At times, such response is because the risks can be prohibitively costly to mitigate. In most cases, groundwater problems in different areas are associated with governance failures rather than mere physical resources characteristics (Bakker et al., 2008).

Furthermore, a fragile physical environment is also witnessed in some areas around the municipal area. There is general inadequacy of housing. This has led to the mushrooming of informal settlements that lack basic sanitary services. Figure 2.4 below shows an image of one of the pit latrines in Maruping informal settlement in Ga-Sengonyana municipality area.

Figure 2 4: Pit latrine in Maruping village

Such informal settlements in the municipality area further present an array of challenges. Some informal settlements have poor building codes and are located in areas that impede the natural flow of water, making the areas prone to floods.

The dumping of waste around informal settlements poses a threat to surface and groundwater sources. Dumping becomes inevitable where people are informally settled. Yet the settlement of communities in those informal areas is mainly a response to some socio-economic factors that can be traced back to root causes such as national political factors and a poor economic system. These activities may lead to accumulation of pollutants in groundwater resources that pose a health disaster.

2.2.4 Hazards and disaster

The Ga-Sengonyana municipality area faces some of the hazards stated in the PAR model. In this research, groundwater pollution is regarded as a hazard due to the health risk it presents to many people. The unsafe conditions bridge the hazard and create a disaster. It is then necessary for the municipality to prevent or reduce unsafe conditions to avert or minimise the impact of a hazard that can lead to a disaster.

Groundwater pollution is classified as a slow onset hazard just like a drought. Meaning, ample time is usually given to mitigate the challenge of water contamination. Mitigation before the disaster strikes may be an advantage to remediate the challenge. Once aquifers are polluted, rehabilitation is prohibitively costly to a developing nation's local municipality. Considering their restrictive budget, they usually prioritise developments that are politically seen as 'more visible'.

2.3 National Disaster Management Framework

The Disaster Management Act of South Africa Section 7(1) provides for creation of the National Disaster Management Framework (NDMF) policy document. Among other important issues, the NDMF documents the diversity of risks and disasters that the republic faces. It therefore supports developmental measures meant to reduce vulnerability in disaster prone areas, communities and households at large (NDMF, 2005). In order to reduce disaster risks, the policy document informs development of disaster management frameworks and plans in provincial and municipal government spheres.

Effective disaster management implementation is enhanced by an NDMF that complies with the international disaster regulations as guided by the Hyogo Framework of Action. Table 2.1 below illustrates the link between NDMF and the Hyogo Framework of Action.

Table 2.1: NDMF and HFA linkage

NDMF	**Corresponding HFA priorities for action**
Key Performance Area 1: Integrated institutional capacity for disaster risk management	Ensure that disaster risk reduction is a national and local priority with strong institutional basis for implementation
Key Performance Area 2: Disaster risk assessment	Identify, assess and monitor risks and enhance early warning
Key Performance Area 3: Disaster risk reduction	Reduce the underlying risk factors
Key Performance Area 4: Response and recovery	Strengthen disaster preparedness for effective response at all levels
Enabler 1: Information management and communication	Use knowledge, innovation and education to build a culture of safety and resilience at all levels
Enabler 2: Education, training, public awareness and research	Use knowledge, innovation and education to build a culture of safety and resilience at all levels

Enabler 3: Funding arrangement for disaster risk reduction	Ensure that disaster risk reduction is a national and local priority with strong institutional basis for implementation

(Sources: South Africa (2002; 2005); UNISDR, 2005)

The NDMF comprises of four key performance areas (KPAs) and three supportive enablers that facilitate the achievement of objectives set out in the KPAs (NDMF, 2005).

2.3.1 Key performance area 1: Integrated institutional capacity for disaster risk management

Key performance area 1 recognises the need of establishing institutional arrangements to enhance disaster risk management in all three spheres of government (National, Provincial and municipal spheres) (NDMF, 2005). To meet this requirement, the following needs to be established:

- Arrangements for the development and adoption of integrated disaster risk management policy;
- Arrangements for the integrated direction and implementation of disaster risk management policy;
- Arrangements required for stakeholder participation and the engagement of technical advice in disaster risk management planning and operations; and
- Arrangements for national, regional and international co-operation for disaster risk management (NDMF, 2005).

Within the three spheres of government, the cooperative governance is facilitated through establishment of Disaster Management Centers and Intergovernmental Committee on Disaster Management (ICDM). The Municipal Disaster Management Centres (MDMCs) are the primary functional unit responsible for disaster risk management in metropolitan and district municipalities (NDMF, 2005). In that regard, the issues affecting groundwater pollution risk in municipal areas can be addressed by the MDMCs through education, training, research and making recommendations regarding funding towards preventing and mitigation of groundwater pollution (Knuppe, 2010).

The ICDM’s structure comprises of the three representatives from three spheres of government. Cabinet members act as representatives at national level, whilst at provincial and local governments by Members of the Executive Council (MEC) and Municipal council members respectively (NDMF, 2005). Cabinet portfolios of importance to issues pertaining to governing water management are Human Settlement, Water and Sanitation and Environmental Affairs, Forestry and Fisheries. An integrated effort of these portfolios can solve the municipal grass root issues of groundwater pollution risk through environmental, water and sanitation management.

Disaster management is a multi-disciplinary approach that requires an integrated participatory approach of stakeholders including the communities, technical experts, NGOs and volunteers (NDMF, 2005). The South African water sector still lacks both the integration between the water administrative structures and cooperation between different departments of government (Knuppe, 2010). However, the establishment of the Disaster Management Advisory forums in all the spheres of government will provide a platform for role players to consult and coordinate their effort towards effective disaster management. Although the establishment of the municipality disaster advisory forum (MDMAF) is not mandatory (NDMF, 2005), the creation of such a forum would foster co-operative water governance and stakeholder participation at local level.

2. 3.2 Key performance area 2: Disaster risk assessment

Disaster risk assessment is crucial in informing disaster risk management planning and disaster risk reduction to organs of state and other role players (NDMF, 2005). The assessment process requires disaster risk identification, analysis, evaluation and monitoring. It is important to identify the hazard involved and categorise it. The magnitude of a disaster risk is described by quantifying the vulnerability and losses resulting from such a disaster, taking into considering capacity available to cope with such a disaster. One of the key indicators in achieving the goal of disaster risk assessment is the establishment of documented clear mechanisms for assessment, monitoring and management of disaster risk by national, provincial and municipal disaster management centers (NDMF, 2005).

The research assesses groundwater vulnerability and pollution risk at a local municipal level in order to inform on prevention and mitigation measures. Research on disaster risks helps the authorities to come up with effective disaster risk management as advocated for by the second enabler of the NDMF.

2. 3.3 Key performance area 3: Disaster risk reduction

Key performance area 3 has the main objective of ensuring that stakeholders in disaster management develop and implement integrated disaster risk management plans at all (three) 3 spheres of government. The development of disaster risk management plans is guided by NDMC in consultation with the ICDM and National

Disaster Management Advisory Forum (NDMAF) (NDMF, 2005). The uniformity of disaster risk management in a nation is ensured by aligning disaster plans in all three sphere of government.

Disaster risk reduction recognises the need to set priorities for disaster management planning at national, provincial and municipal levels. At the municipal level the most vulnerable areas, communities and households are identified and priority is set for prevention and mitigation of disasters.

2. 3.4 Key performance area 4: Response and recovery

The response and recovery approach to disasters require coordinated and appropriate response and relief measures when disaster occurs or conditions prevailing are threatening to turn into a disaster (NDMF, 2005). Early warning is a step in the disaster cycle that can help reduce the impact of a disaster. Thus to be effective early warning systems should involve communities at risk, dissemination of public education and awareness of a pending disaster, effectively communicate messages and ensure community preparedness (UN/ISDR, 2006b).

In the case of disaster occurrence or impending threat it is important to conduct a rapid assessment as such a tool informs decision making. Although disaster impacts differ in context from area to area due to the vulnerability factor, the initial assessment helps to determine the resources that are required to cope with the disaster. The magnitude of disaster impact to the population and resources required to cope with such a disaster are useful as a guide on classification of the disaster and declaration by NDMC (NDMF, 2005). Groundwater pollution rehabilitation in the jurisdiction of a local municipality area could face prohibitive rehabilitation cost to be handled only by MDMC and the local authority. Resource mobilisation from national level could be required. The NDMF was not used as the main theoretical framework in this study as it is a practice lacking direct issues relating to water pollution risks.

2.4 Disaster management system in South Africa

The Disaster Management Act (DMA), National Water Act and Water service Act are discussed as main legislative frameworks guiding water governance in South Africa.

2. 4.1 Background of Disaster Management in South Africa

Post 1994, the Republic of South Africa (RSA) was marked with extensive reforms in the manner in which disasters were to be managed. There was enactment of the Disaster Management Act, 2002 (Act 57 of 2002 (DMA) that repealed the former Civil Protection Act 67 of 1977. The new Act entered into force on 1 April 2004. This was followed by the promulgation of a more detailed National Disaster Management Framework (NDMF) that enabled the nation to be at the forefront by integrating disaster risk reduction in the three government administration spheres through the decentralisation approach (Vermaak and van Niekerk, 2004).

2. 4.2 Disaster Management Act 57 of 2002

Department of Co-operative Governance and Traditional Affairs (CoGTA) administers the Disaster Management Act (DMA). The relevant Minister is assisted in administering DMA and its policy by a chain of administrative levels from the national to district level. The Act and Framework initiated a shift from a traditional reactive disaster response approach; to disaster reduction, prevention and mitigation approaches (Reid and Van Niekerk, 2005).

The South African Disaster management Act 57 of 2002 (DMA) defines disaster management as a continuous and integrated multi-sectorial and multi-disciplinary process of planning and implementation of measures aimed at:

- preventing or reducing the risk of disasters
- mitigating the severity or consequences of disasters;
- emergency preparedness;
- a rapid and effective response to disasters; and
- post disaster recovery and rehabilitation.

In that regard the DMA, as a legislation governing disaster management in South Africa, it focuses on Disaster Risk Reduction (DRR) to address vulnerability in all spheres of government (South Africa, 2002). The DMA ensures reduction of vulnerability through its four-fold focus areas namely:

- creating institutional framework and planning for disaster management;
- development of a detailed policy and strategic framework;
- disaster classification and declaration; and
- addressing funding of disasters.

Furthermore, the act deals with issues of volunteers and other ancillary matters applicable thereto (Department of Cooperative and Traditional Affairs (COGTA), 2012).

2.4.2.1 Institutional framework for Disaster Management

The Act puts emphasis on the establishment of disaster risk management structures within the three ties of government with focus on involvement of local communities, research centres, non-governmental organisations, traditional leaders, government parastatals and private sectors. DMA further requires the country president to establish an Intergovernmental Committee on Disaster Management (ICDM) comprising of cabinet members also involved in disaster management with Members of the Executive Council (MEC) of each province and municipal members also involved in disaster management at their levels.

DMA and NDMF's main thrusts are the establishment of institutions for disaster risk management through formation of disaster risk management centres in all spheres of government (Reid, 2008). The National Disaster Management Centre (NDMC) was established at national level within the Department of Co-operative Governance and Traditional Affairs (CoGTA); whilst at provincial level, the Provincial Disaster Management Centres (PDMC) were established in all nine provinces in the country.

At municipal level the Municipal Disaster Management Centres were established by metropolitan and district municipalities. The disaster management centres in three spheres of government were not supposed to operate as separate entities. They had to integrate their efforts and communication systems as provided for by the DMA. Figure 2.5 below shows an example of an integrated municipal disaster centre.

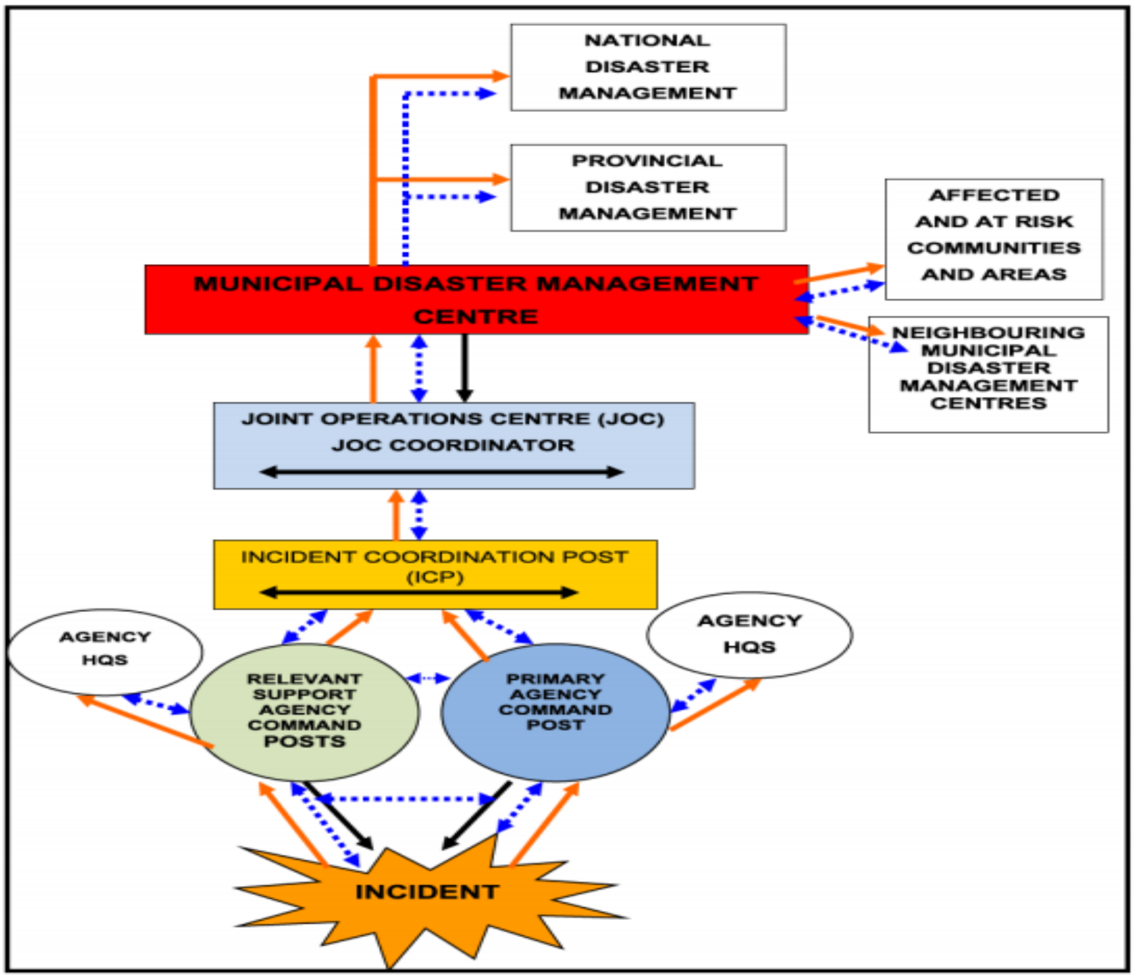

Fig 2.5: Integration of communication and reporting line in disaster management centre's

Source: Tshwane Metropolitan Municipality (2007).

Information is pivotal in DMA. Therefore, there is need for NDMC to establish a National Disaster Management Information system accessible to all stakeholders (DIMS) (S17, DMA). Advisory forums form the last pillar of institutional frameworks that serve as consultation institutions among state officials in the three spheres of government and various disaster management stakeholders. The stakeholders include chambers of mines, institutes of higher education, hospital organisations and paramedics (DMA, 2002). The National Disaster Management Forum (NDMAF) had to be established together with Provincial Disaster management centres (PDMAFs) and Municipality Disaster Management Advisory forum (MDMAFs) for each province and municipality as shown in Figure 2.6 below respectively.

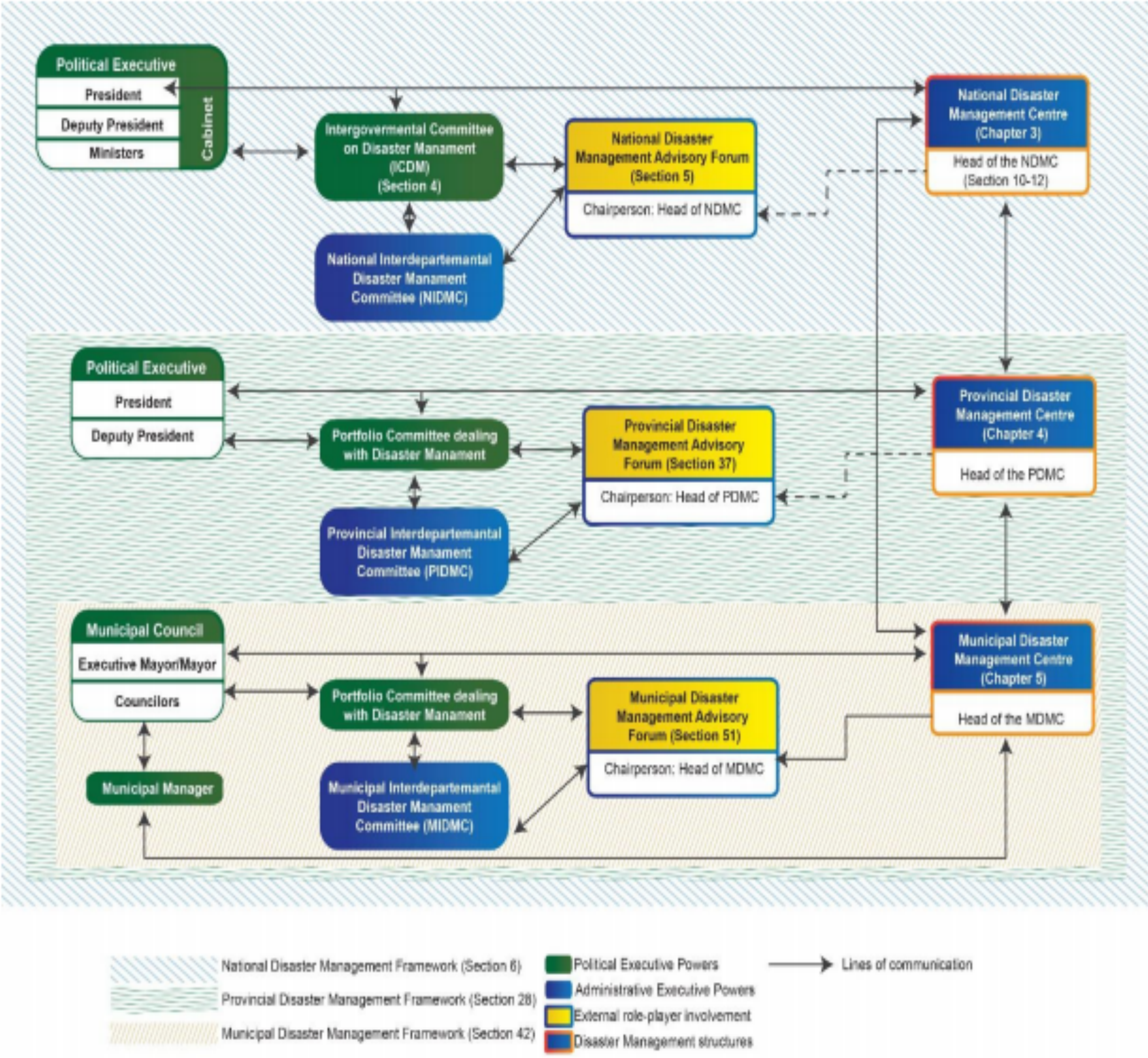

Figure 2.6: Disaster Management Structures at all spheres of government

Source: Van Niekerk (2005)

2. 4.2.2 Policy development and strategic planning framework

The Disaster Management Act states that there should be extensive policy development underpinning disaster management frameworks and plans (DMA, 2002). Disaster management frameworks are prepared at the national level, at provincial level and for each metropolitan area or district. All municipalities and each relevant organ of state must draft a disaster management plan, which translates national policy into an implementation strategy at national and at other relevant levels.

There is need for the plans to be consistent from district to national level. Unfortunately, the hierarchy of drafting plans can cause a drawback to other levels. For instance, the provincial level may not progress with its disaster management plan development if the national disaster management is yet to come up with its own plan. Yet development of such plans is integral for subsequent risk mapping, hazard monitoring, community incentives and empowerment among others.

Beside preparation of the requisite disaster management framework and plans, the DMA provides for a mandatory comprehensive system of annual reporting that applies to the NDMC, PDMCs and MDMCs. This report summarises activities, which include disaster monitoring, prevention and mitigation initiatives that were carried out throughout the year. It also shows the capacity of the relevant sphere of government to cope with the challenges of disasters, review of disaster management plans and evaluation of plans implementation progress.

2. 4.2.3 Classification and declaration of disasters

Disaster classification is the means by which primary responsibility and coordination of disasters, is shifted from one government sphere to another. The power to declare disasters vests in the relevant political head of the sphere. At national level, it is the Minister responsibility to declare a state of disaster. At the provincial and the municipal, level the responsibility lies on the premier of the province or municipality council to declare a state of disaster (DMA, 2002).

Qualification for dealing with a given disaster at national, provincial or municipality spheres is capacity of relevant sphere of government to deal with such a disaster in terms of scope. A localised disaster can be mitigated at the provincial or local municipality level concerned. The essence of declaring a disaster is to prescribe extraordinary measures for effective response and relief in form of emergency personnel, vehicles, facilities, relief holding facilities and temporary evacuation shelters.

2. 5 Linkage of Disaster Management Legislation with other laws

To determine the disaster management approach in a country, one may need to explore how the legislation links, or is complemented by other laws governing a country. It is important that disaster management legislation in a country recognises and works in collaboration with other existing laws and acts.

Legislature relevant to DM addresses vulnerability and disaster management cycle guidelines. These include; The National Veld and Forest Fire Act 101 of 1998; The Fire Brigade Services Act 99 of 1987; Safety at Sports and Recreational Events Act 2 of 2010; The National Environmental Management Act 107 of 1998 (NEMA); Minerals and

Petroleum Resources Development Act of 2002; and The National Water Resources Act 36 of 1998(NWA). For example, The National Environmental Management Act of 1998 and Minerals and Petroleum Resources Development Act of 2002 make it a legal obligation for the mining and other industries to monitor and mitigate pollution of water resources, including groundwater (DWA, 2010).

However, whereas Disaster Management legislation works hand in hand with other legislation as depicted above, in some cases legislation in another department slows the implementation of risk reduction measures in a different department. For example, NEMA requires a full environmental impact assessment to be carried out before commencement of any project, which may slow down any plan to urgently carry out certain risk reduction projects in some cases.

2. 5.1 National Water Act (Act 36 of 1998)

The dawn of democracy in South Africa in 1994 initiated aggressive legislation changes. Water laws were completely revised starting with the White Paper on National Water policy (DWAF, 1997) that was embodied in the Water Services Act (WSA) (Republic of South Africa, 1997) and the National Water Act (NWA) No. 36 of 1998 (RSA, 1998). These changes in water management legislation led to decentralisation and introduction of a participatory approach that was aimed at fulfilling the constitutional right of all citizens as noted that*, 'everyone has the right to have access to sufficient food and water'* (Republic of South Africa, 1996).

The National Water Act (NWA) is a legal instrument governing water resource management in South Africa. The Act prescribes the National government as the sole custodian of water resources. With Promulgation of this Act in 1998, water resources shifted from being regarded as privately owned to being a public commodity (RSA, 1998).

The NWA recognises water as a basic human need with an important role in meeting the goals of ecological sustainability, poverty alleviation and economic development. In order to meet these goals, the ecological reserve instruments were also established to meet basic human needs and ensure ecologically sustainable development including the protection of aquatic ecosystems (Benito, 2010).

The NWA emphasises integrated water resource management, sustainability, social equity, and this makes the law one of the most progressive water legislation in the world

(Van Wyk, Roux DJ, 2006). Despite the progressive nature of this Act, its implementation remains a challenge.

Department of Water and Sanitation (DWS) is the implementer of the National Water Act. The Directorate of Surface and Groundwater information also set the basis for the DWS to delineate groundwater data acquisition, management, regional monitoring, assessment, exploration and evaluation. In addition to that, they are also mandated to recommend water stakeholder applicants, for water licensing.

2. 5.2 The Water service Act

The Water Service Act further provides for strategic development of national and catchment-level water resources. The water management system was changed from the one previously based on administrative boundaries towards promoting management of water resources along hydrological boundaries guided by integrated water resources management (IWRM) approaches as shown in Figure 2.7 below.

Integration was promoted through the introduction of 19 Catchment Management Agencies (CMAs) made up of intermediate level and Water User Associations (WUAs). Local governments carry the responsibility to supply drinking water and sanitation services as well as regulating use of water resources while protection and management of water principally remains the domain of the central government's Department of Water Affairs (Benito, 2010; Pahle, 2016).

