ENVIRONMENTAL GEOHYDROLOGICAL INVESTIGATION: FOCUSING ON THE ONDERSTEPOORT LANDFILL SITE, GAUTENG, SOUTH AFRICA

by

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submitted in accordance with the requirements for

the degree of

MASTER OF SCIENCE IN ENVIRONMENTAL MANAGEMENT

in the subject

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF ENVIRONMENTAL SCIENCES

at the

UNIVERSITY OF SOUTH AFRICA

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NOVEMBER 2022

DECLARATION

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ACKNOWLEDGEMENTS

First and foremost, I give praise and thanks to God Almighty.

I would like to express my greatest gratitude towards my employer, the City of Tshwane, and the Onderstepoort landfill site team for allowing me the opportunity to pursue the dream of furthering my studies. Without your approval, this research project would not have been possible.

I would like to express my deepest gratitude to my supervisor Prof. Linda Lunga Sibali for his motivation, enthusiasm, patience, valuable guidance, immense knowledge, and commitment to ensuring that this project is successful.

I would like to express my appreciation to my previous supervisor Prof Shadung John Moja for his guidance during the inception of this study.

I would also like to thank the Council of Scientific and Industrial Research (CSIR) laboratory team for their assistance and support.

I would like to give my special thanks to my husband for giving me unfailing support and continuous encouragement and motivation throughout my years of study,

- my children for giving me the space and time to study,
- my siblings; sisters and my brother for your encouragement and support.

Finally, I would like to thank all the people who have supported me through this journey. This accomplishment would not have been possible without you.

DEDICATIONS

This research work is dedicated to my late parents, Father (Mr. Nelson Mapholo) and Mother (Ms. Rahab Mapholo). You have been an inspiration to me and supported me from childhood. Am very thankful that you raised me to be the person I am today.

ABSTRACT

The Onderstepoort landfill facility is in the City of Tshwane (CoT) and has been operational since 1996. The facility was developed following the Environmental Conservation Act (ECA) 73 of 1989 and classified as G:M:B- which means that the facility accepts general waste (G), medium in size (M), and with no significant generation of leachate (B-). Onderstepoort landfill facility has reached its full capacity and is in the process of being closed.Tshibalo,(2017) also revealed that the Onderstepoort landfill facility was established without bottom liners and lacked a leachate collection system. Thus, it was necessary to conduct a study to investigate the physical, chemical, and microbiological quality of groundwater samples collected from the three existing boreholes in the facility.

A limited pilot water quality study involved the analysis of water from two boreholes in August 2015 for pH, electrical conductivity, colour, and total coliform count. After a third borehole was drilled, a more comprehensive four-week study was conducted in August, October, and November 2016. Groundwater samples were collected and analysed in an accredited laboratory for comparison against the World Health Organisation (WHO) and SANS 241: 2015 drinking water quality standards.

Physical parameter analysis showed that the sample water colour and electrical conductivity were within both water quality standards of WHO (2017) and SANS (2015). Although the water pH decreased since the 2015 study, the pH of the water samples collected in 2016 still exceeded the WHO (2017) water quality standard. The chemical parameter analysis showed that chloride, fluoride, cadmium, calcium, lead, sodium and zinc were within the water quality standards but higher than standard concentrations of copper, sulphate, nitrate nitrogen, magnesium and manganese determined.

The parameters such as sulphate, copper and iron are within the acceptable limits since the 2015 study. The microbiological analysis also showed high numbers of *E.coli* and total coliforms that had increased since 2015. Based on the results of this study, the leachate from the decomposed waste material may be responsible for groundwater contamination due to the lack of bottom liners and it might make the groundwater unsafe for human consumption or domestic use. As a consequence, there is a need for continuous monitoring of the groundwater quality within and outside the facility.

Keywords: Geohydrological, groundwater, water pollution, landfill site, water contamination, leachate management, parameters, Onderstepoort landfill facility, Tshwane

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LIST OF SYMBOLS

Cd	Cadmium
Ca	Calcium
Cl	Chloride
Cu	Copper
EC	Electrical Conductivity
F	Fluoride
Fe	Iron
Pb	Lead
Mg	Magnesium
Mn	Manganese
Na	Sodium
SO_4^{2-}	Sulphate
Zn	Zinc

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ABBREVIATIONS AND ACRONYMS

CAES	College of Agriculture and Environmental Sciences
Cfu	colony forming units
CoT	City of Tshwane
CSIR	Council for Scientific and Industrial Research
CTMM	City of Tshwane Metropolitan Municipality
DEA	Department of Environmental Affairs (now DFFE)
DFFE	Department of Forestry Fisheries and Environment
DWAF	Department of Water Affairs and Forestry(now DWS)
DWS	Department of Water and Sanitation
EIA	Environmental Impact Assessment
HPC	Heterotrophic Plate Count
IWMP	Integrated Waste Management Plan
L	Litre
LEAP	Landscape Architect Environmental Planner
MSW	Municipal Solid Waste
ml	Millilitre
NWMS	National Waste Management Strategy
NEMA	National Environmental Management Act
RSA	Republic of South Africa
SANAS	South African National Accreditation System
SANS	South African National Standards
TECC	Tshikovha Environmental and Communication Consulting
WHO	World Health Organisation

CHAPTER 1: INTRODUCTION

This chapter outlines the research topic concerning an environmental geohydrological investigation at a landfill facility and the background information on landfill impact on groundwater. It also provides the background of the study (page 1), purpose (page 6), problem statement (page 7), aims (page 8) and objectives (page 8), hypothesis (page 8), limitations (page 9), and ethical considerations(page 9).

1.1 Background

The City of Tshwane manages and operates five landfill facilities within the municipality CTMM (2014). The Onderstepoort landfill facility is one of the five operational landfill sites within the city and has been operational since 1996 according to Tshibalo (2017). The site is about 50 hectares in size. It was developed following the Environmental Conservation Act (ECA) 73 of 1989 and classified as G:M: B- which means that the facility may accept general waste (G), medium in size (M), and with no significant generation of leachate (B-). However,Tshibalo (2017) revealed that the Onderstepoort landfill facility was established without bottom liners and lacked a leachate collection system.

The landfilling method is recognized as the most common practice of Municipal Solid Waste (MSW) disposal in many countries DEA (2012). According to the South African Department of Forestry Fisheries and Environmental (DEA now DFFE), over 90% of municipal solid waste in South Africa is disposed of at landfill sites, a necessary practice resulting from an increase in the generation of MSW due to rapid population growth, an improved standard of living and increase in economy, as well as industrial urbanization (DEA, 2012).

Such MSW includes general and hazardous waste materials (Nevondo and Malehase, 2019). The South African National Environmental Management: Waste Act defines general waste as material that does not harm the environment such as domestic, construction, and demolition waste, while hazardous waste material is defined as waste material comprising organic or inorganic elements that may harm human health and the environment (Republic of South Africa, 2008).

It is important when managing or operating the landfill site to comply with the condition of the permit or license. Hence, the permitting procedure allows the identification of potential impacts and the mitigation actions to be prescribed, to avoid any fatal flaws that may prohibit the development of the landfill in areas such as below the 1 in 50-year flood line. If the condition of the authorization is not adhered to, then a potentially adverse effect on the environment will occur. Impacts may be short-term or long-term (DWAF, 1998).

The short-term impacts comprise bad odour, noise, flies, and air pollution due to smoke from the burning of waste, dust, and litter blown by the wind. These impacts are worsened by poor operational activities at the site. Long-term effects include more serious pollution of the groundwater and gas generation in the landfill site. The problem can be exacerbated by incorrect landfill site selection, design, and preparation (DWAF, 1998).

Historically, South African municipalities have been implementing an end-pipe approach to managing solid waste CTMM (2014). Disposal of waste at the landfill site was the only option utilized in the past prior to the implementation of the waste management hierarchy, hence the focus has been on acquiring space for the development of the landfill sites (DEA, 2011).

The waste hierarchy is an ideal international approach for waste management, and it aims to decrease the dependency on waste disposal on landfill sites DEA, (2011). So far, the new approach to implementing the management system of solid waste is reinforced within the waste hierarchy, which was introduced in South Africa through the developed White paper on integrated pollution (DEA, 2011).

The National Environmental Management Waste Act (Act 59 of 2008) is structured around the phases in the waste management hierarchy, which is the overall approach that informs waste management in South Africa. As indicated in Figure 1.1 (page 3), the waste management hierarchy consists of options for waste management during the lifecycle of waste and is arranged in descending order of priority: waste avoidance and reduction, re-use and recycling, recovery, followed by treatment and disposal (Republic of South Africa, 2008).

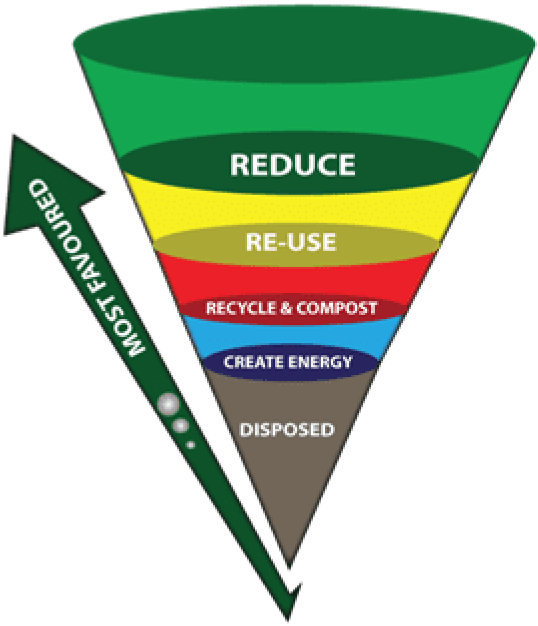

Figure 1.1: The hierarchy of waste management (DEA, 2011).

The main aim of the waste management hierarchy is to achieve optimal environmental outcomes as a guide for prioritizing waste management DEA (2011). It also encourages less generation of waste and allows for the disposal of less waste at landfill sites. The waste management hierarchy comprises several stages. It describes the preferred order of waste management practices from the most to least preferred (DEA, 2012). The waste hierarchy approach is systematic and holistic to waste management during the waste life cycle. Its implementation addresses waste reduction, waste avoidance, waste recovery, treatment recycling, and safe disposal as the last option.

Waste avoidance and reduction are the basis of the waste management hierarchy. The waste products or materials need to be manufactured or created in a manner that reduces the number of waste components or minimizes the waste material quantities used and the possible toxicity generated during the production of waste and after use, as emphasised by (Nkosi et al., (2013). Waste minimization occurs as a result of economic incentives through extended producer responsibility as elaborated by (Nkosi et al., 2013).

According to DEA (2012) waste disposal is considered the ‘last option” within the waste management hierarchy Waste material can be reused for the same purpose without changing its original form. It can become an input for a new product that could be reusable when it reaches the end of its lifespan. This approach focuses on separating waste materials from the waste stream, to process them as new products or raw materials. This supports the cradle-to-cradle approach in waste management. The treatment process of waste minimises the environmental impact of waste by changing waste's physical properties and destroying toxic components. Disposal of waste refers to the burial of waste on the land DEA (2012).