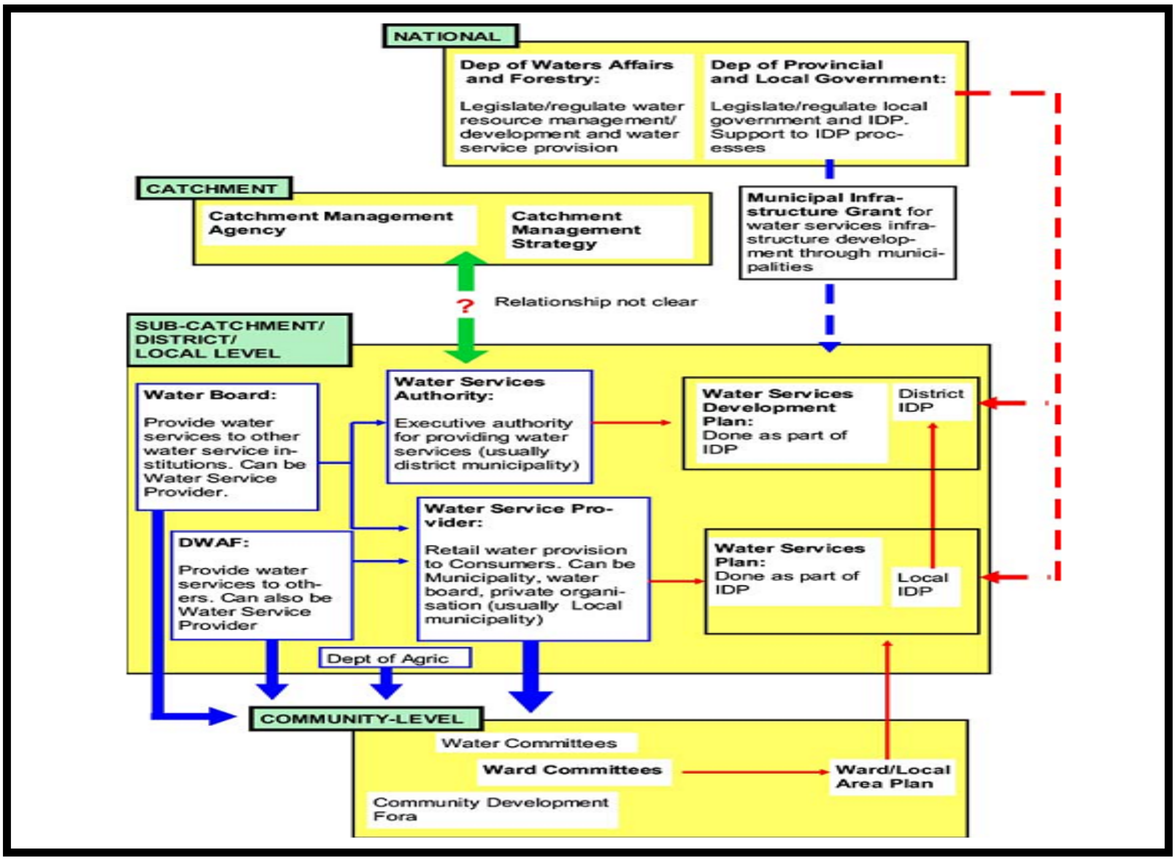

Figure 2.7: Integrated water management in South Africa

Source: Benito (2010)

2. 6 Conclusion

The chapter discussed the PAR model and its application to the study area. The South African government has established laws and administrative structures dealing specifically with Disaster Management as a generic functional area. Moreover, statutes dealing with specific disasters were established including fires and mining accidents. The Chapter also reviewed the Disaster Management System in South Africa giving its strength and weaknesses at all spheres of government. The National Water Act was discussed as the main act that influences water management in the country. The next chapter explores literature on groundwater vulnerability, quality and pollution. Though groundwater is important to water scarce South Africa, the information on its vulnerability to pollution risk is largely unknown.

CHAPTER THREE: GROUNDWATER VULNERABILITY, QUALITY AND POLLUTANTS

3.0 Introduction

This chapter explores groundwater vulnerability assessment methods, water quality and pollution findings from around the world. The chapter identifies groundwater vulnerability assessment methods and explores how they are conducted, and why there is a need for vulnerability assessment. Groundwater quality parameters are reviewed, giving close attention to water standard requirement by SANS 241 and concentration effects of parameters to health. Common pollution sources and pollutants of groundwater are also identified.

3.1 Groundwater vulnerability assessment

The recognition by scientists that some areas are more likely to become contaminated than others has led to terminology and practice of groundwater vulnerability to contamination. The technique of groundwater vulnerability assessment was started by Aller et al (1987) and modification was brought in such as Modified DRASTIC –Land Pattern (Umar, 2009) and Modified DRASTIC (Klug, 2009). Modified DRASTIC methods include the parameters that were not considered before. The Modified DRASTIC-Land Pattern model sometimes referred to as DRASTICA adds another factor ‘A’, called Impact of anthropogenic activities (Anjali et al., 2015). It is used to assess vulnerability in urbanised areas where anthropogenic activities alter the ecology and play a major role in groundwater contamination. Modified DRASTIC by Klug (2009) incorporates local hydrological settings and GIS to create a visual tool representing the risk areas.

While in some areas groundwater is more vulnerable to contamination than others are, it follows that all groundwater is vulnerable. Vulnerability to contamination of groundwater depends on many factors, including the following: depth of water table; composition of soils and geologic materials in unsaturated zone; environmental management influencing biodegradation; and the recharge rate (The National Academies of Sciences Engineering Medicine, 1993).

An increased understanding of factors influencing vulnerability, contaminants characteristics and their transportation mechanisms from or subsurface, has led to development of array of approaches for predicting ground water vulnerability. Effective ground water assessment requires one to determine the purpose of the assessment, selection of a suitable method, accessing quality data, conducting the actual assessment and making use of information gained for further research and use in policy formulation.

3.2 Elements of groundwater vulnerability assessment

Different ground water assessment methods consider key elements that include reference location, degree of contaminant specificity, pathway of contamination and time and spatial scales of the vulnerability assessment (Klug, 2009).

3.2.1 Reference location

The vulnerability assessment can be done based on prediction of time spent on transportation of contaminant to the water table from its source. Although the saturated zone is used as reference location, the contaminants are capable of moving within the aquifer. In reference location, it is important to consider the recharge zones (where precipitation infiltrates to reach groundwater) and discharge zones (where water moves towards a stream or discharge point), (National Academies of Sciences Engineering Medicine, 1993; Klug, 2009). Recharge may take the form of movement from high elevation to lower elevation along the water table gradient. In some cases, recharge can move in substantially downwards in the aquifer far below the water table. Furthermore, contaminants can spread widely on an aquifer potentially polluting large volumes of groundwater.

3.2.2 Degree of contaminant

The two types of vulnerability assessment approaches mainly used are specific vulnerability and intrinsic vulnerability. Specific vulnerability tracks specific contaminant, contaminant class or human activity, the intrinsic vulnerability approach does not refer to attributes or characteristic of a particular contaminant. Intrinsic vulnerability recognizes that a contaminant enters an aquifer by a variety of pathways such as joints, solution channels and biochemical in the zone of unsaturation. Most of the vulnerability assessment methods are intrinsic, as they do not refer to a particular contaminant (The National Academies of Sciences Engineering Medicine, 1993; Armengol et al., 2014).

3.2.3 Contaminant pathways

Vulnerability assessment only considers the contaminant that percolates downwards to the water table. Contaminants can enter the aquifer by many channels as illustrated in Figure 3.1 below. It is not only through percolation from the ground surface that contaminants reach the water table, there are other means that can be aggressive pathways of contaminants (Dochartaigh et al., 2005). These can be in the form of solution channels in the vadose zone, cracks, biochannels (root holes and wormholes) and joints.

In some cases, cross-contamination may occur between the two aquifers where a shallow contaminated aquifer is connected to a deeper aquifer via existing or improperly sealed or abandoned wells (Dochartaigh et al., 2005). In some vulnerability approaches, overlay information on potential cross-contamination of deeper aquifers by shallow aquifers is depicted on traditional maps.

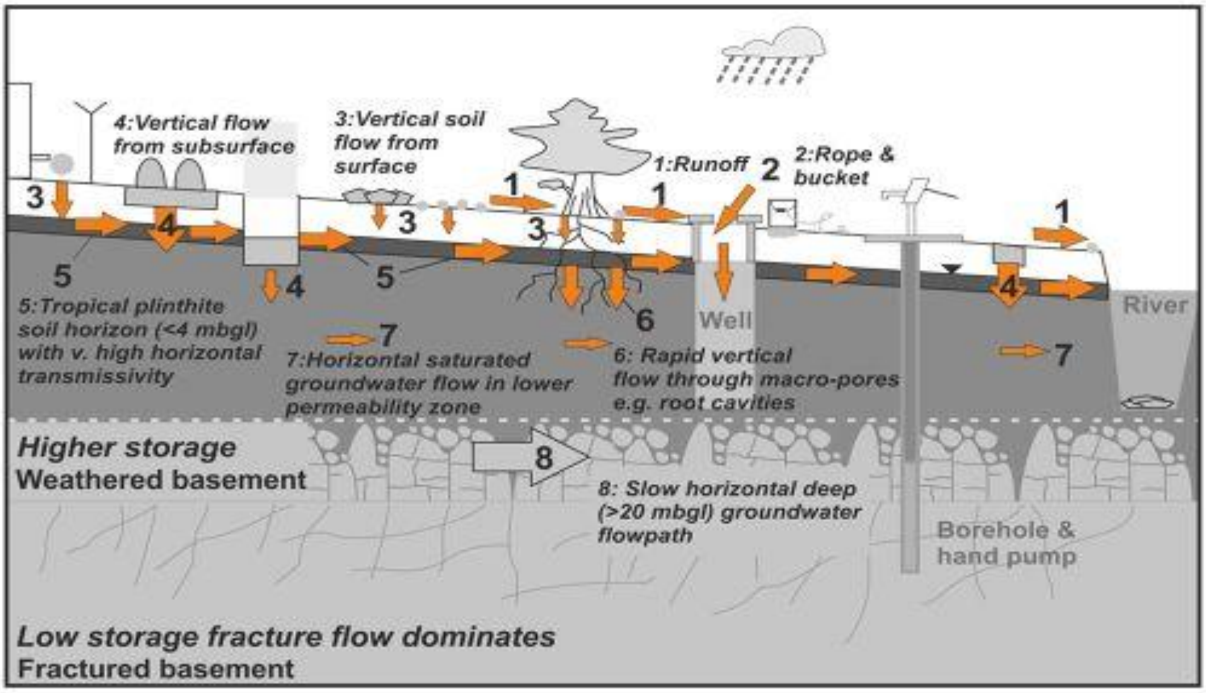

Figure 3.1: Potential contaminants pathways

Source: British Geological Survey Internal report, OR/15/009.

The discharge of water from groundwater by human use of boreholes may result in changing the flow regime of groundwater. While most vulnerability to contamination is treated as static, pumpage induced movement of water from a shallow aquifer to deeper aquifer may be a significant consideration in some cases (Umar & Ahmed, 2009).

3.2.4 Spatial scales

Vulnerability assessment is often shown in the form of map delineating areas of different vulnerability (Klug, 2009). The usefulness of such maps depends on the scale at which data is available, scale at which results are displayed and spatial resolution of the mapping. Vulnerability assessments often differ from small field area to large area such as national level. The degree of resolution required for assessment may depend on the purpose it is intended, the capacity to handle information, available information and the area size being assessed.

3.3 Vulnerability assessment process

The vulnerability process takes into consideration the purpose of assessment; assessment method selection, factoring uncertainty and evaluation issues; identifying data needs, its availability and quality; and use of assessment tools in management of groundwater (National Research Council, 1993; Dochartaigh et al., 2005). The vulnerability assessment process is shown in Figure 3.2 below.

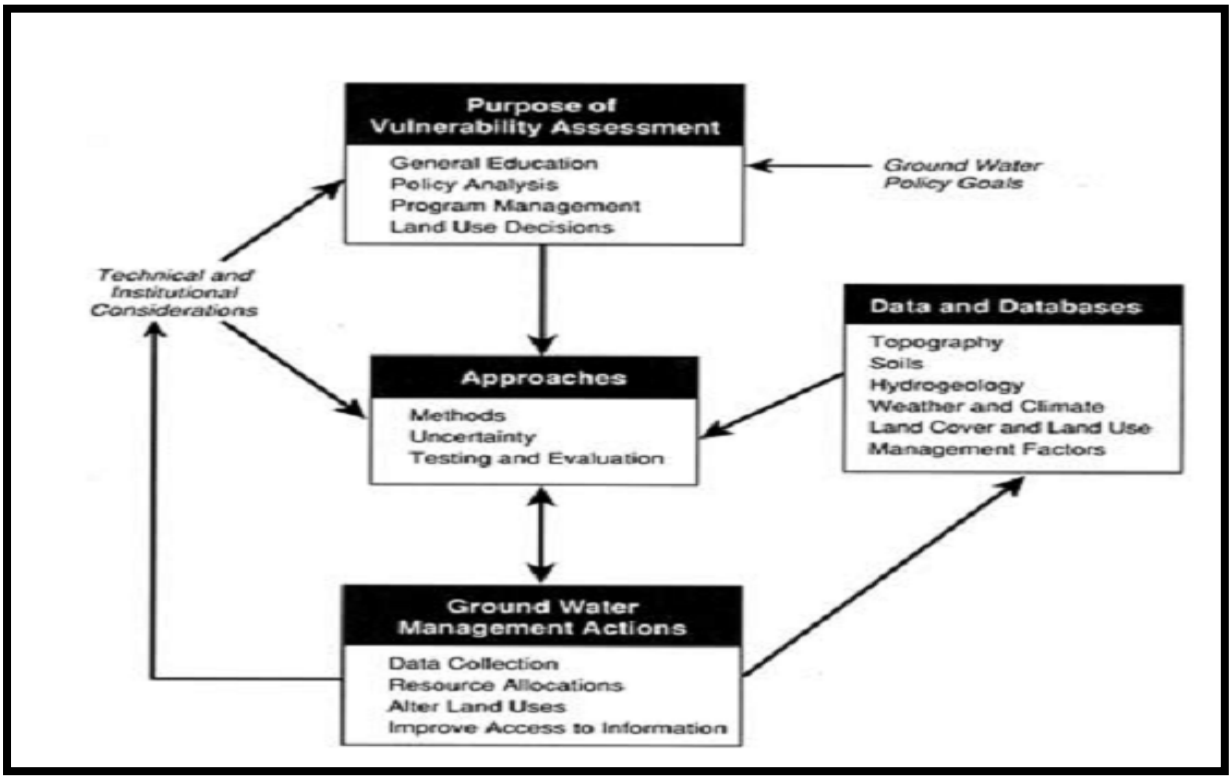

Figure 3.2: Process of vulnerability assessment

Source: National Research Council (1993)

The flow chart (Figure 3.2) shows that the approaches for groundwater assessment are not only central to the process of vulnerability assessment, but is also influenced by data availability, purpose and groundwater management actions.

3.3.1 Purpose of the vulnerability assessment

The process of vulnerability assessment begins with the identification of the purpose of the assessment. The assessments can be used for policy development or analysis; guiding programme management (in allocation of scarce resources); to inform land use decision such as potential of contamination on alteration of land use activities; and to improve general education and awareness of hydrologic resources (National Research Council, 1993; Klug, 2009). Selection of the vulnerability assessment method may also depend on complexity, cost of conducting and available information.

3.3.2 Factors affecting selection and use of vulnerability assessments

Technical and institutional factors influence the match between the vulnerability assessment selected, the use of vulnerable assessment output and the purpose. Technical issues that are considered include type or form of output, the feasibility of technique considering physical characteristics of the area assessed, data availability and its adequacy, and uncertainty in output (National Research Council, 1993; Benito et al., 2010).

Diverse types and forms of vulnerability assessment output may be required to meet various needs (Wright, 2010). The results of the assessment are often illustrated in the form of a map that may show different extent of vulnerability by shading or coloring. Uniqueness of maps in being easy to depict could be suitable means of conveying messages to decision makers.

Analytical techniques used for a specific vulnerability of an area should be compatible with physical dimensions and characteristics of the area. The area to be assessed may range from as small as a field or as big as the whole nation (Kung, 1990).

Data availability and its volume is a major factor that is considered in selecting an assessment technique. Uncertainties associated with vulnerability assessment process are commonly attributed to lack of available data, misunderstanding or relevant environmental process and statistical errors in use of statistics models (Klug, 2009).

Institutional issues are considered in the process of vulnerability assessments, though they are not mutually exclusive, they tend to overlap with technical issues. The period of vulnerability assessment should be carefully chosen as various factors such as pollutant and vadose zone characteristics affect the time of movement from the source of pollution. Thus, a vulnerability assessment may be conducted at regular intervals, longer time spans and greater distances than commonly done in conventional methods of vulnerability assessment (National academic press, 1993).The feasibility of this may be determined by cost and personnel available.

There are costs incurred in carrying out any vulnerability assessment. The vulnerability assessment may require experts, computers, software, and testing equipment that can demand huge cost (National Research Council, 2003). In whatsoever methods and cost incurred, it is imperative that the resources channeled for investment should be consistent with the values of the results. The vulnerability assessment process should work in coordination with other planning programmes and needs.

The vulnerability assessment process can be done as an integral part of groundwater strategies aligned to protection of groundwater, or in some cases, it is done to address a particular groundwater issue. In the case of a one-time activity of an area survey of its groundwater status, the approach usually utilizes existing data using a readily available assessment method to produce results in a short period of time (Aller et al., 1987).

3.4 Approaches to vulnerability assessment

The identification of the purpose is followed by selecting a suitable approach for assessment. In this stage, pitfalls and the data required in the chosen model are determined. The model is tested considering these assumptions. Approaches to groundwater vulnerability assessment ranges in complexity from map data evaluation to use of complex contaminant transport models (U.S. Environmental Protection Agency (EPA), 1992; Al-Zabet, 2002). According to Al-Zabet (2002), groundwater vulnerability assessment can be classified into two broad categories as specific vulnerability and intrinsic vulnerability assessments. While specific vulnerability is referenced to a specific contaminant, intrinsic vulnerability refers to vulnerability determined without referring to a specific contaminant. Three major methods of vulnerability assessment used are:

- Overlay and index method that gives a score on combining specific physical vulnerability characteristics.
- Process based methods using mathematical models that predict substance behaviour in subsurface environment.
- Statistical methods drawing associations from the source of contamination (National Research Council, 2003).

The summary of methods in each classification is shown in Table 3.1 below. The methods have similarities and differences. In general overlay and index methods are usually applied on small map scales (large study areas), while current process based models are applied on larger scales (smaller study areas) (EPA (1992a).

Table 3.1: Methods used to evaluate groundwater vulnerability to contamination in the USA.

Method	References	Reference location	Intrinsic and or Specific
1)Overlay and index methods			
Kansas Leachability Index	Kissel et al, 1982	Soil	Intrinsic
DRASTIC	Aller et al, 1985, 1987	Ground water	Intrinsic and Specific
2) Process-Based Simulation Models			
Gleams	Leonard et al, 1987	Soil	Specific
Mouse	Steenhuis et al, 1987	Groundwater	Specific
3)Statistical Methods			
Discriminant Analysis	Teso et al 1988	Groundwater	Specific
Regression Analysis	Chen and Druliner 1988	Groundwater	Specific

Source: National Research Council (2003).

Overlay and index methods evaluate intrinsic vulnerability or mixed specific and intrinsic assessments in contrast to process-based models and statistical methods that are designed for specific vulnerability assessments such as pesticides or nitrate.

Complex mathematical methods of vulnerability assessment such as process-based numerical models demand more detailed information and can precisely describe transportation mechanisms. Though this method can be precise, the drawback is on the large volume of data required by complex methods that is often unavailable giving way to approximation of some figures (Foster & Hirata, 1988; National Research Council, 2003).

Overlay and index methods are mainly favoured due to readily available data and is less complicated, though it does not fully describe the process that lead to contamination. Despite which method of vulnerability assessment is used, it follows that uncertainty is inherent in all vulnerability assessments as expressed in the second law of groundwater vulnerability. In this research, DRASTIC vulnerability assessment method was used to evaluate groundwater in Ga-Sengonyana district municipality. Different approaches may give different vulnerability rating results from all vulnerability methods; by itself, it cannot be subjected to experimental verification using scientific methods.

3.4.1 Overlay and index methods

Overlay and index methods combine a region's maps of a various physical attributes (e.g water table depth and soils) and assign a score or numerical index to each attribute. The method is well recognised and widely used as a modeling process in assessing aquifer vulnerability (Armengol et al, 2014). In the earliest overlay and index method, attributes were assigned equal weights in which areas of simple characteristic such as sandy soils and shallow groundwater are deemed vulnerable. In some cases, in a quantitative overlay and index method, attributes are assigned numerical scores and weights in developing vulnerability classes that are later displayed in the form of the map (National Research Council, 1993). Variables commonly used in this method include water table depth, groundwater recharge rate, and unsaturated and aquifer properties (e.g. geology and soil) (Klug 2009). The overlay and index methods are mainly driven by available data with less emphasis on processes controlling the groundwater contamination.

The depth to groundwater affects its vulnerability; short distance is more vulnerable than longer distance as the contaminants travel in less time in the former. In deep water tables, there is transit time for biodegradation and physical degradation of contaminants as compared to shallow water tables with lesser time for decontamination before percolating water reaches underground saturation zone (EPA, 1992a). The drawback of the overlay and index method is the use of a single depth of groundwater, yet fluctuations of water tables are common with seasons. Common variables used in the overlay and index method are shown in Table 3.2 below.

Recharge of the ground water varies in time in both seasonal and annual periods and over a region. Estimates of the recharge rate values account for inputs in the form of average monthly or annual rainfall, wastewater irrigation, artificial recharge and losses of water in form of evapo-transpiration and runoff (Hoyer & Hallgerg, 1991; Rahman, 2008). The locating of recharge and discharge zones in an area helps to predict the movement of contaminants to the groundwater zone. The prediction of recharge and discharge can be complicated where groundwater flow systems occur at different scales. Although the prediction of recharge and discharge may be difficult in itself, this variable is more important in groundwater assessment.

Table 3.2: Parameters used in selected overlay and index methods for vulnerability assessment

		Parameters related to			
Method	**Author(s)**	**Depth to groundwater**	**Recharge**	**Unsaturated Zone and Aquifer Material**	**Other**
DRASTIC	Aller et al, 1985, 1987	Depth to water table	Net recharge	Social media, vadose zone media, aquifer media, hydraulic conductivity	slope
Groundwater Vulnerability Regions of Lowa	Hoyer and Hallberg 1991	Depth to private well water sources	-	Aquifer type (alluvial, bedrock, glacial drift)and thickness of confinement by low permeability drift or shale	Location of sinkholes and agricultural drainage wells

Source: National academic press (1993*)*

Unsaturated and aquifer properties are at times incorporated into overlay and index methods. The unsaturated zone usually influences the vertical movement of contaminants towards ground water, while aquifer properties have the potential to affect the lateral movement of contaminants (Foster & Hirata, 1988; Shirazi,Imran & Shatirah, 2012). However, the aquifer material may form part of the unsaturated zone making it difficult to distinguish the two. It is for this reason that the reference location of this variable may be in any part of the groundwater flow system.

DRASTIC method tries to be universally applicable by incorporating parameters available virtually anywhere. The overlay and index method can obtain the information from available soil maps, topographic maps, geological maps and local land-use planning maps (Foster & Hirata, 1988; Rahman, 2008). The two case studies below show the results of the common vulnerability assessment methods (Overlay and Index) carried out in some areas.

3.4.1.1 Lowa area ground water vulnerability assessment (Overlay method)

Ground water contamination became an important political and environmental issue in Iowa In mid-1980s Groundwater contamination was raised as an important environmental and political issue in Lowa. There was research reports and news *making headlines on increasing incidence of contaminants in urban and rural well waters. The nitrate was noticed to be increasing to levels above 22mg/l (as NO_3) in local municipal and private wells as reported by the Lowa Ground water protection Strategy (Hoyer et al, 1987). Besides the high above standard required level of nitrate being served to about 27 % of population in the area, there was similar increase of pesticides detected. The situation in shallow wells in the area could be actually worse.*

Pesticides and fertilizers used in agriculture were most prominent in contaminants with other sources being lawn chemicals from urban areas, landfills and industrial discharge. The pathways used by the contaminants did not reach consensus as some argue the pathway of contaminants occurred due to preferential flow from point source due to anthropogenic influence such sinkhole formation and creation of agriculture drainage wells. On the other hand the argument was based on that there was widespread aquifer contamination due to slow movement of contaminants through the vadose zone.