The Department of Water and Sanitation (DWS) develop the first edition of minimum requirements for waste disposal by landfill in 1994, and intends to introduce the proper engineering of the landfill sites to install bottom liners to prevent groundwater contamination DWAF (1998) and Anza (2018). The DWS introduced second edition of minimum requirements by landfill in 1998. This document assisted with the compliance issues within a landfill site such as landfill permits, siting, operation, closure, and rehabilitation processing as reported by Anza (2018).

The DWS developed three series of documents with the following objectives:

1. Waste disposal by landfill to take steps of inhibiting the degradation of groundwater quality and the environment, and to improve the standards of waste disposal operations and management in South Africa.
2. Water monitoring at waste management facilities to encourage the protection of groundwater as a strategic resource to be protected from excessive contamination.
3. Handling, classification, and disposal of hazardous waste to avoid water pollution and to ensure the sustainability of water resources in South Africa.

Section 24 of Chapter 2: Bill of Rights of the Constitution contains safeguards regarding the well-being of everyone's right to a clean environment and to live in an environment that is not harmful to health Republic of SA (1996). The Constitution of South Africa Act no 108 of 1996 guides all the legislative and policy development in South Africa. Schedule 5 in section 156(1) (a) of the Constitution of South Africa assigns to local government the responsibility for refuse removal, solid waste disposal, and cleansing Republic of SA (1996).

The purpose of the Water Amendment Act 45 of 1999 is to protect water resources that include rivers, streams, and dams. The aim is to ensure that water resources are protected, developed, used, and organized in an integrated manner. Section 19 (2) of the National Water Amendment Act 45 1999 outlines that: ``*A title holder or an occupant of land in which the incident occurs that may likely cause pollution of the water resources he/she must take all the practical procedures to cease pollution or prevent it from occurring''*.

The National Environmental Management Act (NEMA), Act 107 of 1998 is the legislative framework to ensure that the environment is protected. The principles of environmental management outlined in this Act form the basis for dealing with environmental issues.It was developed to ensure a way to enforce, administer and govern environmental legislation and environmental policies.

In addition, NEMA established an environmental framework and introduced several guiding principles into South African environmental legislation, including amongst others the concept of ''polluter pays'','' cradle to grave'', and the precautionary principle of the (Republic of SA, 1998). The overarching principle covers sustainable development, while specific principles addressing waste management are as follows:

***"Polluter pays principle*"** means those who cause damage or produce pollution of the environment must pay the cost to restore the harm to the environment and human health (Republic of SA, 1998).

The National Environmental Management Waste Act, Act 59 of 2008 is structured around the phases in the waste management hierarchy, which is the overall approach that informs waste management in South Africa. As indicated in Figure 1.1, the waste management hierarchy consists of options for waste management during the lifecycle of waste and is arranged in the descending order of priority: waste avoidance and reduction, re-use and recycling, recovery, followed by treatment and disposal as the last option (Republic of SA, 2009).

The National Waste Management Strategy (NWMS) is a legislative prerequisite of the National Environmental Management: Waste Act. The importance of the NWMS is to accomplish the objectives of the Waste Act. The NWMS is structured within the context of eight goals and descriptions (Table 1.1).

Table 1.1 NWMS goals and descriptions (DEA, 2011).

Goal number	Description
Goal 1	To promote waste minimization, re-use, recycling, and waste recovery
Goal 2	To ensure effective and efficient delivery of waste service
Goal 3	To ensure green economy growth by waste sector growth
Goal 4	To alert the public on the impact of waste on their health, well-being, and the environment.
Goal 5	To plan the integrated waste management
Goal 6	To draw comprehensive budgeting and financial management of waste services
Goal 7	To develop remedial measures for contaminated land
Goal 8	To comply and enforce the Waste Act.

1.2 Purpose of the Research

Landfill sites are recognized as some of the main threats to groundwater resources DEA (2011). Upon disposal of waste at the landfill site, it goes through physical, chemical, and biological changes over a period of time. Studies have investigated the level of groundwater quality contamination within landfill sites Ankinbile and Yusoff (2011); Adeolu et al. (2011), Njoku and Edokpayi (2019) and Longe and Balogun (2010) reported that landfill sites are the major cause of groundwater pollution through the production of leachate and its migration through waste. Different practices and methods were explored by these researchers when investigating possible groundwater pollution within the landfill site (Muhammed et al., 2015).

Most of these studies concluded that landfill sites may potentially contaminate groundwater. Chavan and Zambare (2014) outlined that poor waste management practices within landfill sites pose a serious risk to the health of communities and the environment. In addition, Ovelami et al. (2013) reported that landfill waste undergoes biological, chemical, and hydrological changes after some years, which may result in pollution.

1.3 Research Problem Statement

The increasing population size is accompanied by an increase in the consumption of waste products, as well as increasing volumes of waste, which is controlled through the National Waste Management Strategy DEA (2011). The strategy emphasizes the implementation of a waste hierarchy where the municipalities should implement waste minimization programs to increase the life span of the landfill sites as outlined (CTMM, 2014).

Prior to the implementation of the waste hierarchy and an end-of-pipe treatment of waste, the focus of most South African municipalities was on waste collection and disposal of municipal solid waste (DEA, 2011). A consequence of this was that landfill leachate was discharged directly into a watercourse followed by leachate decomposition, resulting in the depletion of dissolved oxygen from the water to negatively impact aquatic life according to Sullivan et al. (2005).