Mandate, selection, and implementation

In the face of public concern over water pollution, the Ground water Protection Act was passed in 1987 through legislation. The policy formulations, which followed, focused on preventing further contamination and programmes were launched for researching and education to enable characterisation of the problem and finding the solutions. The Lowa Department of Natural Resources (DNR) that was given mandate to assess ground water vulnerability in the area came up with a map depicting the intrinsic susceptibility of ground water resources by surface or near surface activities. There were three main purposes of the assessment:

- *To evaluate physical characteristics of groundwater resources in the states;*
- *To assist planning through assessment output and formulate priories towards groundwater protection; and*
- *To create awareness about groundwater contamination and guide policy formulation.*

The assessment considered the potential impact of contamination of water resources and users of groundwater. The areas that had short travel time of water from surface to aquifer were considered to have high vulnerability to contamination, compared to those with long travel time. Radiometrics dating techniques were used to evaluate the travel time. The thickness of material in the vadose zone was also considered in the *assessment among other factors such as natural water quality in the aquifer, patterns of well location, documented occurrence of well contamination and types of aquifer.*

The map showing vulnerability was developed as shown below. Qualitative evaluation was performed for various wells in which areas of loose alluvial soils were considered highly vulnerable compared to areas with consolidated bedrock. The effect of different soils in the region was considered negligible since the soil formation was on average a relatively small part of overall aquifer or well cover. The assumptions and underlying principles were used to evaluate the area and generate output of assessment. In areas with thin overlying materials of sandy nature the vulnerability was considered to be high. Vulnerability was also considered high in areas where various human activities led to creation of sinkholes and agricultural drainage wells that allows passing of water with potential contaminants over natural protective layers to directly settle in a saturated zone.

Inclusion of GIS in vulnerability assessments significantly improved the construction of maps and clearly displayed spatial information. The map that was generated with the use of GIS was in general to communicate the qualitative susceptibility of contamination from the surface basing on material present in unsaturated zone and its depth, water quality of the aquifer, land uses and presence of features that can alter transportation of contaminants. The Lowa vulnerability assessment presents an intermediate programme highlighting the natural ground water system and effects of various land use activities on the system.

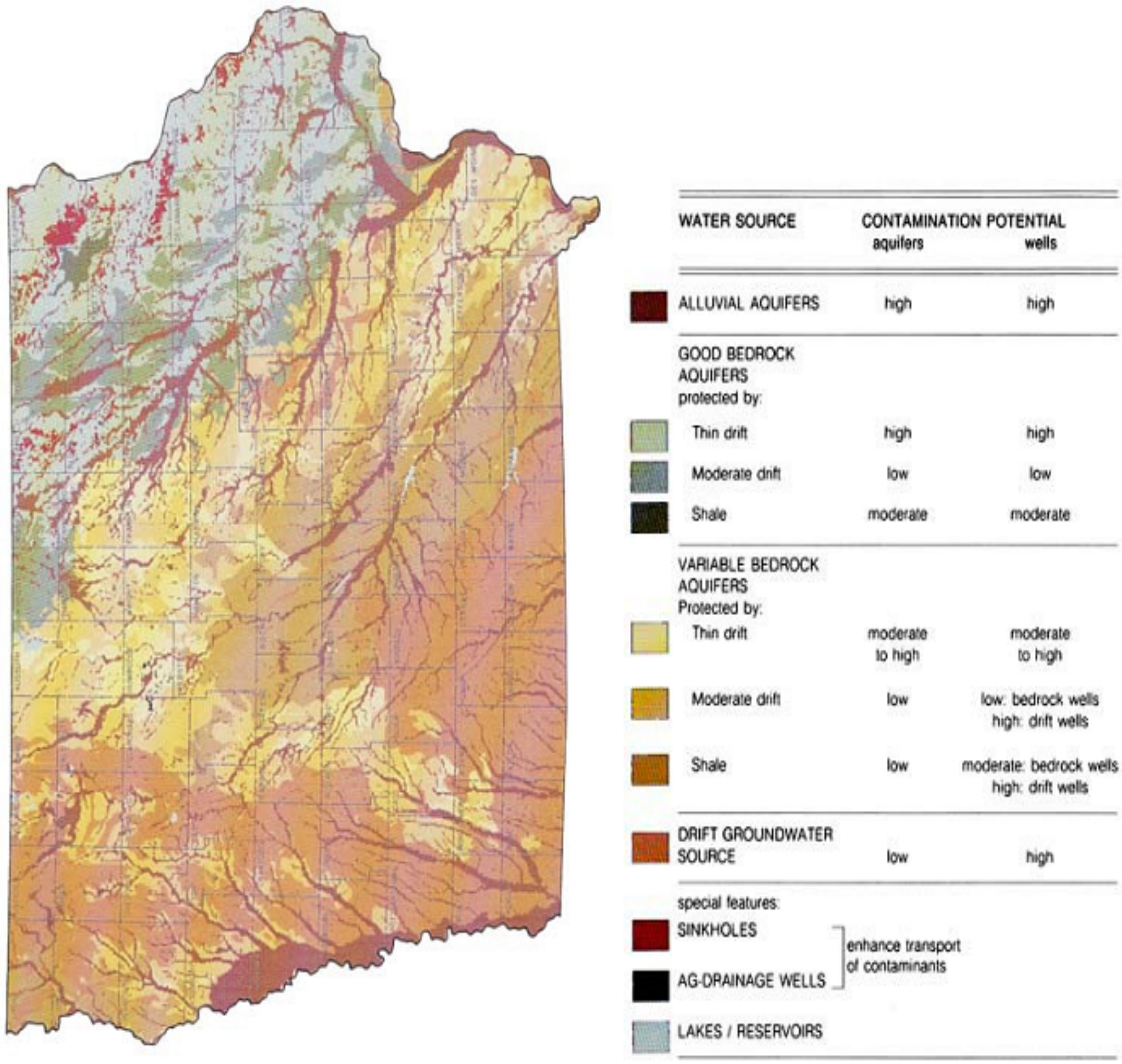

Figure 3.3 Map showing ground water vulnerability regions of Lowa (Hoyer 1991)

Source: National Research Council (2003

The output of the overlay method is usually in the form of an overlay-type vulnerability map that superimposes the series of maps depicting attributes important in identifying potential contaminants such as recharge rate, groundwater depth and soil types. Equal weight is given to the variables with a certain pattern defining differing vulnerability ratings on a single map. Some overlay methods are simpler, for example one developed by Petty John et al (1991) in USA for the evaluation of potential contamination in shallow aquifers in different states. Moreover, the method also includes population density as an additional factor in influencing vulnerability. Overlay methods are usually practiced at regional or state level.

Contrary to overlay maps used in the overlay method, in the index methods a numerical value is assigned based on magnitude or qualitative ranking. Experts assign a weight to each attribute. The final overall numerical score of groundwater vulnerability is obtained by summing up weighted attributes (Aller et al, 1987).

The numerical scores are used to group areas of assessment into different categories (low, medium, and high) and is then illustrated on the map. A common example of index method is DRASTIC index method. Some different types of index methods similar to DRASTIC method were developed for example GWVIP AND GWVIN for vulnerability assessment of nitrates and pesticides (Kellogg, Maizel & Goss, 1992).

3.4.1.2 Cape Cod groundwater vulnerability assessment (Index vulnerability method)

Cape Cod sand and gravel aquifer is the designed sole water source in Massachusetts United States of America, covering an area of 643 km² and serving a population of 500,000 people as well as ponds and marine embayment. Land use changes because of intense development of open land led to contamination incidents. Different associations that include U.S Geological Survey, the Massachusetts Department of Environment Protection and EPA put effort in groundwater management.

As a response to growing pressure on contamination the Area Wide Water Quality Management Plan for Cape Cod (Cape Cod Planning and Economic Development Commission (CCPEDC)., 1978b) was created under auspices of section 208 of federal Clean Water Act. Its mandate was to spearhead the groundwater management strategy for Cape Cod Aquifer. The main aim was to regulate nitrate concentration in drinking water, protection of groundwater and regulate sewage collection systems. The water table map was developed by CCPEDC in 1978. A number of programmes were developed thereafter to improve water management. In 1982, CCPEDC described down gradient and lateral capture limits of a well in a uniform flow field using analytical hydrauli model (Horsely, 1983). In the same area, Health (1988) developed DRASTIC vulnerability assessment of Sandwich Moraine setting and Barnstable Outwash Plain in which two distinct zones were delineated based on hydro-geological settings as shown in the map below.

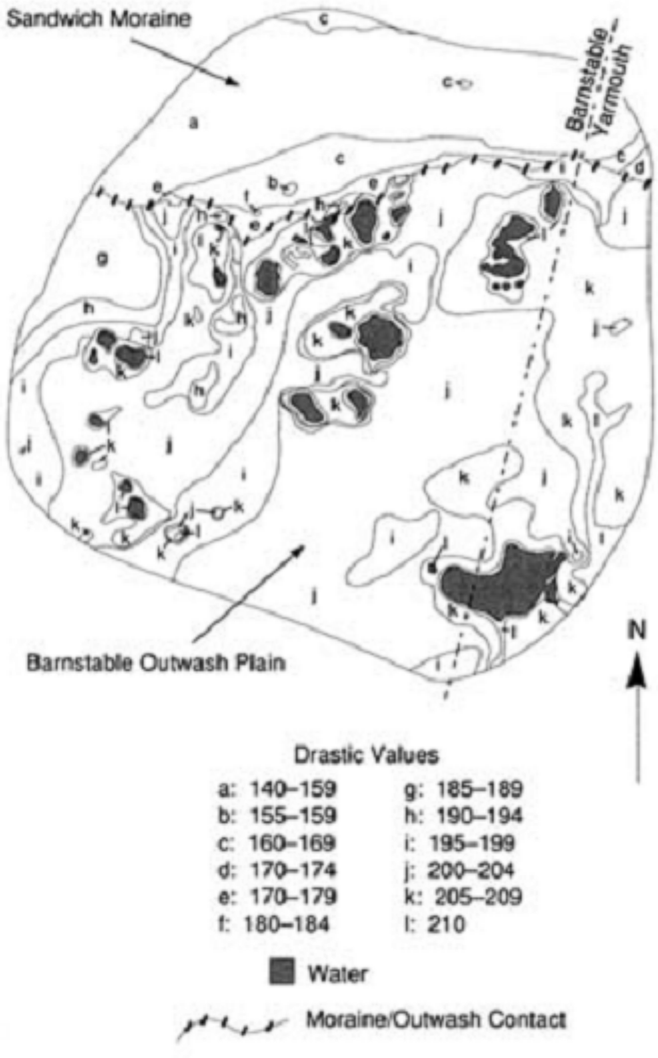

Figure 3.4: DRASTIC contours of Barnstable-Yarmouth Massachsetts

Sandwich marine physiological setting comprise of silt deposits, sand and gravel with water table depth of 43.75m scored values of 140 to 185 and Barnstable Outwash plain characterized by fine gravel, permeable sand deposits and water table depth of 15m yielded drastic score of 185 to 210 as shown in the tables below. The results were interpolated to the Cape Cod area with near similar physiological characteristics to have same DRASTIC scores of moderate to high vulnerability (Heath, 1998).

Table 3.4: Ranges, rating, and weights for DRASTIC study of Barnstable Outwash Plain Setting (feet = 0.305m)

Factor	Range	Rating	Weight	Number
Depth to Water	0-50+ feet	5-10	5	25-50
Net Recharge Per Year	10+ inches	9	4	36
Aquifer Media	Sand & Gravel	9	3	27
Soil Media	Sand	9	2	18
Topography	2-6%	9	1	9
Impact of Vadose Zone	Sand & Gravel	8	5	40
Hydraulic Conductivity	2000+ gpd/ft^2	10	3	30
				Total = 185-210

Table 3.5: Ranges, rating, and weights for DRASTIC study of Sandwich Moraine Setting (feet = 0.305m)

Factor	Range	Rating	Weight	Number
Depth to Water	0-100+ feet	1-10	5	5-50
Net Recharge Per Year	10+ inches	9	4	36
Aquifer Media	Sand & Gravel	8	3	24
Soil Media	Sandy Loam	6	2	12
Topography	6-12%	5	1	5
Impact of Vadose Zone	Sand & Gravel	8	5	40
Hydraulic Conductivity	700-1000 gpd/ft^2	6	3	18
				Total = 140-185

Source: National Research Council (1993)

3.4.2 Process –Based Simulation Models

Process based simulation models are unique because they predict transportation of contaminants over a defined space and time (Jury & Fluher, 1992). The concentration of contaminants can be predicted in their depth and concentration by simulations based on one-dimensional transport. Table 3.6 below indicates the chemical, physical and biological processes used in several simulation models to predict pesticide behavior in vadose zone.

Table 3.6: Process and simulation models showing different processes used in predicting pesticide behavior in the vadose zone

Process	Simulation model	
	CMLS (Ver.4.0, 1987)	**GLEAMS (Ver.1.8, 54, 1989)**
Water flow	Piston displacement of water. Instantaneous redistribution between field capacity and wilting point.	Predicts water flow between soil layers based on a storage similar to the tipping bucket method
Runoff	Runoff not considered	Runoff based on SCS curve number method
Solute transport	Piston displacement of solute	Convection transport of solute using water flow between soil layers.
Solute Dispersal	Tracks a non-dispersive solute point	Numerical dispersion used
Sorption	Input solute and organic carbon	Input solutes and organic matter
Degradation	Input solute	Input solute
Evapotranspiration	Input daily evapotranspiration	Input potential evaporation
Roots	Input maximum rooting depth	Input maximum rooting depth

Source: National Research Council (2003)

Besides prediction of depth and concentration of contaminants, it can make use of computer algorithms to predict the vertical and areal spread of contaminants in defined time and activities in vadose zone and saturated zone such as microbial, physical and chemical processes (National Research Council (NRC, 1993).

The models have different complexity with LEACHM being the most complex and most sophisticated as it includes more processes. The other models such as GLEAMS and PRZM are less sophisticated with less data required and are designed to assist in making management decisions. Though they have the advantage of requiring less data, they provide less prediction of the contaminant behavior.

Sophisticated models do not necessarily provide accurate output as they may encounter data challenges. The lack of data leads to the estimation of unavailable data or extrapolation of data obtained from other locations. This suggests that simplified process representation models can be more useful in some vulnerability assessments as they require less data, which is not readily available. All the simulation models have a drawback on the spatial scale in which process conceptualization is valid (Jury & Fluher, 1992; Umar 2009). Preferential flow may exist, such as bypass flow and in that case, no simulation model takes account of contamination movement in that phenomenon on a finer spatial scale.

3.4.3 Statistical techniques in vulnerability assessment

Statistical approaches are not as popular as overlay, index, and simulation models though they can be used to evaluate, determine and quantify association between measures of vulnerability and information related to vulnerability (Hoyer & Hallgerg, 1991). It predicts uncertainty occurrence as a probability distribution. The vulnerability of groundwater is considered as a probabilistic notion. Therefore, statistical methods should be used frequently in prediction of vulnerability assessment.

While other methods that deal with description of physical relationships cannot predict contamination precisely on a defined scale, statistical method can easily deal with scales. Furthermore, the statistical approach is flexible because of available statistical techniques for handling assorted data. Various statistical methods have the benefit of incorporating quantitative, qualitative, or mixed data and truncated or censored data (National Research Council, 1993). Statistical methods include analysis of variance, simple and multiple regressions for single and multivariate variables, discriminant, cluster and geostatistical analysis.

Statistical methods attempt in mathematical terms to describe the link existing between water quality and natural and or anthropogenic features in a defined area through the surrogate or independent variable use (National Research Council, 1993). Unlike other vulnerability assessment methods, statistical method has no predetermined subset of variables included in the model. The approach in itself is a hybrid approach, with few cases of using it. Statistical techniques have been applied in vulnerability assessment in regionalisation and assessment of vulnerability with probability models (Umar, 2009).

Vulnerability assessment output can be increased by use of statistical analysis (National Research Council, 1993) .The probability of a pollutant to contaminate an area can be predicted in groundwater evaluation using analytical methods such as regression analysis, cluster analysis, components analysis, and discriminant analysis (Klug, 2009). Multivariate of statistical techniques can be used in analysis of water quality. Naturally, water quality is influenced by a variety of factors not by a single constituent (Riley et al., 1990). Therefore, multivariate statistical techniques can be utilised in water quality analysis in a region, which includes techniques such as land management practices, soils and geological information and vegetation. Multivariate approach is also common in overlay and indexing techniques though the methods lack the probability estimates.

The assessment of groundwater vulnerability requires information from a variety of geographic data and databases. Compiling of spatially referenced data in vulnerability assessment, results in generating analog outputs (i.e., paper maps) or more modern digital format storage (Klug, 2009). These databases are used for resource management, vulnerability assessment and policymaking.

3.5 Data and databases

Effective groundwater vulnerability assessment demands information on spatial and non-spatial attributes of physiographic characteristics of an area to be evaluated. Although variety of vulnerability assessment approaches demand different data, a combination of natural factors may commonly be required. The natural factors required in groundwater vulnerability assessment including DRASTIC index may include topography, soil, hydrogeology, weather and climate, land cover and human related factors that include management and land use (Dozier, 1992; Dochartaigh et al., 2005). The uncertainties of any assessment is reduced not only by availability of data, but also the quality of data counts, coupled with the validity of the approach being employed. To come up with a reliable assessment, a synergy is required concerning model development and data collection (Armengol et al., 2014). Availability of data and its quality directs the type of modeling which can be used.

3.5.1 Topography

The landscape of an area affects groundwater quality through its influence on hydrologic processes of infiltration and runoff. Topographic features that influence drainage include slope, slope shape, aspect, snowmelt patterns and drainage basin delineation that can be derived elevation data (National Research Council, 1993). The slope parameter is used as one of the parameters in DRASTIC index scoring. Digital terrain data can be used for groundwater vulnerability assessment in a region, though data may not be accessible with uniform spatial and attribute features. Readily available data at map scales of 1: 50 000 could be used for area analysis or high resolution larger scale of 1:10 000. In some instances maps featuring area of high density features such as forest and towns, its terrain data may be influenced by such features that are above the terrain. Therefore, there is need for caution to be exercised when using such data.

3.5.2 Soils

Soils and parent material that exist in the vadose zone and aquifer itself have great influence on transportation of contaminants to the groundwater and within the aquifer (Aller, 1987). Soil media parameter is an important parameter in determining groundwater vulnerability using the DRASTIC index method. The rapid connection of groundwater to surface waters makes it is imperative to understand how soil as media influences groundwater recharge rate and its quality. Furthermore, understanding of the interaction of possible surface pollutants, soil characteristics and percolation of water through the soil help to predict how certain management practices can influence groundwater pollution risk. Often the soil properties affect degradation rate, rate of contaminant transportation and its retardation (Keesstra, 2012).

In essence, soils in a landscape form a continuum and are spatially variable by nature. The soil characteristics used in vulnerability assessment usually varies in time and space thereby allowing areas to be divided with greater homogeneity (Wilding, 1985). In soil mapping the units are named following dominant soil series within the mapped polygon (U.S. Department of Agriculture, 1991). Hydraulic properties of soil and soil organic carbon content are important for assessing vulnerability.

3.5.3 Hydrogeology

The characteristics of materials below the soil zone and effect of elevation of water table influences the pathway of contaminants to the subsurface. A hydrogeological database fuses data on water table configuration, properties of saturated consolidated and unconsolidated geological units and subsurface geology (Aller, 1987).

Shallow groundwater is generally more vulnerable to point sources and diffuse pollutants, due to short flow paths giving minimum time for biodegradation and absorption (Johnston, 1988; Klug, 2009). Conversely, deep groundwater gives ample time for pollutants to absorb or degrade through the vadose zone. The influence of hydrogeological and groundwater flow system on vulnerability to contaminants is shown in Table 3.7 below. The recharge rates of aquifers have influence on contaminants transport rate. Fractured aquifers may have a faster recharge rate compared to unconsolidated ones, making the former is more vulnerable to contaminates.

The rock nature of the aquifer plays a pivotal role in recharges and discharge rate coupled with its vulnerability (Pavelic et al., 2012). For instance, the dolomite and limestone aquifers are more vulnerable to pollution due to their nature of thin soil cover and being highly permeable with rapid fracture flow (Pietersen, 2004).

Table 3.7 Geological and hydrological features that influence an aquifer's vulnerability to contamination

Features determining aquifer vulnerability to contamination	Low vulnerability	High vulnerability
A. Hydrogeologic Framework		
Unsaturated Zone	Thick unsaturated zone, with high levels of clay and organic materials	Thin unsaturated zone with high levels of sand gravel, limestone, or basalt of high permeability.
Confining Unit	Thick confining unit of clay or shale above aquifer	No confining unit
Aquifer properties	Silty sandstone or shale limestone of low permeability	Cavernous limestone, sand and gravel or basalt of high permeability.
B. Groundwater flow system		
Recharge Rate	Negligible recharge rate, as in arid regions.	Large recharge rate, as in humid regions
Location within flow system (proximity to recharge or discharge area)	Located in the deep, sluggish part of a regional flow system	Located within a recharge area or within the cone of depression of a pumped well

Source: Johnston (1988)

3.5.4 Weather and climate

The water from precipitation and irrigation forms main transport agents for most groundwater pollutants. The weather and climate elements can influence water quality. These elements include; wind speed, relative humidity, air quality variables, air temperature and solar radiation (Pavelic et al., 2012).

3.5.5 Land use and land cover

Natural and anthropological activities occurring on the earth's surface make it possible for likely contaminants to enter the groundwater system. The land use cover does not only influence potential existing contaminants, but also infiltration rate of irrigation and precipitation water (Pietersen, 2004; Umar, 2009). For instance, urban land use may present factory chemical threats while agricultural land may be a potential source of agrochemical contaminants. Furthermore, the land cover has impact on the volume of water, chemicals and soil nutrients that can be taken up by the plants. The land use and land cover are influenced by development and are dynamic. This means data should not be absolute but must be updated frequently to effectively assess groundwater vulnerability. Due to changes in land use patterns and its influence on groundwater, contamination the parameter is now being used in some modified DRASTIC groundwater models (Umar, 2009).

3.6 Groundwater quality and pollutants

Groundwater quality is determined by concentration of physical, chemical and biological constituents in water. In South Africa the standard for water (SAN, 241) is used as a barometer to ascertain the quality of water for health risk, aesthetic, and operational use.

3.6.1 Factors influencing groundwater quality and pollution

There is a report of increased contaminants in the environment with the boom of global production of anthropogenic chemicals from as low as 1 million tons in 1930 to about 400 million tons produced per year in 2000 (Gavrilescu, 2015). This has resulted in increased contamination of surface and groundwater. Besides the chemicals polluting the water resources there are other various human activities that have significantly contributed to contamination of water resources with biological micro pollutants that include viruses and bacteria (David, Learner & Harris, 2009). Micro pollutants in groundwater sources pose a threat to human health, as they are associated with endocrine disruption, pathogen resistance and chronic toxicity (Rosal, 2010).

Groundwater quality is vulnerable to both point and non-point or dispersed sources of pollution (Scanlon, 2005; David et al., 2009). Groundwater pollution falls into two main categories; chemical and microbiological pollution. While chemical pollutants sources such as fluoride, nitrates and trace metals (sulphates, arsenic and chloride) originate from both natural and human source, the microbial nature pollutants posing threat to water sources are associated with human activities that are exposing human and animal faeces (Lehloesa, 2000).

The quality of groundwater is influenced partially by weathering products, length of residence time, depth of the water aquifer, landscape that in turn is highly vulnerable to anthropogenic activities through land use (David et al., 2009; Srivastava, 2012). The deep and less active aquifers have generally low levels of mineralisation than shallow active aquifers that have higher levels of mineralisation (Pietersen, 2004). Besides the effect of depth of water aquifers, land use activities affect groundwater resources through changes in recharge and influences pollutants reaching the saturated zone.

Movement of water in the aquifer is considered slower than on the land surface. The flow rate means pollutants can be effectively measured in years, decades or even centuries (Greswell, 1994). Unconsolidated rocks forming part of the unsaturated zone commonly contributes to intergranular and slow flow of percolation water. While unconsolidated aquifers may have slow water movement, consolidated aquifers are typically fractured, thereby increasing the speed of water flow (Keesstra, 2012).

Specific land use/land cover (LULC) types such as agricultural activities and urban expansions are linked to human activities and their physical characteristics affect water quality (Mukherjee, 2009). High rate of urbanisation, agricultural water demand coupled with demand for domestic water use from groundwater has major influence on changing recharge rates. Poor management of land use is linked to deteriorating water quality through making available point source hazardous chemicals and acceleration of flow into the saturated zone. In LUCL agricultural activities are marked as major non-point source of groundwater pollution followed by industrial and residential area respectively (Basnyat & Teeter, 2000). Poor agriculture activities contribute to increased leaching of nitrates and heavy metals on cleared land for agriculture and salt accumulation in irrigated areas. In this research, vulnerability of aquifers and land use activities leading to groundwater pollution in Ga-Sengonyana municipality area is investigated.

3.6.2 Groundwater constituents

Water constituents and its concentration levels present in natural water are used in South Africa to determine the quality of water, and in cases where they exceed minimum standards they become pollutants. The water constituents are defined as any properties of water and or substances suspended or dissolved in it (Department of Water Affairs and Forestry, 1996). This word is used interchangeably in international and local literature with: water quality variable; water quality parameters; and water characteristics or determinants. Water constituent’s concentrations (nutrients and microbes) that are important in determining water quality are shown in Table 3.8 below.

Table 3.8: Water constituents and its permissible concentration levels

A. Microbiological determinants		
	Risk	**Limits**
E.coli or fecal coliform count/ 100ml	health	Not detected
Total coliforms count/ 100ml	operational	< 10
B. Physical, Aesthetic, Operational and chemical determinants		
Conductivity at 25^{0}c mS/m	Aesthetic	≤ 170
Total dissolved solids mg/l	aesthetic	≤ 1200
Turbity	Operational Aesthetic	≤ 1 ≤ 5
pH at 25^{0}c	operational	≥5 and ≤9.7
Nitrate as N mg/L	health	≤ 0.9
Fluoride as F mg/L	health	≤ 1.5
Ammonia as N mg/L	aesthetic	≤ 1.5
Chloride as CL^- mg/l	aesthetic	≤ 300
Sodium mg/l	aesthetic	≤ 200
Manganese µg/l	Health aesthetic	≤400 ≤100

Source: SANS 241 (2015)

Health risk parameters falling outside the limits in Table 3.8 may cause acute or chronic health problems in individuals. Aesthetic risk parameters falling outside these limits indicate that water is visually, aromatic or palatably unacceptable. Operational risks parameters falling outside these limits may indicate that operational procedures to ensure water quality standards are met may have failed.

3.6.2.1 Nitrates

Nitrate (NO_3^-) occurs as the end product of oxidation of ammonia or nitrite (NO_2^-). Nitrate and nitrite exist together in the environment where interconversion readily occurs between the two. They are common in shallow groundwater associated with urban runoff, densely populated areas, and areas active with agriculture.

There is a demand for food as populations expand at exponential rate. This has resulted in high use on fertilisers to increase crop production that contribute to nitrate concentrations above the required minimum standards of ≤ 10 mg/l (Department of Water Affairs and Forestry, 1996). Nitrate pollution is widely researched in the world as both diffusion pollution and point source pollution from agriculture (David et al, 2009).

Nitrogenous nature pollutants travels from ground surface and subsurface to the groundwater through infiltration and percolation of water from main sources that are pit latrines, animal and domestic effluents, decomposed animal and vegetable matter and fertilisers applied in agricultural lands. The nitrogen levels permissible for various domestic uses are shown in Table 3.9 below.

Table 3.9: South African water quality guideline values of Nitrogen for potable use and livestock use

Drinking water class	as N	As NO3	Coments
Nitrate plus Nitrite (mg/l)			DWAF (1998)
Ideal	< 6	< 26	Negligeble health effects
Acceptable	6-10	26-44	Insignificant risk
Marginal	10-20	44-89	Slightly chronic risk to some babies
Poor	20-40	89-177	Possible chronic risk to some babies
Unacceptable	>40	>177	Increasing acute health risk to babies
Livestock watering	as N	as NO3	DWAF (1996)
Nitrate(mg/l)	0-90.3	0-400	
Livestock watering	as N	as NO2	DWAF (1996)
Nitrite (mg/l)	0-12.3	0-40	

Source: DWAF (1996)

In some areas of South Africa, it is reported that there is high concentration of groundwater nitrate ions (NO_3^-), particularly in the region running north-easterly direction in Northern Cape, North West and Limpopo Provinces (Sililo & Saayman, 2001; Terblanche, 1991; Tredoux et al., 2009).

Diffuse pollution emanates mainly from use of organic and inorganic fertiliser in agriculture, whilst slurry stores and intensive animal husbandry forms important point source of groundwater pollutants (Goody, 2001). This therefore, implies that the base flow from a water table containing excess nitrates and providing a source of permanent base flow to rivers and lakes adds nitrates to surface flow resulting in upset of river ecology by eutrophication.

Besides agricultural contributing significantly to nitrates in groundwater, the important source of nitrates in cities may arise from pit latrines sewer leakages and landfill sites

(Wakida, 2005). Pit latrines are still common in many villages of South Africa and they are a threat to groundwater pollution. Pit latrine is a hole dug into the ground to the depth of about 2 metres over which a seat is raised and is normally enclosed in a structure with roof and a door (Bridgman, 1995). The health risk of these structures lies in infiltration of liquid waste into surrounding soil depending on its composition and texture of waste material. Besides the composition and texture of waste material itself, a combination of factors influence the extent of groundwater contamination such as depth of aquifers, number of pit latrines in an area, rock and soil composition around the aquifers.

Nitrate ions may pose health risk as microbial processes in human stomachs can easily reduce it to toxic nitrite ions. Toxicity of nitrite ions renders its effect in the body by compromising oxygen-carrying capacity of blood that may lead to condition of methaemoglobinemia in infants and can readily react with amino acids to form carcinogenics (Suthar et al., 2009; Wakida, 2005).

Good agricultural practices can reduce nitrate contamination in groundwater. However, when nitrates contaminate groundwater sources it may take as long as decades for aquifers to reduce its pollution, if not centuries (David et al, 2009). This implies nitrates can accumulate in large quantities in aquifers of unconsolidated materials in nature. Yet nitrates are naturally stable, they cannot be easily degraded in groundwater. Nitrate nutrients are of concern in future use of most groundwater, given their prevalent use coupled by its indispensable nature in vadose zone.

3.6.2.2 Fluoride

Groundwater in most areas of South Africa is recorded to be having high concentration above standard levels of fluoride, that usually result in preponderance of dental fluorosis (WHO, 2000; Feenstral, 2007). High fluoride concentration in groundwater poses major health risk. High concentration above 4mg/l is known for causing severe tooth damage and skeletal fluorosis especially in case of continuous use of water, whilst concentration as low as 1.5mg/l can still cause dental mottling and damage of enamel (Department of Water Affairs and Forestry, 1996).

Some provinces in particular Northern Cape, North West and Limpopo are identified as areas with fluoride concentration as high as 30mg/l. Fluoride concentration in groundwater in these provinces is mainly attributed to high pH, high fluorine content of aquifers, high evaporation rates in arid and semi-arid climate and low groundwater recharge rates (McCaffrey, 2001).

High Fluoride concentrations commonly occur in areas with low calcium concentration. In areas with high calcium concentration, fluoride levels rarely exceed the minimum standard levels (Nezli, 2009; Rivett, 2006). High fluoride concentration is also associated with areas of pH > 8 and dominated with carbonate and sodium ions. Alkaline and high temperature conditions promote weathering and leaching of fluoride rich mineral rocks resulting in enrichment of fluoride in groundwater (Ashton, Love & Mahachi, 2001; Edmunds, 1996).

Arid areas are associated with low rate of ground flow that gives ample time for groundwater to react with the rock it meets. This is a suitable condition for dissolution of fluoride–bearing formations. The low flow rate of groundwater coupled with the high evaporation rate reduces the volume of water recharging the saturated zone and the dilution effect of groundwater chemicals.

3.6.2.3 Magnesium

Magnesium is the common constituent of water that readily reacts with water and oxygen to form magnesium hydroxide and magnesium oxide respectively. The solubility of magnesium is influenced by the pH level and carbonate bicarbonate equilibrium (DWAF, 1996). Magnesium hydroxide and oxide are more soluble in neutral pH water but becomes less soluble in alkaline water. Permissible level of magnesium is ≤ 200 (DWAF, 1996).

Magnesium present in drinking water has a bitter taste and in excess amount can cause diarrhea. Magnesium and calcium commonly cause scaling problems in heating elements and pipes that transport hot water and causes scum formation as a result inhibits the lathering of soap (Kempster & Smith, 1985). Scaling of household appliance elements and scum formation has economic implications as more electricity is consumed to overcome the scale effect. Additives are added to bath water to soften the water.

3.6.2.4 Sodium

Sodium occurs naturally in the environment as sodium chloride, sodium sulphate, nitrate and bicarbonate. It is common in areas where geological deposits of sodium chloride (rock salt) occur and in arid areas that usually have low annual rainfall (World

Health Organisation, 1993). Domestic wastewater may commonly have high concentration of sodium due to addition of sodium chloride (table salt) in foods.

High sodium concentration in water intake has adverse effect in infants and persons suffering from renal diseases, hypertension and cardiovascular diseases. The permissible concentration level in drinking water should not exceed 200mg/l (DWA, 2015).

3.6.2.5 Total dissolved solids

Total Dissolved Solids (TDS) is the measure of amount of organic salts dissolved in water. In most cases, Electrical Conductivity (EC) is used to estimate TDS as it is directly proportional to TDS. Electrical Conductivity is a measure of conductivity of electricity in water that usually occurs in the presence of ions such as nitrates, potassium, chloride, magnesium, carbonate, sulphate, bicarbonate, sodium and calcium. Natural water has varying concentrations of TDS from geological formations of parent rock, plant material and soils and its standard stands at conductivity of ≤ 170ms/m (DWA, 2015).

Increased TDS is also associated with effluent discharge from domestic and industrial waste, cultivated areas and urban runoffs. High TDS is closely related to total hardness, scaling and corrosion of water. Its level is more important over a long period of time, hence the seasonal variation should be used to compare with the criteria of TDS (Kempster & Smith, 1985).The health impacts are minimum at lower concentration but at high concentration it adversely affect the kidneys, causes poor lathering of soap, scaling and a general bitterness taste of water.

3.6.2.6 Turbidity

Turbidity is a general measure of clarity or transparency of water that is a factor of suspended material in water. Suspended matter in water is associated with micro-organisms from organic matter, inorganic matter and soil and clay particles. Clear water can have as low as one nephelometric turbidity unit (NTU), whilst highly turbidity water can be over 1 000 NTU (Department of Water Affairs and Forestry, 1996). The turbidity measure is usually done on same day of water sample collection and minimum required is ≤ 1 mg/l. In water used for domestic use the process of flocculation and coagulation usually reduces turbidity.

High turbidity in water can be a health risk as micro-organism tends to grow on particles of suspended matter. Besides the likely presence of microbes in high turbidity water, the particles have absorptive properties that trap undesirable inorganic and organic compounds that may include herbicides (Aucamp & Vivier, 1990).

3.6.2.7 pH in water

pH is the measure of hydrogen ion concentration that occur as complex-base equilibria in natural waters. Permissible standard of drinking water is ≥ 5 and ≤9.7 (DWAF, 1993). pH change in water can be due to acidification and alkalinisation processes that lowers pH and increases water pH respectively. Though the pH level of water seldom has health implications (except at extreme levels), it influences the solubility of heavy metals such as lead, zinc, lead and copper that in turn causes indirect health problems (Aucamp & Vivier, 1990).

It's only at pH >11 that pathogens may become active, effectively turning ammonium into ammonia. pH of natural water is mainly influenced by decay process, acid mine drainage, temperature, microbial activity, acid rain and effluent discharge (Department of Water Affairs, 1993).

3.6.2.8 Total coliforms

A wide variety of pathogens (viruses, bacteria and protozoa) may exist in water and are known to cause diseases such as dysentery, hepatitis, gastroenteritis, typhoid fever and cholera. Perhaps the most important of all these disease causing pathogens is bacteria as they can spread rapidly and may result in high mortality. Pathogens existence in water may pose a health threat to lives especially in densely populated communities.

Total coliform bacteria is primarily used to test for general hygienic quality of water in which the standard recommended concentration level is less than 10 col/100ml of water (Department of Water Affairs and Forestry, 1996). The existence of micro-organism in water is influenced by array of factors such turbidity, pH, sunlight, competition, nutrients, temperature and toxic substances (Payment, 1991). Most of bacteria classified in coliforms are of faecal origin and the most common is *Escherichia coli and Vibrio Cholerae.* The coliform is measured within 24 hours of water sample collection and is enumerated as number of colonies per 100ml (col/100ml).

3.6.2.9 Coliphages

Coliphages are viruses, which replicates in bacteria and its presence in water could be an indication of presence of bacterial hosts such as E.coli (Aucamp & Vivier, 1990). In their existence, the coliphages are divided into two broad categories, the somatic and male-specific coliphages. Male specific coliphages can only be replicated in a specific environment similar to that of gastrointestinal of warm blood animals and humans. This implies that it is an indicator of faecal pollution originating from humans or warm-blooded animals.

Positive test for coliphage indicates the faecal pollution and points to the presence of pathogenic viruses in particular, the enteric viruses that poses a threat of gastroenteritis and hepatitis diseases (World Health Organisation, 1993).

3.6. 3 Groundwater pollution sources

Groundwater practitioners in their effort to protect groundwater resources are faced with challenges of: identifying the pollutants, its source, and mechanisms of its entrance in groundwater systems; prediction of movement of pollutants within the vadose zone and saturated zone; and come up with recommendations that can be implemented through legal and administrative frameworks (Sililo & Saayman, 2001). The main source of groundwater pollution includes municipal, agricultural, mining and industries as shown in Table 3.10 below.

Table 3.10: Groundwater pollution sources

Pollution Category	**Pollution source**	**Main pollutant**	**Potential pollutant**
Municipal	Sewer leakage	Nitrate Virus and Bacteria	Health risk to users, eutrophication of water bodies, odour and taste
	Septic tanks, cesspools, privies		
	Sewage effluent and sludge	Nitrate, Minerals, Organic compounds, Viruses and Bacteria	
	Storm water runoff	Bacteria and Viruses	Health risk to water users
	Landfills	Inorganic minerals, organic compounds, heavy metals, Bacteria and Viruses	Health risk to users, eutrophication of water bodies, odour and taste
	Cemeteries	Nitrate, Viruses and Bacteria	Health risk to water users
Agriculture	Feedlot wastes	Nitrate, Nitrogen, Ammonia, Viruses and Bacteria	Health risk to water users (e.g Metahemoglobinemia)

	Pesticides and herbicides	Organic compounds	Toxic/ Carcinogenic
	Fertilisers	Nitrogen, Phosphorus	Eutrophication of water bodies
	Leached salts	Dissolved salts	Increased TDS in groundwater
Industrial	Process water and plant effluent	Organic Compounds Heavy Metals	Carcinogens and toxic elements (AS, Cn)
	Industrial landfills	Inorganic minerals, Organic compounds, Heavy Metals, Bacteria and Viruses	Health risk to users, eutrophication of water bodies, odour and taste
	Leaking storage tanks(e.g. Petrol stations)	Hydrocarbons, Heavy Metals	Odour and taste
	Chemical transport	Hydrocarbons, chemicals	Carcinogens and toxic compounds
	Pipeline leaks		
Atmospheric Deposition	Coal fired Power stations	Acidic precipitation	Acidification of groundwater and toxic leached heavy metals
	Vehicle emissions		
Mining	Mine tailings and stockpiles	Acid Drainage	
Groundwater Development	Salt Water Intrusion	Inorganic minerals Dissolved salts	Steady water quality deterioration

Source**:** Sililo & Saayman, 2001

3.6.3.1 Municipal

The development of clustered settlements such as towns necessitates the establishment of sewage network and infrastructure for solid waste collection and treatment centres in the periphery of the settlements. Even under strict measures of collection of waste to its last disposal site, there is chance of waste contaminating groundwater and surface water. Groundwater pollution in a clustered settlement can be further exacerbated by erection of informal settlements in which basic infrastructure of refuse collection is usually absent.

The main source of pollution in the municipality is through sewer leaks, pit latrines, storm runoff, landfills and cemeteries (Sililo & Saayman, 2001). Domestic sewage leaks are often rare in well designed and maintained sewage works but may be common in ageing sewage networks to the estimate of about 12% (Eiswirth, Hotzl & Burns, 2000).

Though effects of sewer leaks to groundwater quality are not well understood, there is growing interest in comparison of young sewer areas to aged sewer systems. Elsewhere in the world, there have been reports of common sewer contamination of groundwater. In Germany nitrogen sulphate compounds, sodium and chloride contamination were common due sewer leaks (Eiswirth et al., 2000).

Storm water runoff has been reported to cause microbial contamination of groundwater in form of raw wastewater (Jagals, 1994). The effects of polluted storm water may have serious health impact on groundwater if it finds passage through fractured aquifers. Pollution of surface water by the storm water runoffs may have equal impact on groundwater, depending on recharge rate of groundwater resources that in turn is influenced by characteristics of contaminants present and aquifer characteristic.

Informal settlements in municipality areas may be a significant source of groundwater pollution especially in areas where there are clustered pit latrines and lack of sanitation facilities (Wright, 1999). With the ever-increasing urbanisation in South Africa, there has been large sprawling of informal settlements that happen to lack basic sanitation services. According to Wright (1999), the most significant informal settlement pollutants (nutrients, microbial, biodegradable organics) are from storm water drainage systems, on-site sanitation systems, informal trading sites and garbage disposal and collection sites.

Landfill sites are common areas of both domestic and industrial waste disposal. Though less cases of groundwater contamination were recorded in these sites in South Africa, this may not necessarily mean there is less contamination from these sites but could be attributed to less research present (Sililo & Saayman, 2001). The dumpsites are a common landfill sites in South Africa's settlement areas and usually land surface depressions, pits and quarries are commonly used for this purpose. The most common pollutants from landfill sites are of organic, inorganic substances and microbial in nature.

Whilst landfill sites are common with municipalities to dump the domestic waste, most industries also prefer land filling as it is relatively low cost. Though there are some legislative instruments in place that strictly regulates industrial waste dumping, some companies may opt for low cost illegal dumping which can result in unprecedented contamination of both surface and groundwater sources (Gosling, 2001). The common pollutants from industrial disposal sites include organic compounds that are volatile such as ethylbenzene, benzene and toluene (Sililo & Saayman, 2001).

3.6.3.2 Industry and mining

South Africa has been marked by increase in industrial and mining activities due to a more diverse economy in the past two decades (Sililo & Saayman, 2001). With this growth of industries, there has been a threat of severe impact on the environment including both surface and groundwater sources. Industrial wastewater may contain high contaminant concentration varying with industrial type. While more sophisticated mines and industries may have stipulated waste disposal measures, the small service industries such as dry cleaners and printing industry may pose threat of pollution of water sources as their effluent disposal are not subject to strict control measures (Foster & Hirata, 1988).

The leakage storage tanks, pipeline leaks and chemical transport pose a threat to groundwater sources. The Dense Nonaqueous Phase Liquid (DNALP) and Light on-aqueous Phase Liquid (LNALP) emanating from the petrochemical substances may cause serious health implications in case they reach groundwater sources being used for domestic purposes (Foster & Hirata, 1988).

Mine tailings are a source of pollutants in large mining operations dotted in mining areas of South Africa. They usually contain mining residues that are exposed to the environment and can easily flood into surface waters. Acid rock drainage is an important threat in mining areas. The Sulphur that exists as sulphide in mineral rocks oxidises when it's exposed to air and water and consequently lowers pH of water that in turn mobilises heavy metals in rocks (Sililo & Saayman, 2001). The resultant pollution is evident when poor quality water spread in the aquifer from site of generation to other parts of the aquifer utilised for domestic purpose.

3.6.3.3 Agriculture

Agriculture farming in South Africa falls into two main categories. These are commercial and subsistence agriculture (Conrad et al., 1999). These two farming types are common in outskirts of urban areas and may be a source of pollution emanating from fertiliser use, feedlot wastes and pesticide or herbicides application. For example, high potassium and nitrogen values were recorded from groundwater in Perth, Australia

(Gerritse, Barber & Adeney,1990) and in Philippi horticultural area located close to Cape Town (Conrad et al., 1999).

Feedlots are also a common feature closer to town areas, where there is the major market for meat and closer to inputs needed, such as feed and consumables. On conservational farming practices, the effluent tends to be applied as organic fertiliser in fodder crops providing necessary nutrients for crop production. However, improper use of these effluents can result in pollution of groundwater of bacterial, virus and parasites nature (Conrad et al., 1999).

3.6.4 Common groundwater pollutants

Common groundwater pollutants related to land use caused by point and diffuse types of pollution are shown in Table 3.11 below. The main source of groundwater pollutants can be grouped into microbial nature, nutrients, pesticides, fuel related chemicals, industrial chemicals, heavy metals and novel pollutants (David et al., 2009). Comparatively, point source of pollutants mainly affect the potable source of water that is adjacent and seldom accumulate to cause significant concentration in large groundwater storages, whilst diffusion pollution from agriculture can infiltrate and spread across the whole outcrop of the aquifer (David et al., 2009).

It is imperative for water management practitioners to understand both the source and pathway of the pollutants to prevent, reduce and mitigate contamination of water sources. The sources of pollutants are fairly known, yet the pathway of the pollutants from the sources to the receptors is still poorly understood because of environmental characteristic complexity that may pose unexpected behaviour of pollutants (Gavrilescu, 2015).

Table 3.11: Groundwater pollutants related to land use

Category	**pollutants**	**Problem caused**	**Land use and source in groundwater**	**Type**	**Example**
Microbiological	Bacterial and viral diseases, eg Cholera, Typhoid	Severe human health including death	Urban (leaky sewers) and rural (septic tanks)	Diffuse (urban) and point (rural	Powell et al (2003) (urban), Borchardt et al (2003) (rural)
Nutrients	Nitrogen (mainly nitrate)	Drinking water limit of 50mg/L as NO3. Eutrophication of surface water	Urban – infiltration of waste water effluents. Rural – fertilisers, ploughing,	Point (infiltration and diffuse (agricultural	Gooddy et al (2001) (point agric). Neal et al. (2006) (diffuse

			livestock		agric).
Pesticides	For example atrazine	Very low drinking water limit	Used as pre-emergent weed killer for maize	Diffuse and point	Lapworth et al. (2006)
Fuel-related chemicals	Petroleum hydrocarbon in general e.g benzene and xylene	Taste and odour in very low concentrations and increases toxicity with concentration	Widespread storage and use of petroleum based fuels	Point	Moran et al. (2005)
Industrial chemicals	Chlorinated solvents (e.g phenolic compounds)	Taste and odour in very low concentrations and increases toxicity with concentration	Degree of groundwater pollution in sites where there are leaks and spills	Point but where manufacturing widespread then become diffuse	Bishop et al. 1993 (point). Rivett et al. (1990) (widespread urban)
Heavy chemical	Cu, As, Zn, Pb, Cr	Exceedance of drinking water standards	Industrially contaminate land, mine waters, landfills		Gandy et al. 2007

Source: David et al (2009)

Figure 3.5 below shows the common source and pathway of both groundwater and surface water pollutants.

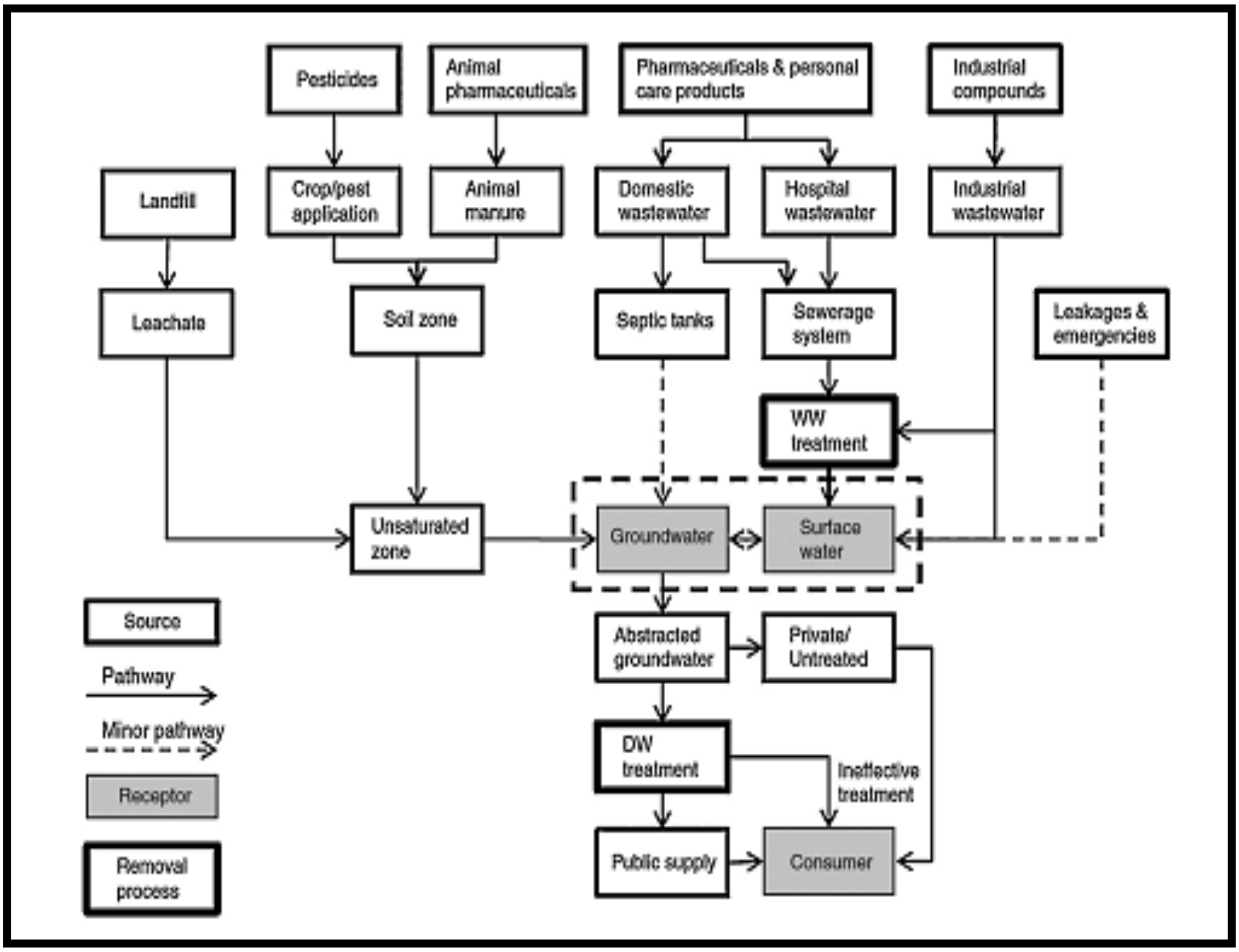

Figure 3.5: Pathway of pollutants from source to receptors

Source: Stuart (2012)

3.6.4.1 Microbiological groundwater pollutants

Groundwater pollutants of concern to humans are microbiological in nature. They are disease threatening and can cause significant mortality, such as *Vibrio Cholerae* which causes Cholera. The source of such bacteria is human faeces and or animal faeces that gains entry to aquifers through sewer leaks, pit latrines and manure disposal (Gavrilescu, 2015).