Groundwater contributes 15 % of the water resources used in South Africa. The major sources of groundwater pollution include industrial and household chemicals, fertilizers and pesticides, mines, landfill sites, sewage sludge, and septic tanks.

This study aimed at determining whether the Onderstepoort landfill facility has the potential of contaminating groundwater concerning its operational activities. To make it possible, groundwater samples were collected from existing boreholes within the landfill site. Groundwater parameters were compared to SANS:241 (2015) and WHO (2017) water quality standards. The output of the research determined if the groundwater near the Onderstepoort landfill site is suitable for human consumption or domestic use.

1.4 Research Hypotheses

The following hypotheses were formulated regarding the environmental geohydrological investigation on a landfill site:

- **H0** –The Onderstepoort landfill site water quality levels are above the recommended levels of SANS 241: (2015) and WHO (2017) water quality standards.
- **H1 –** The Onderstepoort landfill site water quality levels are below the recommended levels of SANS 241: (2015) and WHO (2017) water quality standards.

1.5 Aim of the Research Study

This research study aimed to assess groundwater quality within the Onderstepoort landfill facility using selected chemical, physical and microbiological parameters.

1.6 The Objectives of the Study

In achieving this aim, the following study objectives were addressed within the Onderstepoort landfill site:

1) To assess and compare the groundwater quality physical, chemical and microbiological parameters pollution levels with water quality standards.
2) To investigate possible contamination of groundwater at the Onderstepoort landfill site.
3) To evaluate the potential environmental impacts of groundwater pollution.
4) To recommend the improvement measures as per the analysis and findings of the results.

1.7 Assumptions

Assumptions that applied to this study were as follows:

1) Groundwater is non-industrial water from groundwater that flows from the earth's surface downwards through a process called percolation or seepage and ends up stored in an aquifer (DWAF, 1998).
2) Groundwater for this research study was collected from three boreholes in the landfill site that excludes water from the rivers, dams, and water streams.

Acceptable standards concerning water to be used for human consumption are described in the South African National Standards SANS 241, (2015) and World Health Organisation WHO (2017) water quality standards.

1.8 Limitations

The following were the limitations of the study:

- The study area was limited to one landfill site (Onderstepoort) within the city of Tshwane municipality.
- Three boreholes existing on site were used for groundwater quality data collection. The boreholes were drilled for water monitoring purposes of the facility.
- Groundwater sampling frequency was done for eight consecutive weeks during the wet and dry seasons (12 and 25 August and 28 October, 3 November and 18 November).

1.9 Ethical Considerations

Ethical considerations are important in all types of research studies. Ethics were taken into consideration during the measurement procedure and the results were obtained to avoid fabrication or incorrect data. General principles of the research consideration to ensure that no harm should come out of the research subjects and that people should be respected. The research proposal was approved by the CAES Ethics Team in November 2014 with the reference number 2014/CAES/155.

1.10 Dissertation Overview

This research study consists of six chapters:

Chapter 1: This chapter contains the background of the research study, the research problem statement, the aim and objectives, the hypothesis, limitations, and ethical considerations.

Chapter 2: This chapter reviews the literature on the research topic and describes the landfill legislation framework, groundwater standards, groundwater pollution, and water quality parameters, evaluates the impacts of groundwater quality, and recommends improvement options.

Chapter 3: This chapter describes the study area and data collection methods, as well as techniques used during the study.

Chapter 4: This chapter presents the findings of the study and discusses the analysis of the results of the research study.

Chapter 5: This chapter discusses the results of the research study.

Chapter 6: This chapter presents a conclusion and recommendations of the study.

CHAPTER 2: LITERATURE REVIEW

This chapter reviews the literature on the field of groundwater and offers background information on the definition and characteristics of groundwater. It also covers an overview of groundwater pollution and worldwide information on the impact of groundwater quality at landfill sites. The gaps identified in the literature justify the objectives of the research study.

2.1 Groundwater

Ankinbile and Yusoff (2011) emphasizes that the protection of groundwater is important and needs to be monitored. There are, however, human factors such as spillages, mine drainage, and wastewater discharge, natural factors such as climate and geology, and non-point sources such as landfills, erosion, and urban runoff that influence the sources of water quality (Ankibile and Yusoff, 2011). Surface water is more vulnerable to contamination due to both the human factor and direct contact as compared to groundwater.

Again, according to Bhavika et al. (2014), groundwater within the landfill site becomes polluted when leachate produced from waste material passes through the soil and reaches groundwater. This also may happen during rainfall when surface water gets polluted. Furthermore, the pollutant has been added to groundwater through human activities or natural sources. According to Bhavika et al. (2014) the adverse effects on groundwater quality are due to human activities that include agriculture and waste disposal. According to Aljaradin and Persson (2012), polluted groundwater is generally difficult to keep in its original quality state once it is contaminated.

Industrialization and urbanization developed over some time increased the level of groundwater pollution (Patil and Kumar, 2014). The situation is compounded by the population increase that gives rise to compromised situations in terms of managing waste management. To add, landfilling and/or dumping site facilities seem to be methods that are used for waste disposal all over the world.

It is thus a challenge and a costly process to clean up or take away the contaminant from the water, yet the groundwater quality is of importance due to its determination of suitability for domestic use or irrigation purposes. Magda and EL-Salam (2014) outlined that subsequently, several policies and strategies have been developed in the field of solid waste management. These include waste reduction and waste addition to landfilling of unrecyclable material. In developing countries landfills have a very limited time for operation (Magda and El-Salam, 2014).