However, in most cases, contamination of bacterial nature does not reach the saturated underground water zone because they are short lived compared to typical groundwater travel times that are relatively slow (Price, 2004).

3.6.4.2 Agrochemicals as pollutants

The use of agrochemicals in form of herbicides and pesticides has attributed to increase in food production by marked reduction in losses of crops and animals due to diseases and pest damages. Nevertheless, the agrochemicals threaten groundwater as standard concentrates are set extremely low at 0.1 μġ/l. While the pesticides may not present a problem if applied in accordance with good practices, the point source may pose a risk of groundwater contamination when used for prolonged period that may overwhelm the attenuation capacity of overlying soil aquifers (David et al, 2009).

Pesticide and herbicides contamination in groundwater is influenced by the aquifer characteristics and the substance reactivity (Chilton et al., 2000). Permeable soils in vadose zone are prone to quicker movement of pollutants and the size or volume of the aquifer plays a role in concentration of substances. The volatile substances are unstable, mobile and can react with other substances easily.

3.6.4.3 Fuel related chemical pollution

Groundwater pollution is common to a large or lesser extent in industrial areas where chemicals are manufactured or handled (Learner, 1992). Chlorinated hydrocarbons and petroleum hydrocarbons are common chemical pollutants due to their nature of being mobile and not readily attenuated in the subsurface zone. Chemical pollutants fall mainly into two categories, the Dense Nonaqueous Phase Liquid (DNALP) and Light non-aqueous Phase Liquid (LNALP).

LNALP, due to their insoluble nature in water and being less dense than water, they will stop at water table height once they infiltrate into the groundwater. The DNALP in its low concentrations readily pollutes groundwater sources more than surface water sources and are more difficult to remediate especially in fissured aquifers (David et al., 2009). Organic pollutants may cause array of health problems ranging from impaired cardiovascular functions, liver damage, brain disorders to development of legions (Domenico & Schwartz, 1990).

3.6.5 Conclusion

The chapter gave an insight on groundwater pollution hazard by exploring groundwater vulnerability, groundwater quality and common pollutants and their source. Literature on groundwater was reviewed and will help in engaging best practices of groundwater assessment in the research. The next chapter discusses the methodology used in the investigation of this research.

CHAPTER 4: RESEARCH METHODOLOGY

4.0 Introduction

Areas dealt with in this chapter include the research design, study samples, data collection and analysis procedures. Research methodology entails activities that the researcher does, including explaining ideas behind selected research methods and techniques (Welman; Kruger & Mitchel, 2007). Hussey and Hussey (1997) further defines a research methodology as an approach that involves identification of the study's theoretical underpinning, methods for data collection, analysis of data to presentation of results.

In general, the importance of a research methodology lies in presenting the procedures for conducting the research and reliability of the research data collected. Research procedures ought to be purposeful and systematic if they should yield objective data for the problem at hand (McMillan and Schumacher, 1989). These procedures may include collection of data through primary or secondary data collection methods such as interviews, analysis of a collection of documents, measuring of given entities and observation.

The study sought to determine present groundwater quality from water sample evaluation. It further found out variation of groundwater quality with seasons (rainy summer and dry winter) as well as groundwater vulnerability. That gave an indication of nature and scale of pollution risk in the area.

4.1 Research design

Research design can be viewed as the plan envisaged for the research process (Thomas, 2009). In this thesis, both quantitative and qualitative approaches were used in an exploratory research design to achieve the study objectives. Maree (2016) explains that an exploratory design is conducive for a research problem where the sample size involves both quantitative and qualitative approaches.

The researcher opted to use the exploratory research design because of the following reason according to Wright (2010) and Maree (2016):

- It enables a detailed study of groundwater quality since both quantitative and qualitative techniques are involved;

- ensures that parameters get refined for more systematic investigation and formulation of new research questions for future research;
- exploratory research it allows for contextual interpretations, use of multiple methods and flexibility in choosing the best strategies to answer most research questions such as what, why, how?;
- it provides opportunity to define new terms and to clarify existing problems in groundwater quality; and
- The researcher is meant to provide details where a small amount of information exists.

The qualitative approach captures opinions, statements and perceptions from the respondents, while the quantitative approach caters for the numerical observation or trends. These approaches are complementary (Maree, 2016).

The researcher used mixed research methods to investigate groundwater aspects from boreholes in Ga-Segonyana municipality. The quantitative method is discussed under section 4.3 and 4.8 on water sampling and procedures below. The quantitative research method was employed in the research to gather numerical data and establish the prevailing situation. The researcher also conducted in-depth interviews as part of the qualitative approach and gathered descriptive data. It was important to conduct interviews to gather information on the social aspect of water use. This was done with water experts working at Sedibeng Waters, Geo-science and the local municipality. Sedibeng Waters has the mandate to provide drinking water to the local municipality.

4.2 Quantitative research methodology

The aspects explored for the quantitative research approach include:

- Water quality parameters or properties measurement (pH, total alkalinity, EC, TDS, total hardness, calcium hardness, magnesium hardness, nitrites, and fluorides);
- Aquifer vulnerability assessment using the DRASTIC method.

Numerical data is collected in conjunction with the quantitative research method (Muijs, 2011). This research is an empirical study in which knowledge is gained by means of direct and indirect observation or experience. Empirical studies are appropriate for real life problems research because they allow for the quantification of information that assists in the interpretation of data in the form of mathematical symbols, figures and tables (Bless & Higson-Smith, 1995).

4.3 Qualitative research methodology

The qualitative research approach usually generates descriptive data in which the observations do not involve numbers or counts. In-depth interview method was used complementary to the quantitative approach. The nature of this study necessitates the inclusion of a qualitative approach in a quest to understand and interpret the intentions and meanings that exist in everyday human life activities (Kincheloe, 1991; Van Schalkwyk, 2000). It therefore gives a sense of reality of the data collection in a natural setting. In that regard, different perceptions of groundwater vulnerability and pollution were obtained from groundwater practitioners through in-depth interviews. They provided real life data of the groundwater problem.

4.4 Data sources

In this research, primary and secondary data sources were utilised. According to McNabb (2002) the data sources can be diverse ranging from formal to non-formal, symbols to non-verbal signs (including body cues) and non-written communication to written communication. The researcher collects primary data directly, while secondary data is collected indirectly from sources such as maps and records. Issues of primary and secondary data collection are discussed further in section 4.5 that deals with data collection techniques.

4.5 Data collection technique

The collection of data enables the researcher to meet the study objectives pivotal in any research (Allwright, 1998). Data should be collected until it cannot bring any new relevant information in the process of satisfying the set objectives of the study (Ritchie & Lewis, 2013; Strauss & Corbin, 1990). Both primary and secondary data were used in this research.

Primary data was collected through in-depth interviews with prelisted questions guiding the process. Participants were personnel from Sedibeng Waters. Sedibeng Waters's personnel have the mandate to extract water from boreholes around Ga-Sengonyana and deliver it to industries and communities through the standing pipes. Geo-science and local municipality health department skilled personnel were also interviewed. Furthermore, groundwater parameters were measured on the site of sample collection from boreholes (pH, temperature and turbidity).

Secondary data was obtained through an internet search and from the journal on groundwater vulnerability maps from the Department of Water Affairs (DWA). DRASTIC values were collected from Sedibeng technicians and council of Geosciences. Thus past studies values of elements of DRASTIC were used to compute groundwater vulnerability assessment.

Data collection instruments are devices that are used to collect information. To collect primary data, instruments used were interview questions, pH meter, microprocessor turbidity meter and conductivity meter for measuring Electric Conductivity analysis as representative of TDS. The physical, chemical and biological groundwater constituents results were obtained from Sedibeng Laboratory, these are: Fluoride, nitrate, magnesium, calcium, sodium and biological parameters (total coliform count).

4.6 Population

Population is defined as a large group of cases from which a representative can be selected (Leedy & Ormrod, 2014; Maree, 2016). According to Bryman (2012) and LeCompte & Preissle (1993) a study population is a specified group of participants that are of interest to the researcher and useful in generating results in a research. The population in a study is not limited to human entity, but can include objects and non-human phenomena.

The target population for this research includes:

- 10 Sedibeng Water specialists
- 8 Council of Geoscience personnel
- 6 Ga-Sengonyana district health personnel
- 45 municipality boreholes in Ga-Sengonyana district
- Approximately 104 408 Ga-Sengonyana district residents (Stats S.A, 2016)

The local authority gives Sedibeng Water specialists' mandate to extract and deliver borehole water to the municipality population from different areas of the district. The Ga-Sengonyana district health personnel monitors the health status of borehole water and Council of Geoscience technicians have input in technical and research of the geo-hydrological aspects. The sample utilised for in-depth interview was purposively selected. They were selected because of their knowledge of the problem under review.

The boreholes in which samples were collected are: Kuruman, Mahojaneng, Mothibistad, Seven Miles, Maruping, Batlharos and Mapoteng as shown in Figure 1.3 of the district area in Chapter 1. Figure 4.1 below shows an image of one of boreholes sampled in the study area.

Figure 4.1: One of borehole sampled in Magojaneng village

4.7 Study sample and sampling procedures

Researchers usually choose a representative group out of the entire population and that group is called a sample. A sample is a certain group that is selected from the entire population under review and is less than the total population but is representative of the population (Leedy & Ormrod, 2013). While the sample is representative of a population, sampling is the process by which a sample is obtained (Saunders et al., 2012).

4.7.1 Borehole samples and water sampling procedures

The researcher chose 17 borehole samples from 45 boreholes with heterogeneous characteristics using the stratified sampling design. The 17 borehole water samples were taken two times from the sampled boreholes for water quality parameters testing in two seasons (winter of 2018 and summer of 2019). The locations of the boreholes sampled are shown in Table 4.1 below. Stratified sampling was used because of two existing distinctive groups (Town set up with formal sanitary services and farm/village without formal sanitary services but pit latrines). Stratified sampling is a sampling method that divides the population into non-overlapping, homogenous groups called strata (Maree, 2016). This sampling method is best utilised where there is a problem of non-homogenous populations as it guarantees equal and proportional allocation of samples (Omrod, 2013).

Table 4.1: List and locations of the boreholes surveyed in Ga-Segonyana municipality area

Locations surveyed	**Number of boreholes**
Kuruman (T)	2
Mothibistad (T)	8
Magojaneng (V)	1
Seven Miles (V)	2
Maruping (V)	2
Batlharos (V)	1
Mapoteng (V)	1
TOTAL	17

T = Town set up with sewage system.

V = village set up with no sewage system but pit latrines.

The boreholes were allocated between two distinctive environments. The town set up (with sewer system) has 26 functioning boreholes (T) and village/farm set up (with no sewer system but pit latrines) has 19 functioning boreholes (V). A stratified sample size of 17 boreholes was drawn from the total functioning boreholes of 45 using the following formula shown below as advised in Maree (2016).

$$n_1 = (h_1 / N)\, n$$

Where n_1 = sample size

h_1 = strata

N= population size

Therefore the sample size for the Town set up (T) with 29 boreholes is

n_1 = (26/45) x 17

= 10 boreholes

Therefore the sample size for the Village set up (V) with 19 boreholes is

n_1 = (19/45) x 17

= 7 boreholes

Therefore, 10 boreholes and 7 boreholes were allocated in the town set up and the village setup respectively as shown in Figure 4.2 below. Simple random sampling was then used to select the 17 boreholes from the two strata.

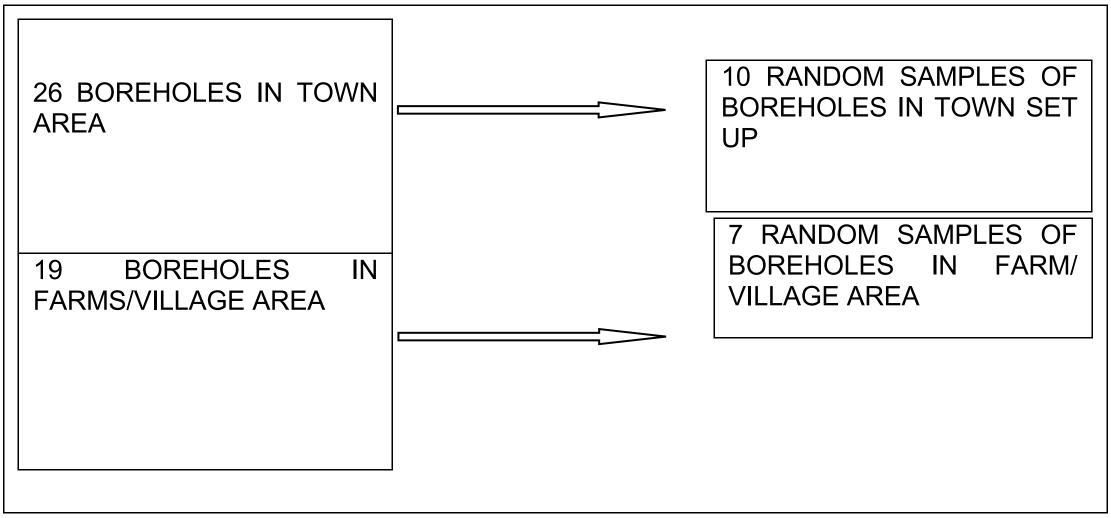

Figure 4.2: Stratified random sampling design

Scientifically, findings from a sample of 5% of the total population or above are acceptable for generalisation of the results since in some instances, randomness is usually more important than the sample size (Swanepoel & De Beer, 1992). This study adopted a sample of 38%, which is above the minimum recommended 5%, from the total borehole population of 45. The boreholes were chosen based on accessibility in both areas. A bigger sample was chosen to increase validity and generalisability.

Seventeen (17) samples of borehole water were collected for quality testing in the wet and dry season at Bothaville laboratory. Each sample was subjected to 10 variables (pH, temperature, turbidity, EC, TDS, calcium hardness, magnesium hardness, nitrates, fluorides and total coliform) using the exploratory research design as shown in Table 4.2 below. Physical and chemical water analysis was performed following the standard methods (Ramteke & Moghe, 1986; APHA, 1998).

Table 4.2: Exploratory research design for water parameters testing

Study	Sample study groups	Borehole population
First stage-Quantitative	17 Borehole samples in Summer (wet)	17
	17 Borehole samples in Winter (dry) (same selection as for summer)	17
Second Stage-Qualitative	Analysis of Summer (wet) and Winter(dry) borehole samples	17

To test for seasonal water quality variation, the sample design was used as shown in Table 4.3 below. It is useful where the effects of each treatment are temporary and localised (Maree, 2016). In this case, Obs means observation.

Table 4.3: Seasonal sample design

Where Group 1 = entire sample (34 samples)
summer Obs a =subgroup a observation 17 wet season samples (10 urban environment, 7 village/farm areas)
winter Obs b =subgroup b observation 17 dry season samples (10 urban environment, 7 village/farm habitable areas)

Water samples were collected from the 17 boreholes between May 2018 and February 2019. The water samples were collected using 2 litre sterile containers direct from the identified boreholes. The plates containing coliform isolates and samples for chemical analysis were placed in ice bags. Those were transported to the Bothaville laboratory for further analysis.

4.7.1.1 Water sample quality parameters assessment

Water quality equipment were used to measure water parameters of the 34 samples in winter and summer in accordance to SANS 241 (2006) and the South African water quality guidelines (DWAF, 1996). The pH, turbidity, temperature and EC were measured on site using Sedibeng Water laboratory equipment. The pH was measured using a pH meter. A microprocessor turbidity meter was used to measure turbidity. E.C was measured using a conductivity meter.

The concentrations of minerals; nitrates and fluoride were determined in the laboratory using the Spectroquant Nova 400 manual water analyser. The Bothaville laboratory (South Africa National Accredited System) carried out off-site water quality parameters analytical work. The water quality parameters were then compared with South Africa National Standard of drinking water (SANS 241: 2006) and class 1 drinking water as shown in Table 4.4 below.

Table 4.4: Class 1 drinking water, compared to SANS 241 of 2006

Sample ID	**pH**	**conductivity**	**Turbidity**	**ca2+**	**Mg2+**	**Na2+**	**K**	**Mn**	**Cl-**	**NO3-**	**Fl**	**Coli count**
units	at 25◦C	mS/m at 25◦C	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	Count/100 ml
SANS 241	5-9.5	70	≤ 1	80	30	100	25	0.05	100	6	0.7	10
Class 1 water	7	150	1-5	150	70	200	50	0.1	200	10	1	10

Source: DWA hand book (2006)

According to the Water Research Council (WRC) and SANS 241(2006), domestic water can be classified into 5 categories: class 0 (the most ideal); class 1 (causes rare instance of sub-clinical effects); class 2 (may cause some effects); class 3 (may pose risk of chronic health); class 4 (may cause severe acute health).

In conclusion, thirty-four (34) samples of groundwater were collected for quality test in both summer and winter seasons from the same boreholes. Those two groups of results were compared for seasonal variation with use of statistical analysis standard deviation and variance. Correlation was performed on data using Anova and SPSS 10.0 windows for significant variations and inter-element relationships (Banjoko, 2007).

4.8 Aquifer vulnerability assessments

DRASTIC vulnerability index was used in this study to evaluate the aquifer vulnerability as advised in Aller et al (1987). The information required to compute the index was obtained from past studies on factors related to DRASTIC index and from Sedibeng Water specialists and Council of Geoscience technicians. Vulnerability index is the weighted sum of ratings of the parameters under consideration. The DRASTIC index computes the factors according to the following equation:

DRASTIC Index = DrDw + RrRW + ArAw + SrSw + TrTw+ IrIw + CrCw

Where D, R, A, S, T, I and C are seven parameters: **D**epth to water level; Net **R**echarge; **A**quifer media; **S**oil media; **T**opography; **I**mpact of vadose zone; and **C**onductivity (Abdullahi, 2009). Hydraulic conductivity refers to the volume of water that passes through the unsaturated zone to the water table per unit of time. The subscripts r and w are the corresponding ratings and weights, respectively. The rating table was used to evaluate the DRASTIC score of the Ga-Sengonyana municipality area following Aller et al (1987) as shown in Table 4.5 below.

Table 4.5: DRASTIC parameters range and ratings

Depth to the water table (m)		Net recharge (mm)		Topography slope (%)		Hydraulic conductivity (m day^{-1})	
Range	Rating	Range	Rating	Range	Rating	Range	Rating
0.0–1.5	10	0–51	1	0–2	10	0–4.1	1
1.5–4.6	9	51–102	3	2–6	9	4.1–12.2	2
4.6–9.1	7	102–178	6	6–12	5	12.2–28.5	4
9.1–15.2	5	178–254	8	12–18	3	28.5–40.7	6
15.2–22.9	3	>254	9	>18	1	40.7–81.5	8
22.9–30.5	2						
>30.5	1						

Soil media		Aquifer media		Impact of the vadose zone	
Range	Rating	Range	Rating[a]	Range	Rating[a]
Thin or absent	10	Massive shale	1–3 (2)	Confining layer	1
Gravel	10	Metamorphic/igneous	2–5 (3)	Silt/clay	2–6 (3)
Sand	9	Weathered metamorphic/igneous	3–5 (4)	Shale	2–6 (3)
Peat	8	Glacial till	4–6 (5)	Limestone	2–5 (3)
Shrinking and/or aggregated clay	7	Bedded sandstone, limestone and shale sequences	5–9 (6)	Sandstone	2–7 (6)
Loam	5	Massive sandstone	4–9 (6)	Bedded limestone, sandstone and shale	4–8 (6)
Silty loam	4	Massive limestone	4–9 (8)	Sand and gravel with significant silt and clay	4–8 (6)
Clay loam	3	Sand and gravel	4–9 (8)	Sand and gravel	4–8 (8)
Muck	2	Basalt	2–10 (9)	Basalt	2–10 (9)
Non-shrinking and non-aggregated clay	1	Karst limestone	9–10 (10)	Karst limestone	8–10 (10)

Source: Aller et al (1987)

The rating of each DRASTIC parameter is multiplied by the given weight of that parameter. The relative weights that were used corresponded with the DRASTIC parameters by Aller et al (1987), as shown in Table 4.6 below.

Table 4.6 Relative weights assigned to DRASTIC parameters

Parameters	Relative weight
Depth to the water table	5
Impact of the vadose zone	5
Net aquifer recharge	4
Aquifer media	3
Hydraulic conductivity of the aquifer	3
Soil media	2
Topography slope	1

Source: Aller et al, (1987)

The vulnerability range used was DRASTIC index as recommended in commonly referenced literature (Corniello et al. 1997; Deregibus & Civita, 1995). Table 4.7 below shows the recommended DRASTIC ranges. The final index obtained is divided into vulnerability classes of low, moderate, high and very high. DRASTIC index ranges from 23 to 230, with higher DRASTIC index value indicating higher potential of groundwater pollution and aquifer vulnerability.

Table 4.7: DRASTIC index ranges and corresponding vulnerability

Vulnerability	Ranges (DRASTIC index)
Very low	< 80
Low	80 - 120
Moderate	120 - 160
High	160 - 200

Source: Corniello et al. (1997); DeRegibus & Civita, (1995)

DRASTIC index is relatively inexpensive; with little requirements on field data inputs; easy interpretation and usefulness in decision-making (Abdullahi, 2009). Shirazi et al., (2012) shares the same sentiment that the method easily computes extensive volume of data in semi-arid, arid regions as well as in regions with basaltic rocks.

4.9 In-depth interviews

The main aim of an interview is to obtain in-depth understanding of qualitative aspects of the research (Denzin and Lincoln, 2003). An in-depth interview, also referred to as semi-structured interviews was administered. Individuals with knowledge and experience on the study subject were selected to answer open–ended questions (Appendix 1). In-depth interviews allows information to be gathered from the workplace and people associated with institutions (Swanson & Watkins, 1997). Moreover, it allowed the researcher to explain the questions further, to avoid ambiguity. The in-depth interview was administered to twenty four (24) key respondents in the Ga-Sengonyana municipal area in order to obtain information face-to-face.

4.10 Data analysis

The two groups of water parameter results were compared for seasonal variation with use of statistical analysis standard deviation and variance. Correlation of data was performed using Anova and SPSS 10.0 windows for significant variations and inter-element relationships (Banjoko, 2007). Mouton (2006) defines data analysis as a process of seeking to understand the various constitutive elements of data through examining the co-relations between concepts, isolated variables and repetitive themes. The analysis of data involved five steps, as argued by Cresswell (2012) and these are organising study details, categorising data, interpretation of single instances, pattern identification and synthesis as well as generalisation of information. The researcher in the analysis followed these steps.

4.11 Validity and reliability of data

The triangulation of methodologies allowed exploration of different data (quantitative and qualitative) which then increased validity of the research results. The use of one method and one source of data can bring intrinsic bias in the outcome (Patton, 1990). Primary and secondary data obtained was processed and presented through diagrams, numerical and textual description. The responses to interview questions were captured by means of Microsoft word and processed.