The characteristics of groundwater are determined by the total number of contaminants found in the water (DWAF, 1996).These are mainly influenced by the activities undertaken at landfill sites. The contaminants are chemical, physical, and microbiological in character and have different influences on the groundwater quality (DWAF, 1996). Water quality is determined by analysing various parameters including physical parameters (pH, turbidity, electrical conductivity, colour, and total hardness), chemical parameters (chloride, fluoride, nitrate-nitrogen, sulphate, cadmium, copper, iron, lead, magnesium, manganese, zinc and sodium) and microbiological parameters (total coliforms, *Escherichia coli* and heterotrophic plate count) and comparing these to waste quality standard levels (DWAF, 1996a).

2.2 Physical parameters characteristics

According to DWAF (1996a) the occurrence of colour in the water can be naturally due to the presence of metals such as iron and manganese that contribute to brown discoloration in the water. Tiwari (2015) defines colour as vital for water users and the determination of colour can ensure the quality of the water.

Water pH is the measure of the hydrogen ion concentration in the water. According to Tiwari (2015) pH is defined as an indicator of the biological life's existence in the water. Prasanth et al. 2012 described acidic water as having a pH value from 0 to 7.0, while a pH of 7.0 describes neutral water. Exposure to alkaline water with a pH level greater than 11 may result in irritation to the eyes, skin, and mucous membranes emphasises by Magombeyi and Nyengera (2012).

Electrical Conductivity (EC) indicates the presence of ions in the water Tiwari (2015). Oyiboka (2014) highlighted the EC of water depends on the water high temperature, as a result, lead to higher EC ions in the water.

According to Prasanth et al. (2012) **turbidity** is caused by a diversity of suspended materials. Turbidity may increase the possibility of waterborne diseases. If turbidity is caused by algae, the light would not infiltrate the water, and cyanobacteria favor this situation because it possesses a flotation mechanism (Tiwari, 2015).

High values of turbidity indicate high levels of suspended matter, which could cause clogging of both soil and groundwater systems. Increased water turbidity may reflect the possibility of waterborne diseases associated with microorganisms such as viruses, parasites, and some bacteria Tiwari (2015).These organisms can cause symptoms such as nausea, cramps, diarrhea, and headaches according to Oyiboka (2014).

The **total hardness** effects are the formation of scale in instruments and boiling water systems in boilers. The treatment of hardness in water involves a reverse osmosis process and the utilization of a softener ion exchange (Dohare et al., 2014).

A study was undertaken by Anilkumar et al. (2015) highlighted that the total hardness parameter is considered important for water quality, whether the water is used for domestic, industrial, or agricultural purposes, particularly as this water elevated total hardness may be associated with cardiovascular disease.

2.3 Chemical parameters characteristics

A high concentration of **chloride** may impart a salty taste to water. According to Dohare et al. (2014), all types of raw and natural water contain chloride but elevated levels of chloride in water are associated with effluent from agricultural and industrial activities. Chloride ions in water result from the dissolution of salt and the use of household detergents, water softeners, and disinfectants, as well as sewage contamination of the water (Albek, 1999).

A research study conducted by Anilkumar et al. (2015) reported that people drinking chlorinated water over a long period have a 21% increase in the risk of contracting bladder cancer and a 38% increase in the risk of rectal cancer.

Fluoride concentration is controlled by the climate in the region and the presence of minerals in the rock (Dohare et al., 2014). According to DWAF (1996), health problems associated with the condition known as fluorosis may occur when fluoride concentrations in groundwater exceed 1.5 mg/l and the staining of tooth enamel may become apparent (dental fluorosis).

Phosphorus controls the growth of an aquatic plant and is an important plant nutrient. Due to low solubility in water, phosphorus contains a minimum level in groundwater. High levels of phosphorus in the water may cause algae growth and potential groundwater contamination DWAF (1996a).

Sulphate ions are created by corrosion procedures and are present in industrial waste. Sulphate ions are contained in natural water resulting from the corrosion of rock DWAF (1996a). The high levels of sulphate content in water cause scale to build up in water pipes and impart a bitter taste to drinking water that is harmful to humans and livestock (DWAF, 1996a; Muhammed et al., 2015).

Nitrates are created from domestic and industrial discharge, chemical fertilizer factories, and decaying vegetable matter (Ward, 2009). Nitrates and nitrites may be converted in the body into a class of compounds identified as nitrosamines that are known carcinogens (Anilkumar et al., 2015).

According to WHO (2004) **manganese** occurs naturally mainly in groundwater but also surface water, and its presence in water imparts an undesirable taste to the water and stain laundry.

Sources of **lead** released into the environment include water, food, and waste from industrial processes involving batteries, pipes, and paints. Ingested water with a lead concentration higher than 0.01mg/L can cause neurological damage, especially in young children and foetuses (Kwame et al., 2019).

Magnesium, together with calcium, is responsible for scaling problems in appliances using heating elements and plumbing (DWAF, 1996a). **Iron** is characterized as a lustrous, ductile, malleable, silver-grey metal (Oyiboka, 2014), and is considered the second most abundant metal in the earth`s crust and a crucial element for the growth of all living organisms. and iron deficiency in the human body may lead to anaemia whereas the presence of iron in water may change the colour of the water and in its insoluble form, iron affects aquatic life, as it may interfere with normal biochemical processes (Hider and Kong, 2013).

Zinc present in the earth's crust is measured at around 0.05 g/kg. Sphalerite is the main common mineral in which zinc is coordinated with sulphides. Prasanth et al. *(*2012) reported that excessive ingestion of zinc leads to symptoms in humans including abdominal pain, dehydration, vomiting, and electrolyte imbalance.

2.4 Microbiological parameters characteristics

According to Tiwari (2015), the importance of microbiological water testing is to determine the extent of water pollution created by organisms in the water, especially of human origin. Coliform bacteria are used as a sign of organism presence during water testing. The bacteria present in the water ensure the indication that the water pollution resulted from human and animal faeces.This indicator is used to evaluate the quality of groundwater, river, or seawater used for drinking. Historically the microbiological quality of groundwater is measured by the presence of indicator organisms such as total coliforms including *Escherichia. coli*.

The most common bacteria, which are present in water contaminated with faecal material and that are the easiest to detect are *E. coli*. *E. coli* are classified as rod-shaped Gram-negative bacteria in the family of *Enterobacteriaceae* that mainly inhabit the human intestinal tract. The presence of *E. coli* in water is an indicator of faecal contamination (WHO, 2011). The best method used for testing the quality of water is to test for *E. coli* and total coliforms (Price, 2017).Faecal coliforms are a common bacterial indicator of faecal pollution in water and high concentrations of faecal coliforms in water indicate the risk of contracting a waterborne disease, even if small amounts of water are consumed (DWAF, 1996).

Anilkumar et al. (2015) confirmed that faecal coliforms are part of the group of coliform bacteria that are generally harmless but include microorganisms that can cause mild or serious illness.According to WHO (2003) the HPC is a simple, non-specific plate test used to count heterotrophic microorganisms cultured from water samples to indicate the proper functioning of water treatment processes, indirectly monitor water safety, and act as a control in other microbial growth assays. Health-wise, there is little evidence to support that HPC values from ingested water, in the absence of faecal contamination, have associated health risks (WHO, 2003).

2.5 Landfill Site Leachate

Rajkumar et al. (2012) define leachate as a liquid containing innumerable organic or inorganic compounds that accumulated underneath the landfill site and infiltrate through the soil and reach groundwater. Raghab et al. (2013) further define leachate as a type of fluid that goes through a landfill and has dissolved suspended matter. Leachate characteristics differ in composition, volume, and biodegradable matter present in the leachate generated within some time (Raghab et al., 2013).

According to Raghab et al. (2013) leachate composition depends on numerous factors comprising the climate, moisture content in waste, and degree of the compaction of waste. In addition, the characteristic of leachate by low pH concentration during the initial stage depends on high volatile fatty acids (Kamaruddin et al., 2013).

Kamaruddin et al. (2015) elaborated that the climate, landfill cover, and type of waste at the landfill site composition have the most important role in the rate at which leachate is generated. Hot and arid regions' landfill generate less leachate due to low precipitation whereby high leachate is generated in landfills in hot or tropical weather climates. Bhalla et al. (2012) reported that rainfall, infiltration, and surface runoff are several factors generating landfill leachate.

Mudau (2012) emphasized that the following factors influence the generation of leachate in the landfill site: the geohydrological terrain around the landfill site; the rock type acting as a groundwater aquifer, the soil type beneath a landfill site; and sandy soil due to high porosity, as compared to clay soil characterized by small pores that prevent the movement of leachate. It was further elaborated by Oyiboka (2014) that researchers such as Longe and Balogun (2010) defined that the characteristics of leachate generation are influenced by several factors such as waste composition, landfill design, operation, degree of compaction, hydrology, and hydrogeology of site, age of landfill, moisture and temperature conditions, and available oxygen within the waste.

Oyiboka (2014) emphasized that the age of a landfill site determines the composition of leachate. Smaller quantities of leachate can be noticed in a young landfill site as compared to that of an older one. Tshibalo (2017) defines a young landfill site as a landfill that commenced operation over five years and an old landfill (matured phase) site as above ten years of age, and that leachate is characterized by high acid concentration.

2.5.1 Factors affecting leachate quality

The quality of the leachate usually varies at landfill sites. The extent of variation is attributed to many factors such as the composition of waste, moisture and oxygen availability, temperature, processed waste, and waste toxicity (Oyiboka, 2014).

Oyiboka (2014) outlined the composition of the waste within the landfill site as determined by the biological components within the landfill site and the waste material such as organic waste aggravates the generation of leachate and other waste materials including paper decreases waste decomposition in the landfill sites.Landfill site leachate quality and waste stabilization are influenced by water within the landfill site. It is noted that the role of water in the landfill site supports the fermentation of solid waste (Adhikari et al., 2014).

The availability of oxygen determines the types of decomposition (anaerobic or aerobic) within landfill sites. Aerobic decomposition occurs during the initial stage of the process. The temperature in the landfill site is considered an influencing uncontrollable factor of leachate quality. It has been outlined as fluctuating with seasonal temperature variations (Adhikari et al., 2014).

2.5.2 Leachate management and treatment techniques

According to Raghab et al. (2013) leachate is characterized by great volumes of heavy metals and other metals such as ammonia, pH, and nitrogen. The leachate characteristics vary concerning their composition and volume. These make the treatment of leachate challenging and problematic. Therefore, according to Kamaruddin (2013), it is important to understand the characteristics of leachate and the methods of treating leachate and the leachate treatment is classified according to three types which include aerobic, anaerobic, and semi-aerobic.

According to Tshibalo (2017) emphasised that various methods can be used to treat leachate generated from landfill sites. The selection of the leachate treatment method is determined by the main leachate parameters namely, heavy metals, Chemical

Oxygen Demand (COD), and Total Organic Carbon (TOC). The methods for leachate treatment are adapted for the processing of wastewater treatment and divided into main categories such as biological treatment, and chemical and physical treatments.

Oyiboka (2014) outlined that the biological treatment process of leachate is the common method used for the removal of leachate containing high concentrations of chemicals. Biological processes have been effective also in removing organic matter from undeveloped leachates. Biological treatment methods include membrane bioreactors (MBR), activation of sludge process (ASP), sequencing batch reactors (SBR), aerobic lagoons, and constructed wetlands (Oyiboka, 2014).