4.12 Conclusion

The Chapter discussed the research methods and techniques. The ideas were arranged in different sections namely research design, the sources of data used, data collection techniques, population of the research, sampling and sampling procedures, aquifer vulnerability assessment, in-depth interviews, data analysis and validity as well as data reliability. The mixed methods approach was utilised and that included both quantitative and qualitative research methods. This ensured adequate exploration of the problem. The procedural standard testing of some water quality parameters on the sample collection site also ensured reliability of data collected. The stratified sampling method was used to select the boreholes for water sample collection. The sampling method ensured homogeneity of the sample and increased the validity of the results. The next chapter presents the findings.

CHAPTER 5: DATA ANALYSIS AND PRESENTATION OF RESULTS

5.0 Introduction

The previous chapters covered the introduction, theoretical frameworks, literature on groundwater vulnerability, and the methodology.. Chapter 5 presents the results of the study on groundwater vulnerability, quality and pollution risk in Ga-Segonyana Municipality. Seventeen (17) water samples (from different sites) and other data were collected using quantitative and qualitative methods. Water samples from sites were sent for processing, validation and tabulation at Sedibeng, Bothaville laboratory. Bothaville laboratory has standard instruments, which are SANS compliant. The findings were analysed using SPSS Version 10 and presented systematically to address the objectives of this study. The DRASTIC index of the area was assessed and the resultant score was given. Results were also generated from in-depth interviews and laboratory observations. The key findings for this research pointed out that some of the sites water quality parameters such as nitrates, calcium and total coliform concentrations exceeded the standard recommended by SANS, 241:2006. The detailed analysis is presented in the ensuing sections.

5.1 Physiochemical and biological characteristics: water quality assessment

The physiochemical analysis was performed following standard methods (APHA, 1998). Tests on pH, turbidity, TDS (measured by E.C), fluoride, nitrate, magnesium, calcium, sodium and biological (total coliform) were carried out at Bothaville laboratory by following standard analytical techniques. In-order to assess water quality, physicochemical and biological parameters of the groundwater samples from the Ga-Sengonyana municipality were collected during May 2018 and February 2019. Table 5.1 below shows the summary of the water quality parameters of samples of water conducted at Bothaville laboratory for year 2018-2019..

5.1.1 pH and temperature of water samples

The values of pH from water samples of all the 17 understudy boreholes were observed to be near neutral (pH=7.0), ranging from 7.3 to 7.6 with the highest value observed in Mothibistad village.

Table 5.1: Water quality parameters sample results (Bothaville Lab)

Village Name	Borehole Nam																		
		ph at 25◦C		TURBIDITY		EC at 25◦C		FLUORIDE		NITRATE		MAGNESIUM		CALCIUM		SODIUM		COLI BACT	
	UNITS	ph units		NTU		ms/m		mg/l		mg/l N		mg/l Mg		mg/l Ca		mg/l Na		cfu	
SANS 241,2006 requirements		5-9.5pH		≤	1			≤ 1mg/l		≤6mg/l		≤30mg/l		≤32mg/l		≤100mg/l		10cfu/100n	
	SEASON	DRY	WET	DRY	WET	DRY	WET	DRY	WET	DRY	WET	DRY	WET	DRY	WET	DRY	WET	DRY	WET
Kuruman	**Borehole A1**	7.4	7.5	<0.2	0.3	70.2	70.7	<0.5	<0.6	3.5	3.5	36	36	97	98	9.6	9.7	0	0
Mahojaneng	**Borehole B**	7.4	7.3	<0.2	0.4	60.3	60	<0.5	<0.6	3	3	30	30	93	93	<6.0	<6.0	0	0
Mapoteng	**Borehole C**	7.4	7.4	<0.2	<0,2	89.4	89.6	<0.5	<0.6	17	17	55	56	98	98	14	14	1	2
Mothibistad	**Borehole D1**	7.6	7.7	0.2	0.4	83.7	84	<0.5	<0.5	13	13.4	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	36	43
Mothibistad	**Borehole D2**	7.4	7.5	0.2	0.3	89.1	90	<0.5	<0.6	18	18	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	0	1
Mothibistad	**Borehole D3**	7.5	7.5	0.2	0.2	66	67	<0.5	<0.6	2.8	2.8	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	0	0
Mothibistad	**Borehole D4**	7.5	7.5	0.2	0.2	58.9	58.8	<0.5	<0.5	1.2	1.2	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	0	1
Mothibistad	**Borehole D5**	7.4	7.3	<0.2	<0.2	60.5	60.6	<0.5	<0.5	1.8	1.9	29	30	<6.0	<6.0	8.4	8.5	0	0
Mothibistad	**Borehole D6**	7.4	7.6	0.2	0.2	58.8	59	<0.5	<0.6	1.3	1.3	28	28	74	75	6.9	7	1	1
Seven miles	**Borehole E1**	7.4	7.6	7.2	7.4	59.6	60	<0.5	<0.6	3.1	3.2	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	0	0
Seven miles	**Borehole E2**	7.3	7.3	6.1	6.2	59.4	59.7	<0.5	<0.6	3.1	3.1	<6.0	<6.0	<6.0	<6.0	<6.0	<6.0	0	0
Maruping	**Borehole F1**	7.6	7.5	0.2	0.3	47.2	47.4	<0.5	<0.5	<1.2	<1.3	1.2	1.2	58	60	<6.0	<6.0	0	0
Maruping	**Borehole F2**	7.6	7.6	0.2	0.2	30.8	31	<0.5	<0.5	0.5	<0.5	10	10	41	42	<6.0	<6.0	0	1
Batlharos	**Borehole G**	7.4	7.5	0.3	0.4	61.4	62	<0.5	<0.5	3.2	3.2	28	29	<6.0	<6.0	<6.0	<6.0	0	2
Kuruman	**Borehole A2**	7.4	7.4	0.3	0.3	61.5	61.5	<0.5	<0.6	3.2	3.3	29	29	75	76	75	78	0	0
Mothibistad	**Borehole D7**	7.5	7.6	<0.2	<0.4	84.1	84.3	<0.5	<0.5	14	16	<6.0	<6.7	<6.0	<60	<6.0	<6.0	0	1
Mothibistad	**Borehole D8**	7.6	7.8	<0.2	<0.4	84.1	84.1	<0.5	<0.6	4.8	4.9	11	12	79	80	<6.0	<6.0	27	33

In addition, the temperatures of the groundwater samples were observed as ranging from 20.0 to 25.9°C. The mean annual pH of sampled boreholes obtained from the wet and dry seasons is shown in Figure 5.1 below.

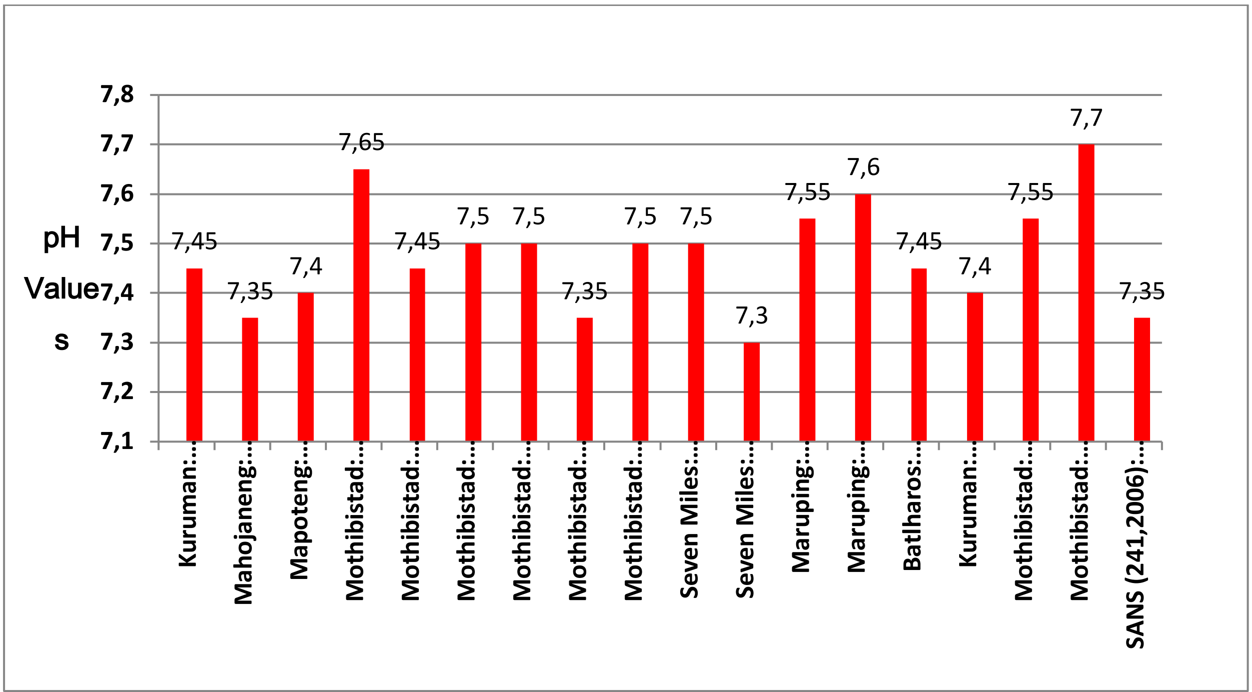

Figure 5.1: Annual mean pH variation for boreholes in the Ga-Segonyana municipality: pH water quality assessment

This study showed that the pH and temperature values of all water samples from the different municipal areas were within the recommended limit for drinking and domestic purposes of 5 to 9.5 and 18°C to 25°C (SANS 241, 2006; DWAF, 1996). The higher pH values above neutral of all groundwater samples indicate groundwater in Ga-Sengonyana municipality area is slightly alkaline. These findings concur with groundwater quality measurement done in the same area by Wilcox (1995).

5.1.2 Electrical Conductivity (EC) and Total Dissolved Solids (TDS)

EC occurs in water with ions such as nitrates, potassium, chloride, magnesium, carbonate, sulphate, bicarbonate, sodium, calcium and chloride. EC measurement of water samples was conducted over two seasons. Its recommended standard is ≤ 170ms/m (DWA, 2015) and all the water samples were within the range of recommended EC. Figure 5.2 below shows the EC results. In some studies by Sililo et al, (2001) in Lusaka informal settlement the EC levels indicated values of over 340 ms/m suggesting poor quality water.

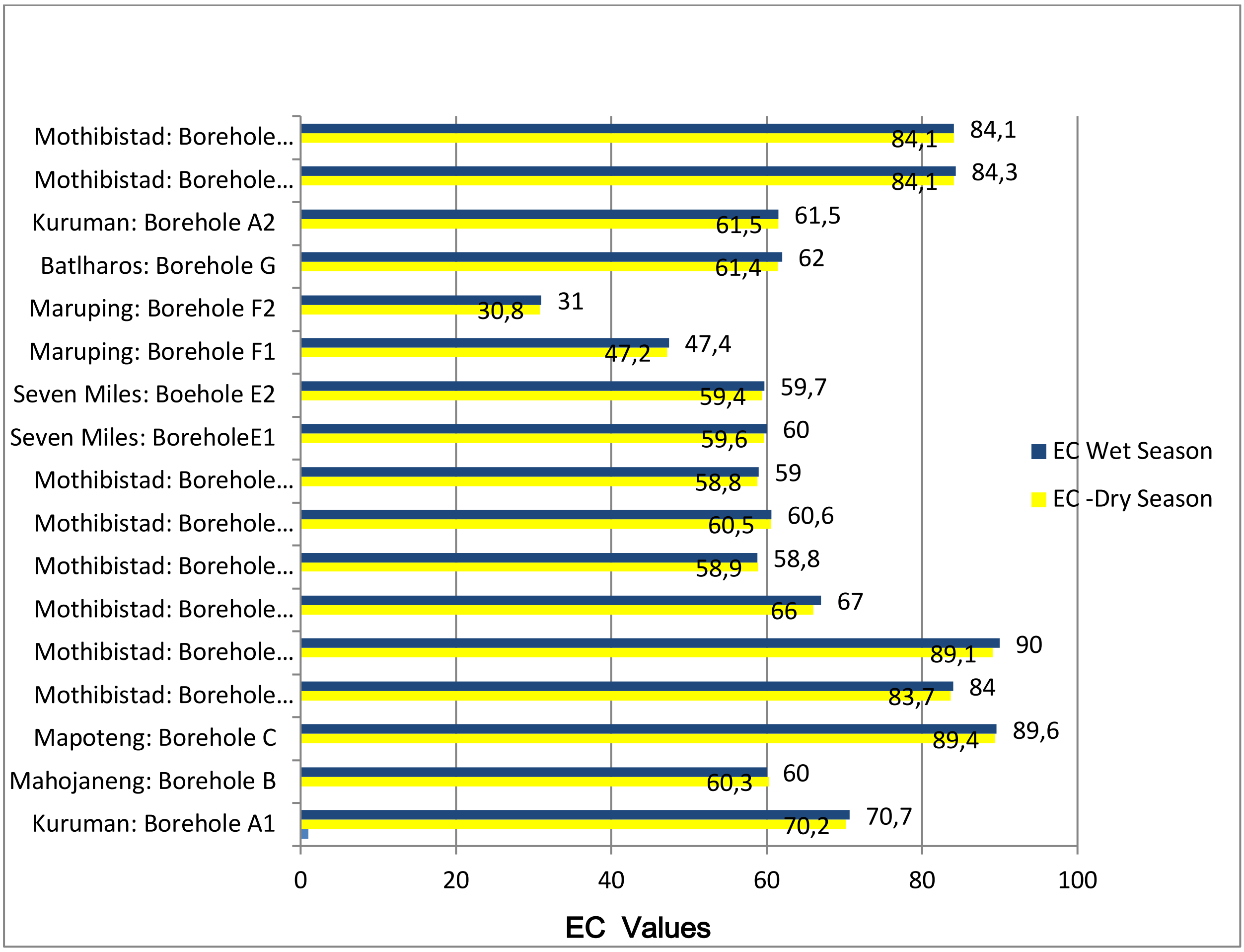

Figure 5.2: EC Levels of boreholes in the Ga-Segonyana Municipality

TDS was estimated using the Electric Conductivity (EC) due to its easiness of measurement. Electrical conductivity is used to estimate the TDS as it is directly proportional to the TDS (DWAF, 1996). As an approximation for converting EC to TDS a conversion factor of 0.8 is used for water with high calcium concentration in the formula: TDS(mg/l) = 0.8*E.C ms/cm (Atekwana et al., 2004). The EC is normally expressed as Siemens/cm and occasionally as Siemens/m. If 1ms/m is equivalent to 10ms/cm, the TDS level estimation obtained from the results of EC in Table 5.1 shows the TDS ranges from 246mg/l to 720mg/l. The results revealed that all of the borehole samples were within the recommended limit of 1200mg/l TDS for no risk (SANS 241, 2006; DWAF, 1996). A study conducted by (National Research Council, 1993) also recorded low values of TDS for Northern Cape. TDS represents the amount of inorganic substances (salts and minerals) in the solution. Water with a high TDS usually has characteristics of an objectionable or offensive taste, total hardness, scaling and corrosion. A higher concentration of TDS usually poses no health threat to humans until the values exceed 3000 mg/l (DWAF, 1996).

5.1.3 Turbidity

The turbidity levels of all groundwater samples ranged between 0.2 and 7.4 NTU, against a standard turbidity level of ≤1. The highest recorded level of turbidity was 7.4 NTU, in the Seven Miles area during wet season and 7.2 in dry season respectively. In addition, the results also showed that Seven Miles area borehole samples were exceeding (>7) the recommended limits (0 to 1 NTU) for potable water with regard to turbidity (DWAF, 1996; SANS 241, 2006).

Highly turbid water in Seven Miles area at 7.4 NTU cannot be considered safe for drinking purposes. This might be due to silt, as the water sample appeared to be brown in colour. Turbidity in water is caused by the presence of suspended matter, which usually consists of a mixture of inorganic matter, such as clay and soil particles, and organic matter (DWAF, 1996). High turbidity also implies that there is media in which the microorganism can grow. A high turbidity level in water is often associated with the possibility of microbiological contamination, as high turbidity makes it difficult to disinfect water effectively (DWAF, 1996; WHO, 2007). Due to the high level, the water may pose a health hazard to the community, especially the infants.

5.1.4 Nitrates concentration

With regard to nitrates concentration in the water samples, values were observed to range from 0.5mg/l to 18 mg/l nitrates. Figure 5.3 below shows nitrate distribution in sampled boreholes during the wet and dry season.

The highest nitrate concentration of 18 mg/l as N was found in the Mothibistad area. The results revealed that 23% of the borehole samples were above the recommended limits (0 to 6 mg/l as N) for potable water (DWAF, 1996; SANS 241, 2006).

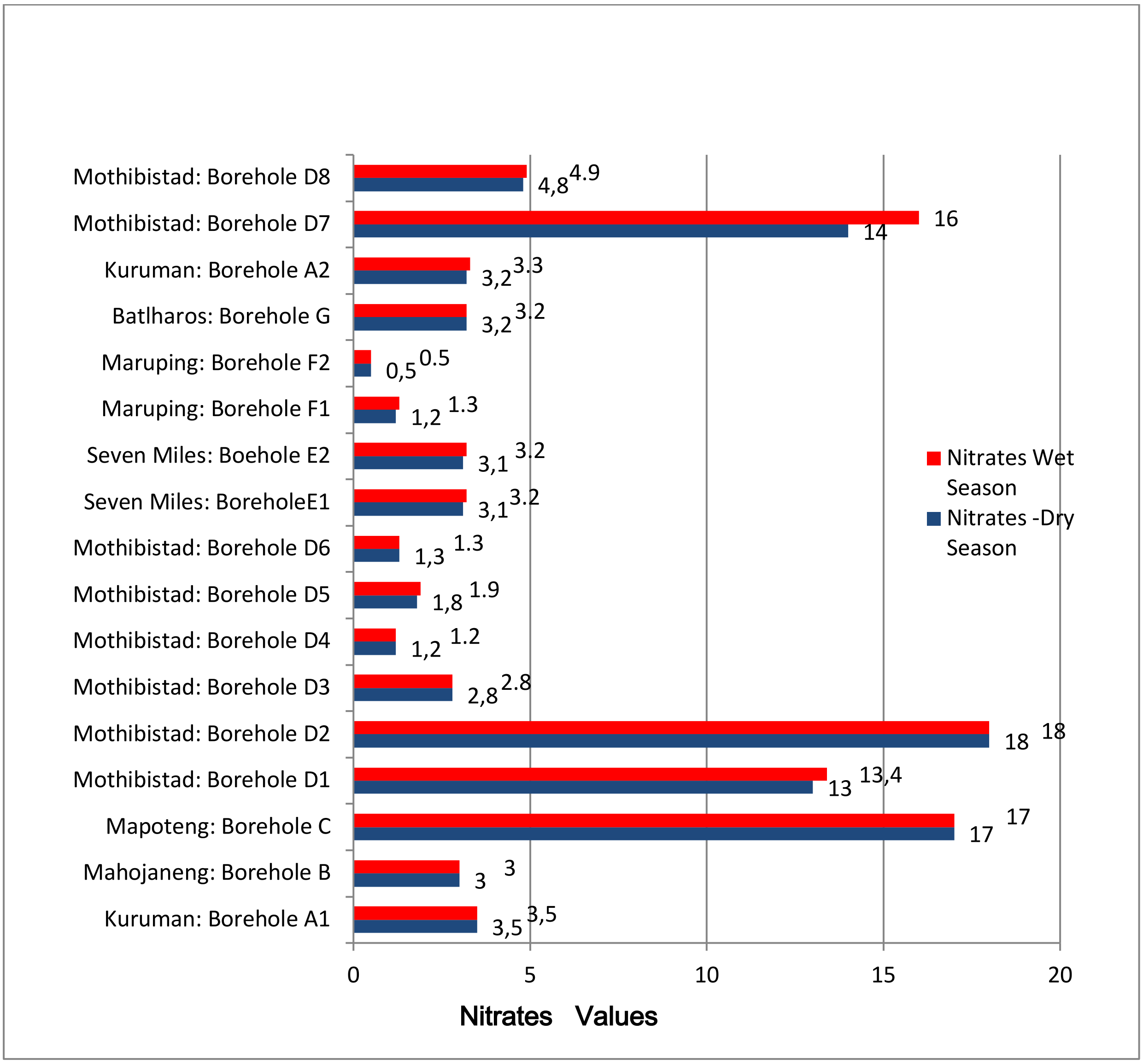

Figure 5.3: Nitrate levels in sampled boreholes

The water samples were collected from some boreholes in Mothibistad and Magojaneng areas. Findings of high groundwater nitrate levels in some parts of the Ga-Sengonyana municipalities concurs with studies which reported high levels of nitrates that naturally exist in the North east region of Northern Cape (Sililo & Saayman, 2001; Terblanche, 1991; Tredoux et al., 2009 & Merry et al., 2010). Consequently, the presence of nitrates in groundwater could also have been amplified by agricultural activity or leaking effluent from on-site sanitation associated with the simultaneous presence of bacterial contamination (WHO, 2007). However, Water Wheel (2005) reported that nitrates occur naturally in the Northern Cape as inorganic nitrates from geological formations such as basalt rocks. Conrad et al (1999), argues that high nitrates found in some regional groundwater is isotopic of soil nitrogen. The soil nitrogen nitrification process and leaching into soils that occurs after tilling the land was identified as the source of the nitrates.

High nitrate concentrations can cause methaemoglobinaemia (blue-baby syndrome) in bottle-fed infants and could result in occurrence of mucous membrane irritation in adults (DWAF, 1996; WHO, 2007). Furthermore, high nitrates levels present an array of ecological problems when they are discharged from aquifers into the environment. Nitrates increase, in rivers and lakes can result in the eutrophication process occurring. Consequently, the algae boom in water systems deprives the biota of oxygen in water and causes death of aquatic creatures. Though such an upset may not be viewed as a disaster risk, the livelihoods of people who rely on aquatic food such as fish become more vulnerable.

5.1.5 Fluoride concentration

Fluoride concentrations in water samples ranged from 0.5 to 0.6mg/l. The fluoride concentration results were within the recommended limit of 0 to 1 mg/l (DWAF, 1996; SANS 241, 2006). The present results are in accordance with the findings of other researchers (Ncube & Schutte, 2005). Health problems associated with the condition known as fluorosis may occur when fluoride concentrations in groundwater exceed 1.5 mg/l and staining of tooth enamel may become apparent (dental fluorosis).

With continued exposure, teeth may become extremely brittle (DWAF, 1996). The incidence and severity of dental fluorosis and skeletal fluorosis, depends on a range of factors including the quantity of water consumed and exposure to fluoride from other sources, such as high-fluoride coal, as was noted in China (WHO, 2006).

5.1.6 Sodium

The Batlharos area had the highest recorded sodium concentration (78 mg/l), while low levels were common in all areas (<6 mg/l). With regard to sodium, the borehole samples were within the recommended limits for no risk (0 to 100 mg/l) (DWAF, 1996). The high levels of sodium in some areas can be associated with chemical erosion of rocks in the aquifer system.

There is no indication of adverse health effects in the general population associated with high sodium levels in drinking water, although such water may not be suitable for bottle-fed infants because of its faintly salty taste (DWAF, 1996; WHO, 2007).

5.1.7 Magnesium and Calcium

The values recorded for magnesium and calcium concentrations in the water samples ranged from 1.2 to 56 mg/l and <6 to 98 mg/l, respectively. The highest magnesium concentration was observed in the Mapoteng village area with 56mg/l in wet season and slightly lower recorded level in dry season at 55mg/l. The highest calcium concentration was also observed in Mapoteng village area with 98mg/l recorded in both dry and wet seasons.

The results also indicated that some samples from Batlharos and Mothibistad were above the recommended limits of 0 to 30 mg/l and 0 to 32 mg/l, with regard to magnesium and calcium respectively. The presence of high calcium and magnesium in water contributes to water hardness (Tredoux et al., 2009). Groundwater in the dolomitic areas in Northern Cape and the northern parts of the country tends to be very hard. There are no health implications, except where concentrations of magnesium are extremely high. Magnesium has a bitter taste and may have a laxative effect on people not accustomed to the water (WHO, 2007). Magnesium, together with calcium, is responsible for scaling problems in appliances using heating elements and plumbing (DWAF, 1996; WRC, 1998). A high concentration of calcium impairs the lathering of soap (DWAF, 1996).

Furthermore, the in-depth interviews conducted with water quality specialists from the District municipality revealed that the water quality is generally higher in magnesium and calcium. These groundwater quality parameters are responsible for the bitter taste of groundwater existing in that area, though it does not have a health implication.

The higher than normal level of magnesium and sodium is responsible for scaling of the heating elements and lathering of soap. This scaling effect and lathering of soap has economic implications as higher than required amount of electricity may be used in heating and wastage of soap due to lathering. Figure 5.4 below shows the calcium levels in different sites.