Chemical and physical treatments are regarded as the preferred method for the treatment of leachate, which can be utilized for the preparation of inorganic and organic composites within the leachate (Oyiboka, 2014). Physical-chemical treatment methods include evaporation, filtration oxidation, coagulation/flocculation, activated carbon, and stripping, the selection of technologies to treat leachate depends upon the characteristics of the leachate (Oyiboka, 2014).

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

This chapter presents the research design and methodology employed in this study, to examine the impact of the Onderstepoort landfill facility operational activities on groundwater quality. A quantitative research method was used to determine groundwater quality through water sampling and laboratory analysis.

3.1 Research Process

Based on the literature review, the following guidelines for the research design were used:

- Three boreholes that exist within the Onderstepoort facility were evaluated for the physical, chemical, and microbiological levels of contamination.
- Groundwater samples were collected from the existing borehole within the landfill site. The parameters required to investigate environmental geohydrology and the level of contamination were identified and defined.
- The groundwater samples were analysed at an accredited private commercial laboratory.

3.2 Description of the Study Area

Figure 3.1 (page 19) indicates the location of the Onderstepoort landfill facility on the remainder of portion 42 of the farm de Onderstepoort 300 JR, within the City of Tshwane Municipality in the Gauteng Province, Pretoria North. The landfill facility is 6 km southeast of the Rosslyn area and is situated at the corner of N4 Rustenburg highway and can be accessed from the R566 road. The coordinates of the facility are latitude (S): 25^{o} 39.039 and longitude (E): 28^{o} 09.429 (City of Tshwane Metropolitan Municipality (CTMM), 2014).

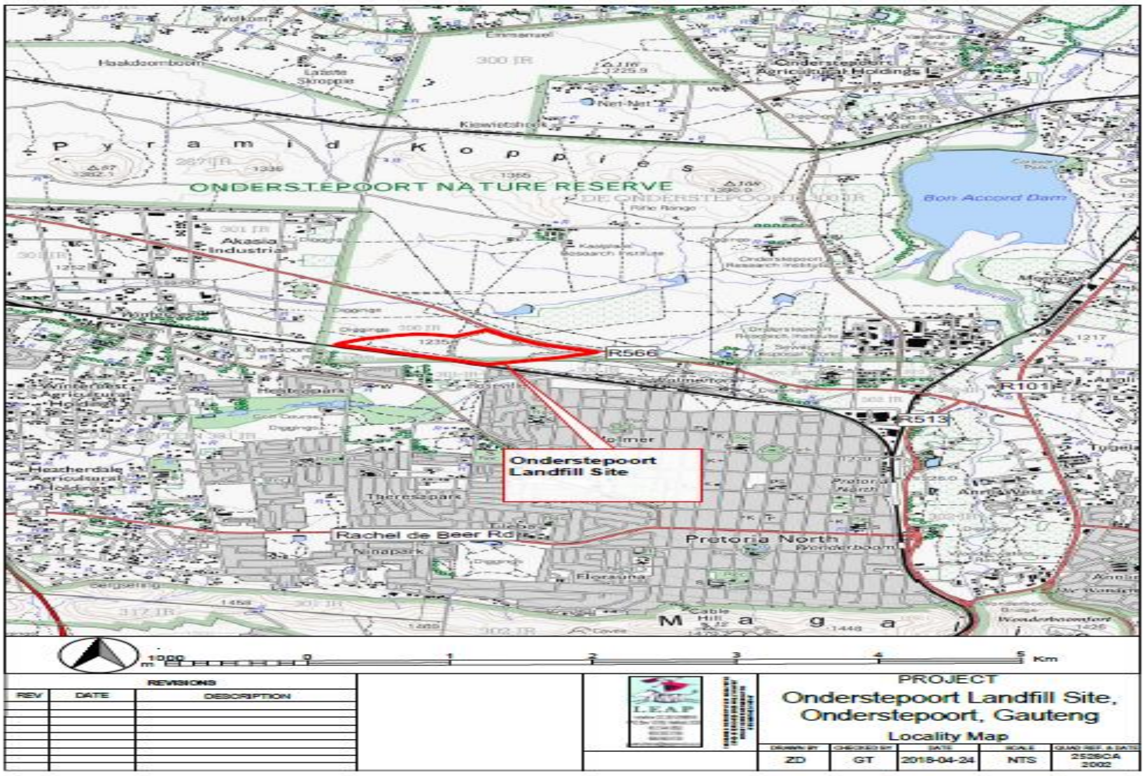

Figure 3. 1: Locality map of Onderstepoort landfill site (LEAP, 2019).

The Onderstepoort landfill site was licensed under the provision of the Environmental Conservation Act, 1989 (Act No 73 of 1989) according to TECC (2016), and has been in operation since its establishment in 1996. The site accommodates waste from businesses such as shopping malls or complexes and waste produce includes packaging boxes, paper, tins, cans, plastic bottles, and communities within the northern suburbs of Pretoria.

The facility is classified as a **G:M: B-** landfill site. **G** means it is permitted to receive non-hazardous waste such as nuclear, electric, medical, mining, and scheduled pharmaceutical products. **M** means that it is a medium-size facility with a maximal disposal rate of not greater than 250 tons daily, while **B-** means its location is in negative climatic water balance without the potential to generate leachate Nyika et al. (2019).