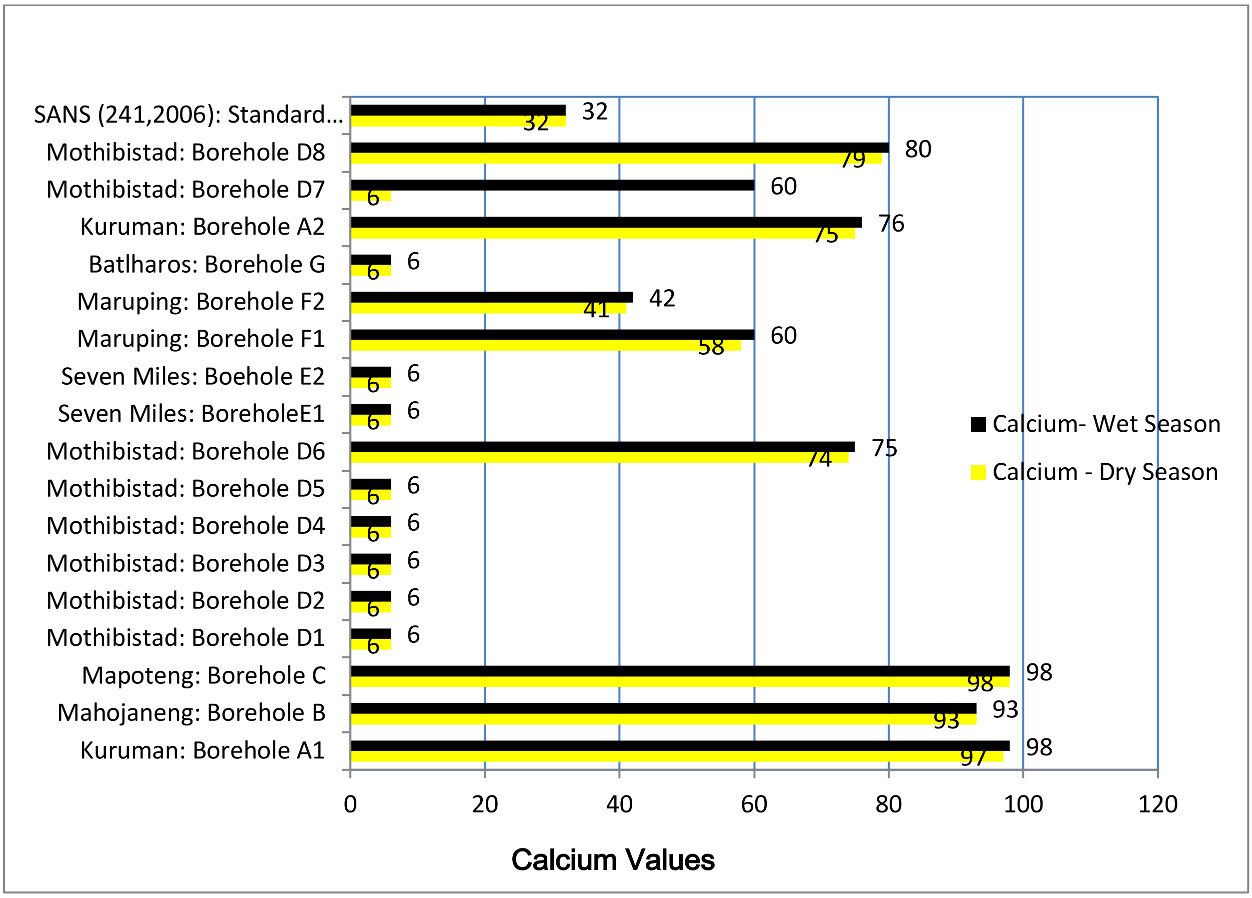

Figure 5.4: Calcium levels in groundwater samples

5.2 Seasonal differences in water quality parameters

The differences of water quality parameters between seasons for some important water quality parameters were computed to find an average between seasons and counter the fluctuation of some parameters with seasons. The physiochemical and biological parameters from 17 water samples were measured in dry and wet season. Figure 5.5 below shows the pH variation between seasons.

Higher pH was recorded in the wet season compared to the dry season. This could signify the increase of concentrations in dissolved salts from water infiltration. There was also an increase of nitrates during the wet season with an increase of variance from 34.397 to 37.073. Higher nitrate concentrations could be associated with high seepage of organic materials from the land surface during the wet summer rain season. High storm water drainage in the urban environment during the wet season can result in the increase of nitrates in groundwater. Moreover, storm water drainage often results in sewer pipe breakages resulting in further contamination of water.

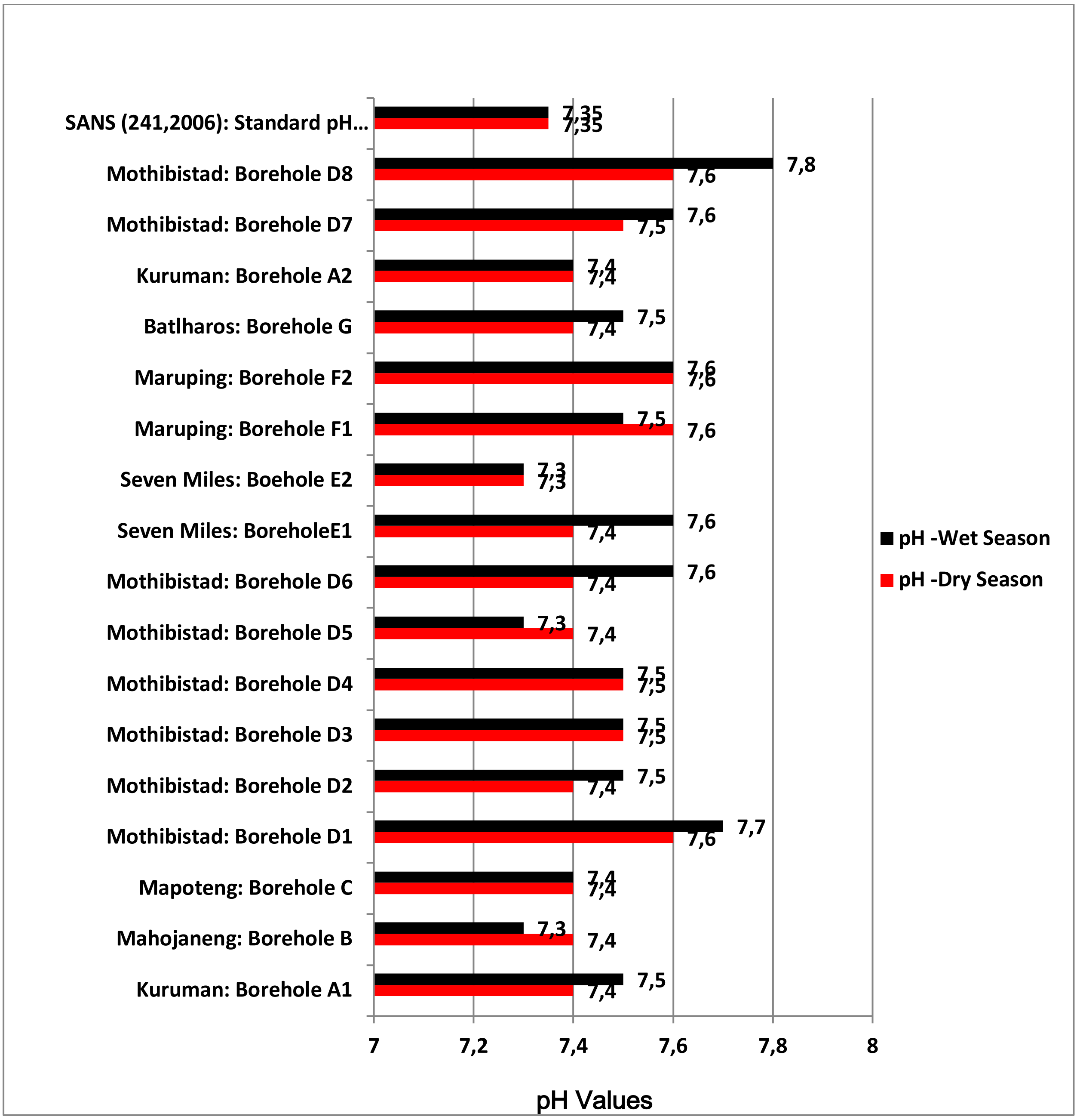

Figure 5.5: Seasonal pH variation (wet and dry)

The statistical analysis showed significant variance of some water quality parameters between seasons as given in Table 5.2 below. In general, most groundwater quality parameters increased in the wet season signifying the effect of seepage during the wet season. The highest variance between seasons was observed with nitrate, from 34,397 in the dry season to 37.073 in the wet season.

Table 5.2: Statistical analysis of water quality parameters

		Turbidity Dry	TurbidityWet	Ph Dry	Ph Wet	NitrateDry	NitrateWet	FluorideDry	FlourideWet
N	Valid	17	17	17	17	17	17	17	17
	Missing	0	0	0	0	0	0	0	0
Mean		.971	1.059	7.459	7.506	5.571	5.724	.500	.5324
Std. Deviation		2.1467	2.1729	.0939	.1391	5.8649	6.0888	.0000	.13339
Variance		4.608	4.721	.009	.019	34.397	37.073	.000	.018
Percentiles	25	.200	.200	7.400	7.400	1.550	1.550	.500	.5000
	50	.200	.300	7.400	7.500	3.100	3.100	.500	.6000
	75	.250	.400	7.550	7.600	8.900	9.150	.500	.6000

5.3 Ground water pollutants: Microbiological characteristics

The analyses of the total coliform counts obtained from 17 borehole water samples in two seasons are shown in Figure 5.6 below and Appendix 2. There is a positive co-relation between the nitrates levels and coliform count in water samples with areas having high nitrates also having a high coliform count. This is discussed further in section 5.4. The highest concentration of total coliforms was observed in Mothibistad area.

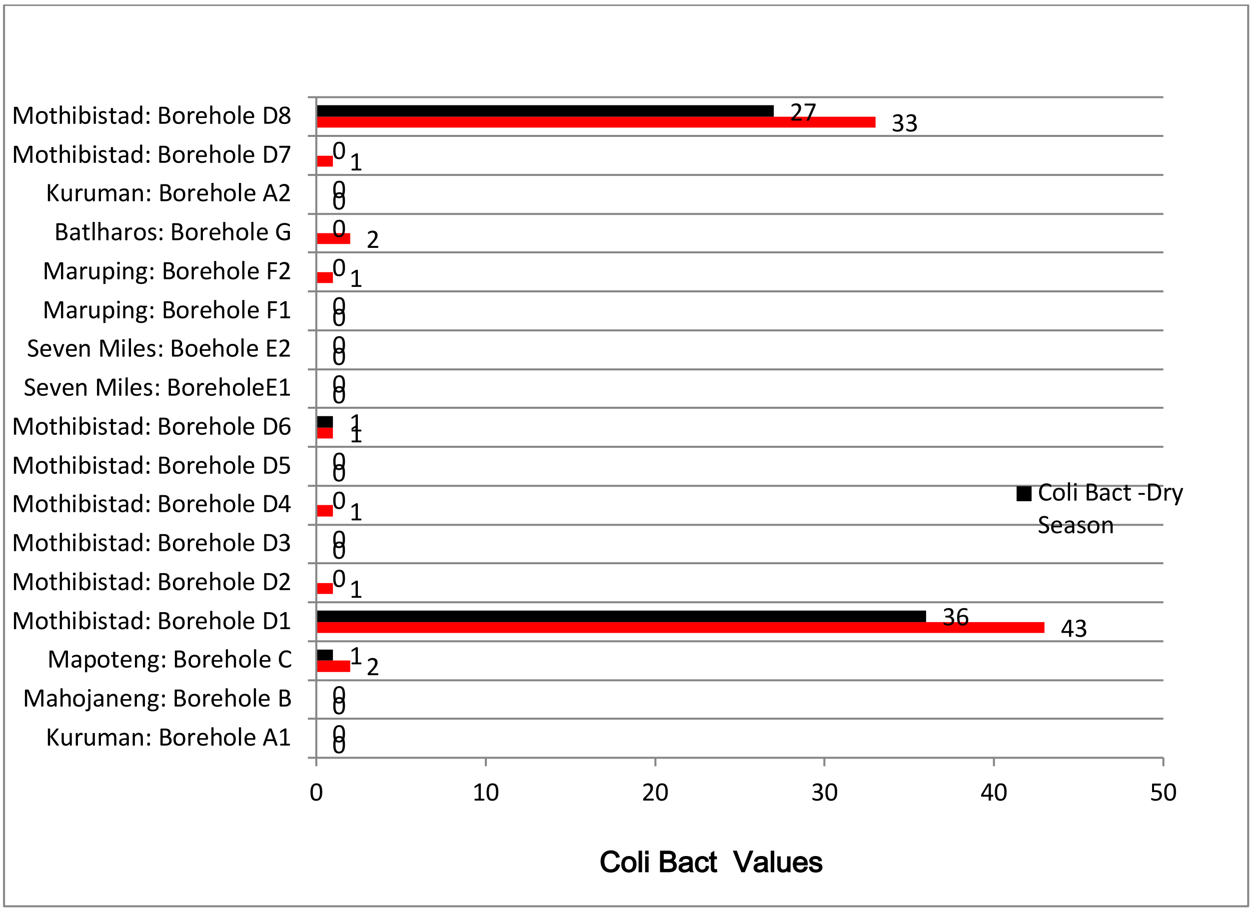

Figure 5.6: Total coliform count of samples in wet (summer) and dry (winter) periods

Statistical analysis of total coliform count carried out for seasonal differences is as shown in Table 5.3 below. There is significant increase of coliform bacteria in the wet season (mean 5.0, standard deviation 12.5648), whilst in the dry season there is significantly low coliform (mean 3.824, standard deviation 10.5430) in all boreholes sampled. A high level of nitrate infiltration and rise of groundwater in shallow wells may have caused the higher levels of total coliform in the wet season compared to the dry season groundwater samples (Nishida et al., 2014; Dongol et al., 2005).

Table 5.3: Statistical analysis of coliform bacteria count in two seasons

		Coli Dry season	Coli Wet season
N	Valid	17	17
	Missing	0	0
Mean		3.824	5.000
Std. Deviation		10.5430	12.5648
Variance		111.154	157.875
Percentiles	25	.000	.000

	50	.000	1.000
	75	.500	1.500

Moreover, the presence of coliform bacteria in Mothibistad water might indicate the possible presence of bacterial pathogens (DWAF, 1996). Consequently, the range of bacterial pathogens that might result in diseases and sicknesses in the municipal area should be accurate.

The presence of the opportunistic pathogens in the groundwater samples indicates that the community in Mothibistad, especially immuno- compromised individuals, infants and the elderly, are at a potential risk of contracting infections and diseases such as bacillary dysentery, respiratory infections, urinary tract infections and gastroenteritis during exposure to or consumption of groundwater from these sources (Payment, 1991). Diarrhoea and bacillary dysentery are mainly caused by enteric pathogens such as *E. coli, S. dysenteriae, S. enteric* and *B. cereus* (WHO, 2006).

It is reported that in South Africa, diarrhoeal diseases are responsible for about 20% of all deaths of 1 to 5 year olds (Bakker et al., 2008). In addition, *M. morganii* causes a disease known as “Summer Diarrhoea”, which is also often encountered in postoperative patients and is mainly associated with urinary tract infections (Department of Water Affairs and Forestry, 1996). The *C. freundii, S. marcescens, A. veronii and E.r cloacae* are known to cause a wide variety of nosocomial infections of the respiratory tract and urinary tract (Bakker et al., 2008)

A.veronii can cause infections in humans, including septicaemia, particularly in immune compromised patients, and in patients with wound infections and respiratory tract infections (Water Wheel, 2005). There have been some claims that *A. veronii* can cause gastrointestinal illness, but epidemiological evidence is not consistent (WHO,, 2000).

5.4 Comparison of the water quality in a town and a rural set up environment

Samples from the town and rural stratum were compared for differences in water quality and vulnerabilities. The results shows that there is a higher nitrate water quality parameter in a formal town set up with a sewage system as compared to a rural set up as shown in Figure 5.7 below.

The higher than expected nitrate level in the formal set up was identified mainly in one of the location in Mothibistad. This could have been attributed to the fact that the area was once having a pit latrine system before the construction of a sewer system. Interviews with the municipality health personnel reveals that the old sewage system in the area could be having leakages that contribute to high nitrate levels in groundwater. However, on average there is higher nitrate levels above the recommended 6mg/l in a town set up, there are some isolated cases of boreholes showing higher nitrate levels in Mapoteng village (17mg/l) with pit latrines as shown in Figure 5.7 below.

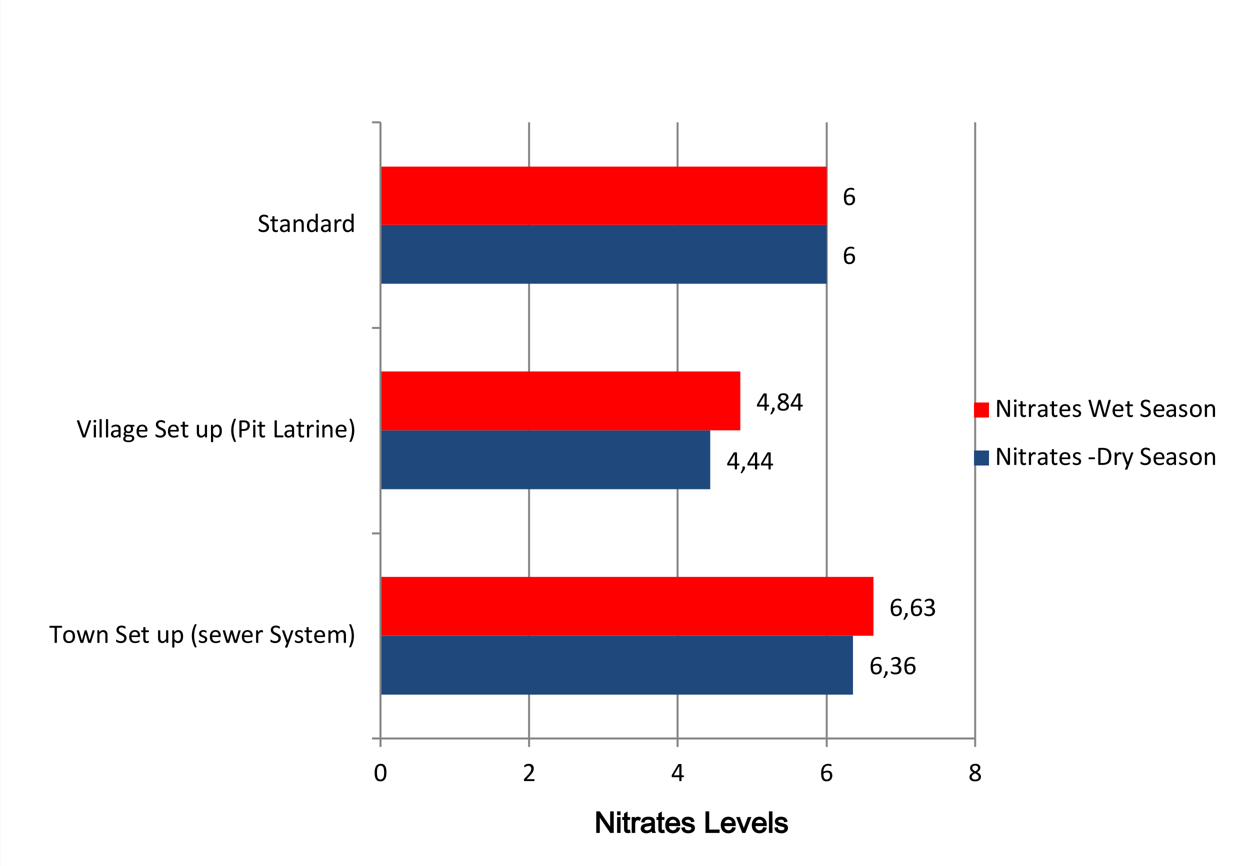

Figure 5.7: Urban and rural water nitrate comparison

Close analysis of biological water quality parameter between the two set ups shows higher than expected total coliform in a town set up as shown in Figure 5.8 below.

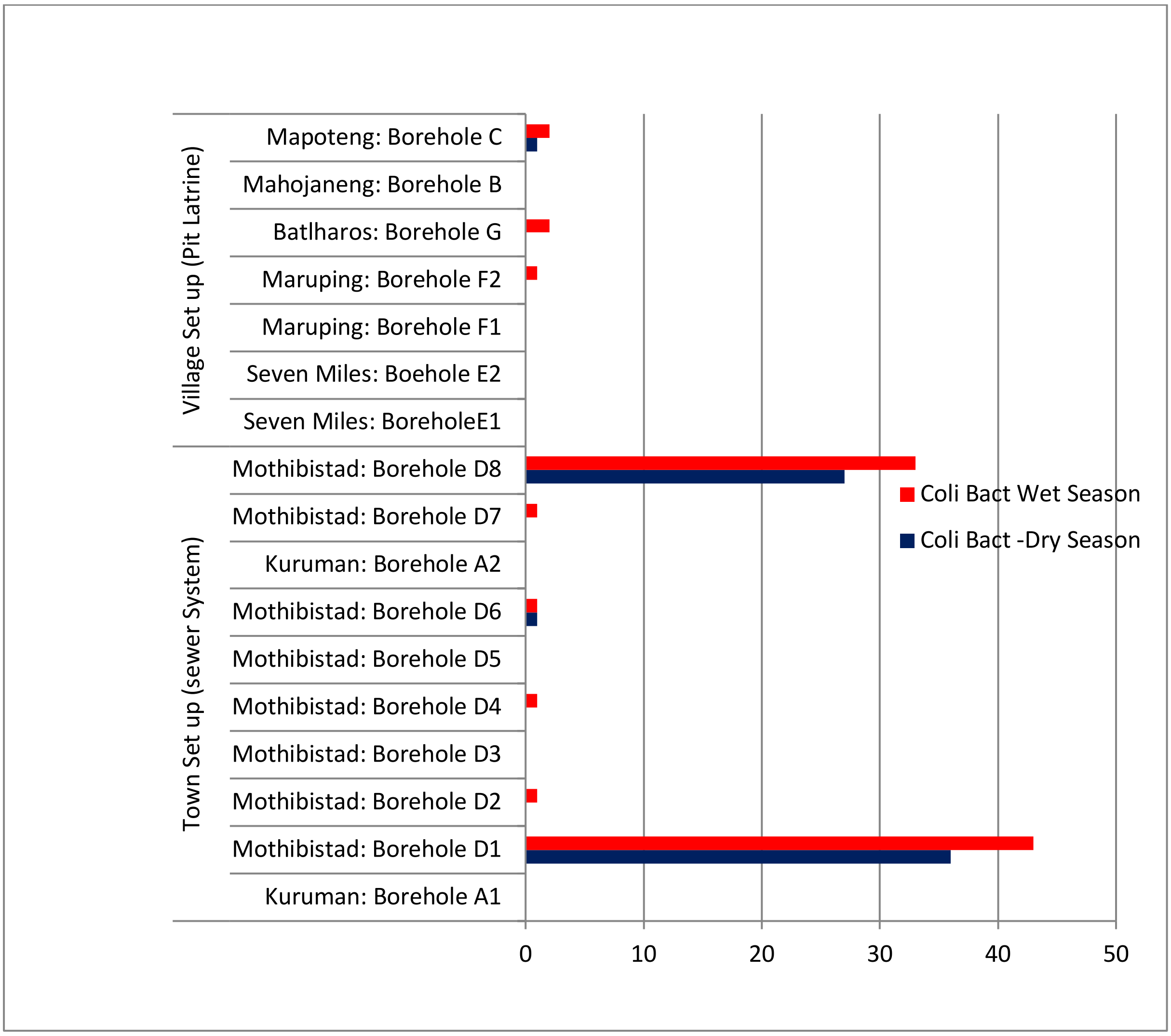

Figure 5.8: Urban and rural boreholes total Coli bacteria levels

The results obtained agree with findings by Wright (2010). Studies of groundwater pollution in developing urban settlements revealed general deterioration of water quality. There is a direct correlation between the nitrate level and total coliform in the urban setup. These findings are supported by WHO (2007), that in higher nitrates occurrence areas, there is possibility of higher total coliform. This points to the fact that the same source of the two pollutants (nitrate and total coliform) are sewer leakages or previous pit latrines that once existed before it was transformed into current urban set up.

5.5 Groundwater vulnerability assessment

The DRASTIC ranges for DRASTIC index scoring were obtained from past studies of similar factors in the same area. The relative weights that were used corresponded with the DRASTIC parameters by Aller et al (1987), as given in Table 4.7 in Chapter 4. Tables 4.5 and 4.8 in Chapter 4 were used to estimate aquifer vulnerability using

DRASTIC index. The DRASTIC score for Ga-Sengonyana municipality was evaluated at 140 as shown in Table 5.8 below.

Table 5.8: DRASTIC score of water aquifer in Ga-Sengonyana municipality area from computed factors

Factor	Range	Rating	Weight	DRASTC INDEX
Depth to water table (m)	22.9-30.5	2	5	10
Impact of vadose zone	Bedded limestone, sandstone, dolomite and shale	6	5	30
Net aquifer recharge (mm)	102-178 mm	6	4	24
Aquifer media	Sand and gravel and dolomite	8	3	24
Hydraulic conductivity of aquifer (m day^{-})	40.7-81.5	8	3	24
Soil media	Sand	9	2	18
Topography slope	0-2%	10	1	10
Total 140				

An average depth of 30 meters to the water table was obtained through measuring 17 borehole samples. The depth of other boreholes for the whole area was supplied from Sedibeng waters, which have the mandate to extract and supply borehole water in the municipality. The average depth to the water was close to the one obtained in the research carried out by Sililo and Saayman (2007).

Net recharge estimates were obtained in Sililo and Saayman's (2007) report to the Water Research Commission. The area has arid to semi-arid characteristics with recharge rate as high as 102-178 mm per year. Though the area is arid and receives an average annual rainfall of 250mm (Rutherford, 1996), the vadose zone (unsaturated zone) consists of unconsolidated material of sand that allows rapid infiltration. Furthermore, the catchment area is considered an endorheic basin, in which there is no natural discharge in the basin other than evaporation (Saayman, 2007).

The water recharge rate can be influenced by groundwater use and groundwater regimes. The high urban population growth coupled by rural urban migration in Kuruman town and periphery villages necessitates more groundwater extraction by authorities to serve the population as the sole source of water in the area. The high groundwater extraction often changes the water regime and increases hydraulic conductivity (rate of water infiltration).

The high demand and extraction of groundwater could have led to dolomite dissolution, leading to formation of fractured channels in the aquifer. Fractured channels in the aquifer allow direct aquifer recharge and groundwater flow thereby increasing vulnerability (Pavelic et al, 2012). Besides the high groundwater extraction rate having an effect on recharge rate, clearance of the natural biomes to establish both formal and informal houses modifies the natural hydrological patterns. High surface water flows often lead to drainage pathways that are directly connected to the aquifers, increasing the recharge rate. Overgrazing commonly occurs in the veld of the district area. Limited vegetation reduces rainfall interception and thereby increases recharge rates.

The topography in terms of the slope was obtained from Rutherford (1996), in the study of vegetation in Southern Africa. The average slope of the Ga-Sengonyana is 0- 2 %, signifying that it is relatively flat and allows relatively higher infiltration of rainwater compared to steep slopes.

Information on hydraulic conductivity was obtained from Water Research Commission, (2005). There is considerable high hydraulic conductivity due to the soil media nature of sand and gravel in vadose zone. The hydraulic conductivity was ranked at 40.7-81.5.

Data relating to lithology and soil was obtained from Sililo and Saayman (2007) & Thomas and Shaw (1991), from a report of deposition and development of Kalahari Group sediments in Central Southern Africa. The area is composed of calcified sand, gravel, limestone and shale meaning there is a high vulnerability range of Aquifer media at 4-9. It is at the edge of the Kalahari Desert to the east and is composed mainly of soil media of Kalahari sands, making it very vulnerable, with a rating of eight.

A Drastic index of 140 was obtained as shown in Table 5.8 above. The area ranges from moderate to high vulnerability. The score agrees with the DRASTIC score of 124 to 192 obtained by Wilcox (1995) in sandstone aquifers. However, the DRASTIC score of 140 given in this study is lower than the higher vulnerability figure of the aquifers obtained for the whole region of Northern Cape by WRC (2005).

5.6 Chapter summary

This chapter presented the research findings and data interpretation in order to meet the objectives and answer the research questions. The quantitative and qualitative methods were used to come up with the findings. Findings of the study were not treated in isolation but a comparison was made with relevant past groundwater studies done locally and abroad. This study revealed that the groundwater in Ga-Sengonyana reflects a moderate to high pollution risk potential, due to both natural characteristics of existing groundwater aquifers and different anthropogenic activities. The next chapter presents the summary of study findings and recommendations.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.0 Introduction

The chapter provides a summary of the study as well as recommendations for preventing and reducing pollution risk of groundwater in the Ga-Sengonyana municipality area. Recommendations for future studies are also given to prevent and mitigate groundwater vulnerability. A summary of findings on the research questions is given followed by study and chapter conclusions

6.1 Summary of findings

6.1.1 Research Question 1: What are the specific water quality parameter measurement levels of Ga-Segonyana municipality area?

The results showed that a number of Ga-Segonyana water sites were compliant with standards requirements (SANS, 241:2006) during both wet and dry seasons. However, based on the outcome of the study, there is evidence of physicochemical and microbiological pollution of the groundwater supplied to some of the communities living in the Ga-Sengonyana municipality area. There were high water quality parameters concentration in some groundwater samples above recommended SANS 241(2006), of total coliforms (>4 times) observed in some boreholes in Mothibistad, turbidity (>7 times) in Seven Miles, calcium (>3 times) in Maruping, nitrates (≥3 times) in Mothibistad and Mapoteng, magnesium (≥2 times) in Mapoteng. These levels are exceedingly high when compared to the guidelines. This means the water in some areas is not fit for human consumption. The limestone and dolomite ($(CaMg(CO_3)_2)$ rocks that largely form part of the vadose zone and aquifer media are rich in minerals, calcium and magnesium that enriches the local groundwater with these minerals.

6.1.2 Research Question 2: Which are the groundwater pollutants and sources of contaminants threatening the Ga-Segonyana municipality area groundwater?

Perhaps the threat to humans in Ga-Sengonyana is biological water quality parameter in the form of total coliform. The results of the study revealed that out of the 17 boreholes, 52 % tested positive for total coliform and 0% for Escherichia coli. Total coliform in the formal location of Mothibistad exceeded the minimum requirement of < 10 col/ 100ml. This is of importance and of immediate concern in the municipality area, as it can cause disease outbreak such as typhoid, cholera and diarrhoea. There is higher than recommended level of nitrate in Mothibistad (town set up) and Mapoteng (village set up with pit latrines). This signifies that pollution is not limited to areas with pit latrines but also with connected sewage systems.

6.1.3 Research Question 3: How vulnerable is the aquifer under Ga-Segonyana municipality's urban and village jurisdiction areas to pollution?

The groundwater vulnerability assessment conducted using the DRASTIC index revealed the DRASTIC score of 140, implying that there is moderate to high vulnerability of aquifers in the Ga-Sengonyana district municipality. Gentle terrain allows ample time for water to sink thereby increasing the net recharge of the aquifer. Furthermore, the soil media in unsaturated zone consisting largely of sand soils contributes to high recharge rate and renders high vulnerability of the subsurface water to pollutants. The recharge rate is exacerbated by existing dissolution fractures in dolomite rocks that are evidenced by common water springs in the area. The existence of the fractures in the vadose zone and aquifer media increases the aquifer's vulnerability by allowing direct aquifer recharge within a short time .The catchment area is endorheic in nature (no natural catchment discharge except only by evaporation) (Rutherford, 1996). This implies that naturally no pollutants can be removed from this aquifer making it highly vulnerable to pollution.

6.1.4 How does wet season water quality differ from that of the dry season?

Water quality parameter may fluctuate with seasons; hence the use of the seasons average to get insight on true levels. Some groundwater quality parameters showed a significant change between seasons with higher concentration being present in wet season (pH, Nitrates & Total coliform). Change in quality parameters in different seasons also gave an insight on the vulnerability of groundwater. The increase in total coliform in the wet season could be associated with recent seepage of water that carries microbial components from the surface. Moreover, the old sewer system leakage and pit latrines existing in areas such as Mothibistad and Mapoteng respectively could result in a huge amount of waste being transported with seepage rainwater (Nishida et al., 2014).

6.2 Recommendations for groundwater management

The study findings from literature review, collected, evaluated and analysed data shows that groundwater in Ga-Sengonyana municipality area is vulnerable to pollution due to natural aquifer formation and anthropogenic factors. The results revealed that some areas in Ga-Sengonyana municipality have water quality parameters that exceeded the recommended SANS 241(2006). The DRASTIC score shows the aquifer has moderate to higher vulnerability.

The outcome of the research presents recommendations to prevent and or mitigate the water pollution risk in the local municipality area. Municipality authorities should be cautious in land use planning. Urban sprawl should be under control to avoid ecosystem damage and the change of existing water regimes.

6.3 Study conclusion

Based on the outcome of the study, there is evidence of physicochemical and microbiological pollution of the groundwater supplied to some communities living in Ga-Sengonyana municipality area.

6.3.1 Vulnerability of groundwater in Ga-Sengonyana municipal area

Groundwater vulnerability assessment conducted by DRASTIC index score obtained a relatively high DRASTIC score. The high groundwater vulnerability is associated with existing gentle terrain; loose material forming the soil media, vadose zone and aquifer media and; high hydraulic conductivity. Groundwater vulnerability is exacerbated by lack of rivers in the area to allow natural discharge. Consequently, this study calls for urgent involvement of the authorities to provide protection of groundwater source by preventing and or mitigating the risk of groundwater pollution.

6.3.2 Quality of the groundwater

Assessment of groundwater quality was fully achieved as the research established the water quality parameters complying and exceeding the standard requirements by SANS 241(2006). The outcome of this study revealed that the quality of groundwater supplied in some areas of Ga-Sengonyana municipality communities is not fit for human consumption and is a ticking time bomb for a health disaster. The research determined and concluded that boreholes in Mothibistad, Seven Miles, Maruping and Mothistad and Mapoteng exceeded the minimum requirements for potable drinking water in total coliform, turbidity, nitrates and magnesium water quality parameters respectively. However, chances are that the contamination may spread laterally in water aquifer systems in the municipal area. Therefore, mitigation measures need to be implemented.

6.3.3 Pollution risk of groundwater in the area

The study on groundwater pollution risk was based on the interaction of the following factors: vulnerability of aquifer; hazard of nature contaminant load, coping capacity of the aquifer and manageability of groundwater resources. The outcome of the study proved that high aquifer vulnerability coupled with the threatening pollutants of anthropogenic nature (pit latrines and sewer leakages) renders high groundwater pollution risk.

Linking the conclusion to the hypothesis, pollutants have partially affected the groundwater of Ga-Sengonyana municipality area. The study revealed presences of important biological pollutants (total coliform) and nitrates in 52% and 23 % of the boreholes respectively. However, there is a threat of the pollutants spreading to the entire aquifer considering the vulnerable nature of the aquifer that can readily allow lateral movement of pollutants.

6.4 Recommendations for future research

- The impacts of climate change on altering groundwater pollution risk. Very little is known about the effects of climate change on groundwater
- Effect of land use changes on groundwater pollution risk. Land use is dynamic; hence close monitoring of the impact of these changes to groundwater should be investigated.
- Effect of pit latrines use on groundwater resource in clustered villages. The effect has to be investigated in different geophysical environments to ascertain the pollution risk associated. The land use should then be carefully planned taking into consideration groundwater vulnerability in the area.
- Integration of groundwater governance and groundwater protection from pollution. The groundwater resources are less known and often ignored and yet it is a sole source of water in many arid and semi-arid regions. There is need to close the gap in groundwater governance and general management. It is assumed that good groundwater governance embodies technical, economic, judicial, social, institutional and administrative structures, and an adequate policy arena that ensures the responsible use and maintenance of groundwater systems and related ecosystem services. Groundwater resources need a creative approach that moves the local authority toward adaptive and integrated management. Moreover, sectoral integration helps to coordinate policy

implementation and conflict resolution towards groundwater protection. Both vertical and horizontal integration in groundwater governance could also help in increasing groundwater quality and the general awareness of important ecosystem services it provides.

6.5 Chapter conclusion

The chapter presented a summary of the findings. It also presented the recommendations for groundwater management and future research relating to deteriorating water quality in the area.

6.6 General synopsis

The research set out to ascertain groundwater vulnerability to pollution and groundwater quality in Ga-Sengonyana municipal area. The thesis used a set of four objectives to come up with results. Eighteen (18%) of the sampled boreholes complied with all recommended standards by SANS, 241(2006). Although a substantial number of sampled boreholes (82%) exceeded the minimum standard requirements of some water constituents required by SANS, 241 (2006), 52% of the sampled boreholes showed presence of biological nature pollutants. These pose a major concern to health disaster in the area. The high groundwater vulnerability score obtained in the studies coupled with presence of pollutants already existing in the aquifer system points to a high groundwater pollution risk in the municipal area. The findings obtained can be projected to the regional level in areas that share similar hydro-geological and land use patterns. Consequently, this study calls for the urgent involvement of the local authority to prevent and mitigate the groundwater pollution.

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APPENDIX

Appendix 1: In-Depth Interview

Questionnaire for Sedibeng waters/Ga-Sengonyana municipal health/ Council of Geoscience.

Questionnaire Number: ______/______/______

INTRODUCTION AND BRIEF INSTRUCTIONS

I am a master's student in Disaster Management student at the University of the Free State. I am conducting a study titled: **Assessment of groundwater vulnerability, quality and pollution risk in Ga-Segonyana municipality area, Kuruman, Northern Cape in South Africa.**

Your institution is selected to participate in this interview and I would appreciate your participation in the study. The information you will provide will assist in groundwater management in Ga-Sengonyana municipality. The results of this study will also assist the authority to know its position regarding prevention and or reduction of groundwater pollution risk. The interview takes 30 minutes to complete. The information that you will provide will be used for academic purposes only. Your participation in this study is voluntary, you can chose not to participate if you so wish and no any form of incentive is given. Please may you answer the questions as honestly as possible. Confidentiality is assured to all participants. Participants in the end are asked if they have any questions.

Interviewer ____________________ Date: ______________ Start Time: _______________

Respondent's Name: ____________________________ Gender: _________Age ________

Organisation and designation: ____

Geographical areas under respondent's jurisdiction:________________________________

Postal Address: __________________________ Tel No: Landline/s _________________

Mobile________________ Fax: ________________ E-mail _________________________

Can you please describe the role of your organisation and work you do in community?

____

____

REF	THEME	QUESTION(S)	PROBES/PROMPTS	RESPONSES
1	Specific measurement parameter water quality levels	=Are there elements in local groundwater that exceed recommended		

		class 1 drinking water? =If there are any exceeding what are their concentrate? =what is the average recorded pH of groundwater in village, town and mining area boreholes ?		
2	Groundwater pollutants and source of contaminants common	= How often do you test for pollutants in boreholes? = Are there any recorded pollutants in boreholes? = If they are there what could be the source of pollutants?		
3	Vulnerability of aquifers	= Are there any existing measures to evaluate vulnerability of groundwater aquifers to pollution risk? = If there are any measures are there any vulnerability identified? = What contributes to the vulnerability of the aquifer?		
	Water quality	= Are there any		

4	differences in wet and dry	recorded difference in groundwater quality between dry and wet season? = if any which elements shows significant changes?		
5	Recommendations	=What can be done to avert or reduce the pollution risk of groundwater? = What resources are needed to implement such measures? = Are there any stakeholders who are critical in the process?		

Appendix 2: Borehole sample results

Sedibeng WATER

sanas
Lab T 0134

Final Test Report: NB 20 06 2018 G

Sample Point			KU A1	MAH B	MAP C	MOT D1	MOTD2	MOT D3
Sample No								
Chemistry	Units	SANS req						
pH at 25°C	pH units	5-9.5 pH	7.4	7.4	7.4	7.6	7.4	7.5
Turbidity	NTU	≤1	<0.2	<0.2	< 0.2	0.2	0.2	0.2
EC at 25 °C	mS/m	≤170mS/M	70.2	60.3	89.4	83.7	89.1	66
Fluoride	mg/l	≤1mg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Nitrate	mg/l	≤6mg/l	3.5	3	17	13	18	2.8
Magnesium	mg/l	≤30mg/l	36	30	55	< 6.0	< 6.0	< 6.0
Calcium	mg/l	≤32mg/l	97	93	98	< 6.1	< 6.0	< 6.0
Sodium	mg/l	≤100mg/l	9.6	< 6.0	14	< 6.2	< 6.0	< 6.0
Total Coliform Bact	cfu/	10 cfu/100ml	0	0	1	< 6.3	0	0
Sample Point			MOT D4	MOT D5	MOT D6	< 6.4	SEV E2	MAR F1
Sample No								
Chemistry	Units	SANS req						
pH at 25°C	pH units	5-9.5 pH	7.5	7.4	7.4	7.4	7.3	7.6
Turbidity	NTU	≤1	0.2	0.2	0.2	7.4	6.1	0.2
EC at 25 °C	mS/m	≤170mS/M	58.9	60.5	58.8	59.6	59.4	47.2
Fluoride	mg/l	≤1mg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Nitrate	mg/l	≤6mg/l	1.2	1.8	1.3	3.1	3.1	<1.2
Magnesium	mg/l	≤30mg/l	< 6.0	29	28	< 6.0	< 6.0	1.2
Calcium	mg/l	≤32mg/l	< 6.0	< 6.0	74	< 6.0	< 6.0	58
Sodium	mg/l	≤100mg/l	< 6.0	8.4	6.9	< 6.0	< 6.0	< 6.0
Total Coliform Bact	cfu	10 cfu/100ml	0	0	1	0	0	0
Sample Point			MAR F2	BATL G	KUR A2	MOTD7	MOTD8	
Sample No								
Chemistry	Units	SANS req						
pH at 25°C	pH units	5-9.5 pH	7.6	7.4	7.4	7.5	7.6	
Turbidity	NTU	≤1	0.2	0.3	0.3	< 0.4	<0.4	
EC at 25 °C	mS/m	≤170mS/M	30.8	61.4	61.5	84.1	84.1	
Fluoride	mg/l	≤1mg/l	<0.5	<0.5	<0.5	<0.5	<0.5	
Nitrate	mg/l	≤6mg/l	0.5	3.2	3.2	14	4.8	
Magnesium	mg/l	≤30mg/l	10	28	29	< 6.0	11	
Calcium	mg/l	≤32mg/l	41	< 6.0	75	< 6.0	79	
Sodium	mg/l	≤100mg/l	< 6.0	< 6.0	75	< 6.0	< 6.0	
Total Coliform Bact	cfu	10 cfu/100ml	0	0	0	0	27	

Note:
Results marked "Not SANAS Accredited in this report are not included in the SANAS Schedule of Accreditation for this laboratory.

M MALUNGANA
CHEMISTRY
(TECHNICAL SIGNATORY)

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Lab T 0134

Final Test Report: 05 02 2019 G

Sample Point			KU A1	MAH B	MAP C	MOT D1	MOTD2	MOT D3
Sample No								
Chemistry	Units	SANS req						
pH at 25°C	pH units	5-9.5 pH	7.5	7.3	7.4	7.7	7.5	7.5
Turbidity	NTU	≤1	0.3	0.4	<0.2	0.4	0.3	0.2
EC at 25 °C	mS/m	≤170mS/M	70.7	60	89.6	84	90	67
Fluoride	mg/l	≤1mg/l	<0.6	<0.6	<0.6	<0.5	<0.6	<0.6
Nitrate	mg/l	≤6mg/l	3.5	3	17	13.4	18	2.8
Magnesium	mg/l	≤30mg/l	36	30	56	<6.0	<6.0	<6.0
Calcium	mg/l	≤32mg/l	98	93	98	<6.0	<6.0	<6.0
	mg/l	≤100mg/l	9.7	<6.0	14	<6.0	<6.0	<6.0
Total Coliform Bact	cfu/100ml	10 cfu/100ml						
Sample Point			**MOT D4**	**MOT D5**	**MOT D6**	**SEV E1**	**SEV E2**	**MAR F1**
Sample No								
Chemistry	**Units**	**SANS req**						
pH at 25°C	pH units	5-9.5 pH	7.5	7.3	7.6	7.6	7.3	7.5
Turbidity	NTU	≤1	0.2	<0.2	0.2	7.4	6.2	0.3
EC at 25 °C	mS/m	≤170mS/M	58.8	60.6	59	60	59.7	47.4
Fluoride	mg/l	≤1mg/l	<0.5	<0.5	<0.6	<0.6	<0.6	<0.5
Nitrate	mg/l	≤6mg/l	1.2	1.9	1.3	3.2	3.1	<1.3
Magnesium	mg/l	≤30mg/l	<6.0	30	28	<6.0	<6.0	1.2
Calcium	mg/l	≤32mg/l	<6.0	<6.0	75	<6.0	<6.0	60
Sodium	mg/l	≤100mg/l	<6.0	8.5	7	<6.0	<6.0	<6.0
Total Coliform Bact	cfu/100ml	10 cfu/100ml				<6.3		
Sample Point			**MAR F2**	**BATL G**	**KUR A2**	**MOTD7**	**MOTD8**	
Sample No								
Chemistry	**Units**	**SANS req**						
pH at 25°C	pH units	5-9.5 pH	7.6	7.5	7.4	7.6	7.8	
Turbidity	NTU	≤1	0.2	0.4	0.3	<0.4	<0.4	
EC at 25 °C	mS/m	≤170mS/M	31	62	61.5	84.3	84.1	
Fluoride	mg/l	≤1mg/l	<0.5	<0.5	<0.6	<0.5	<0.6	
Nitrate	mg/l	≤6mg/l	<0.5	3.2	3.3	16	4.9	
Magnesium	mg/l	≤30mg/l	10	29	29	<6.7	12	
Calcium	mg/l	≤32mg/l	42	<6.0	76	<6.0	80	
	mg/l	≤100mg/l	<6.0	<6.0	78	<6.0	<6.0	
Total Coliform Bact	cfu	10 cfu/100ml						

Note:
*Results marked *Not SANAS Accredited in this report are not included in the SANAS Schedule of Accreditation for this laboratory.*

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CHEMISTRY
(TECHNICAL SIGNATORY)

Appendix 3: Ethical clearance

UFS·UV

Faculty of Natural and Agricultural Sciences

28-Nov-2018

Dear Mr Kuziwa Saungweme

Ethics Clearance: **ASSESSMENT OF GROUNDWATER QUALITY AND POLLUTION RISK IN GASENGONYANA MUNICIPALITY AREA, KURUMAN, NORTHERN CAPE PROVINCE IN SOUTH AFRICA**

Principal Investigator: **Mr Kuziwa Saungweme**

Department: **DiMTEC Department (Bloemfontein Campus)**

APPLICATION APPROVED

This letter confirms that a research proposal with tracking number: **UFS-HSD2018/1412** and title: **'ASSESSMENT OF GROUNDWATER QUALITY AND POLLUTION RISK IN GASENGONYANA MUNICIPALITY AREA, KURUMAN, NORTHERN CAPE PROVINCE IN SOUTH AFRICA'** was given ethical clearance by the Ethics Committee.

Your ethical clearance number, to be used in all correspondence is: **UFS-HSD2018/1412**

Please ensure that the Ethics Committee is notified should any substantive change(s) be made, for whatever reason, during the research process. This includes changes in investigators. Please also ensure that a brief report is submitted to the Ethics Committee on completion of the research.
The purpose of this report is to indicate whether or not the research was conducted successfully, if any aspects could not be completed, or if any problems arose that the Ethics Committee should be aware of.

Note:

1. This clearance is valid from the date on this letter to the time of completion of data collection.
2. Progress reports should be submitted annually unless otherwise specified.

Approved

Yours Sincerely

Dr. Karen Ehlers
Chairperson: Ethics Committee
Faculty of Natural and Agricultural Sciences

Natural and Agricultural Sciences Research Ethics Committee
Office of the Dean: Natural and Agricultural Sciences
T: +27 (0)51 401 2322 | +27 (0)82733 2696 | E: smitham@ufs.ac.za
Biology Building, Ground Floor, Room 9 | P.O. Box/Posbus 339 (Internal Post Box G44) | Bloemfontein 9300 | South Africa
www.ufs.ac.za

Appendix 4: Permission letter from Ga-Sengonyana local municipality in JTG District

John Taolo Gaetsewe
District Municipality

PO Box 1480
4 Federale Mynbou Street
Kuruman
8460

Enquiry: M Ngomane

5 March 2018

Kuziwa Evans Saungweme

Unit 7380

Mothibistad

7484

RE: REQUEST FOR AUTHORITY TO CONDUCT A RESEARCH STUDY TITLED ASSESSMENT OF GROUNDWATER VULNERABILITY, QUALITY AND POLLUTION RISK IN GA-SEGONYANA MUNICIPALITY AREA, KURUMAN, NORTHERN CAPE IN SOUTH AFRICA.

The above subject matters refers

I am writing to you to inform you that following assessment of your research proposal for study, the request to undertake the field research has been approved and authority for the research study to be conducted has been granted.

Based on ethical merits of the proposed research, the John Taolo Gaetsewe District Municipality (Ga-Sengonyana LM) has no objection to the proposed research being carried in John Taolo Gaetsewe District Municipality (Ga-Sengonyana LM area) as it is for academic reason.

Yours Sincerely

M Ngomane
Environmental Health Practitioner

Tel: 053 712 8700 • Fax: 053 712 2502 • Web: www.taologaetsewe.gov.za