According to Tshibalo (2017), the facility has no operational weighbridges to measure quantities of waste disposed of on-site and there is no bottom liner on the site to prevent groundwater pollution. The proposed study area is about 53 hectares in size (Figure 3.2). The site reached its 20 years lifespan and is in the process of being officially closed (LEAP, 2019).

Figure 3. 2: Onderstepoort landfill facility (LEAP, 2019).

3.2.1 Drainage and Topography

The Onderstepoort landfill facility falls within a quaternary catchment A23E. The topography around the landfill site (within a 2 km radius) ranges in elevation between 1225 m and 1273 m above mean sea level. The drainage from the site is towards the easterly and northeasterly direction of the site (City of Tshwane Metropolitan Municipality CTMM, 2014).

3.2.2 Geology

The investigated area falls within the *2528 Pretoria 1:250 000 geology* series maps (See Figure 3.3), and this landfill facility is predominantly underlain by norites, gabbro, magnetite gabbro, anorthosite, and pyroxenite of the Rustenburg Layered Suite of the mafic to ultramafic Bushveld Igneous Complex (BIC). Rustenburg Layered Suite is overlain by the younger Rayton formation and comprises four quartzite horizons alternating with four thin beds of shale and intruded by diabase sheets (Aqua Earth Consulting, 2015). Approximately 500 m from the site, in the western direction, the site is covered by Rayton quartzite, shale, and subgreywecke (Vr). There is a syenite dyke about 4 km east of the site that passes the site from South to North (yellow linear structure on the map) the distance was estimated from the edge of the site (TECC, 2016).

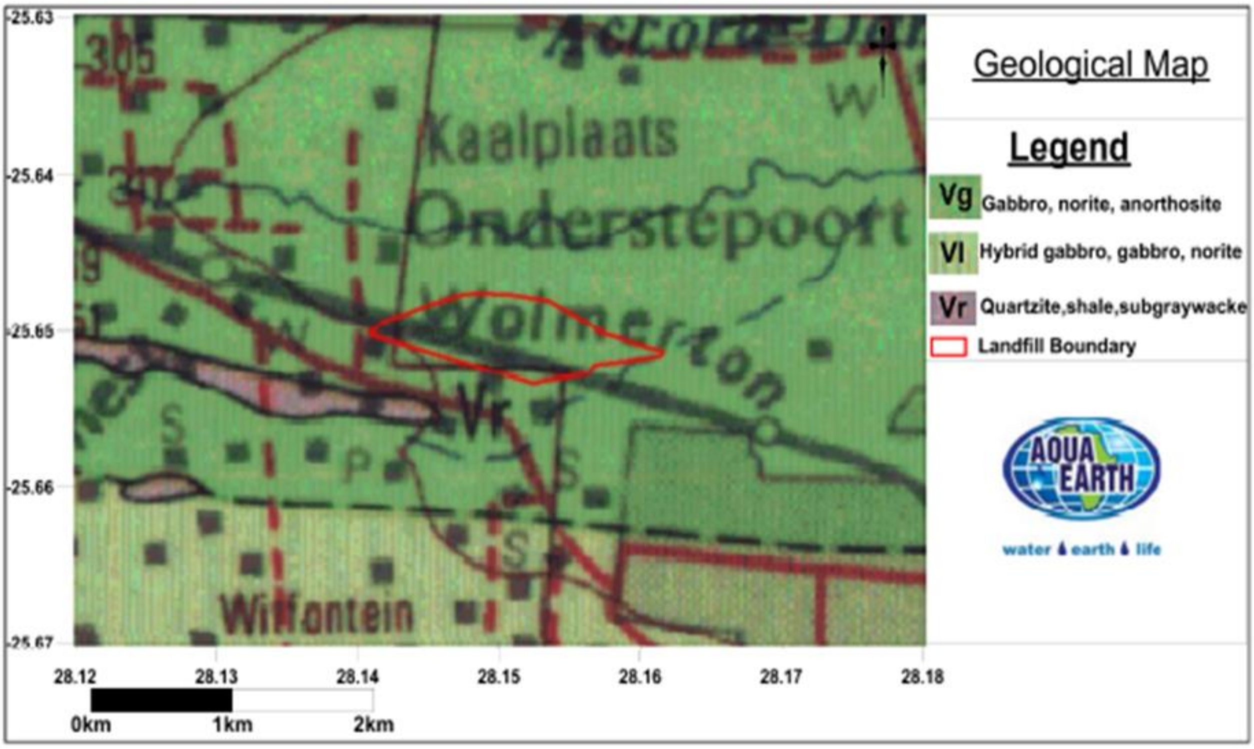

Figure 3. 3: Onderstepoort landfill facility geology map (Aqua Earth Consulting, 2015).

3.2.3 Hydrology of the study

The water bodies closest to the site are the Apies River situated approximately 15 km from the site and the Bon Accord Dam, which is approximately 22 km from the site (Tshikovha Environmental and Communication Consulting TECC, 2016).

3.2.4 Climate

Pretoria has cool and cold dry winters and a humid subtropical climate with long rainy summers. The annual average temperature is 18.7°C (Tshikovha Environmental and Communication Consulting (TECC, 2016).Tshibalo (2017) outlined the driest cold weather is in winter ranging from an average of 04 ºC to 19 ºC; and the area is too hot in the summer season with an average temperature ranging from 18 ºC to 29 ºC.

3.3 Research Methodology

A quantitative research method was carried out to investigate environmental geohydrology focusing on the Onderstepoort landfill facility for data collection. The data was collected from two existing boreholes and later on from three existing boreholes, which include a newly drilled one.

3.3.1 Quality Control (QC) and Quality Assurance (QA)

The acceptance criteria for the calibration curve coefficient of determination (R^2 value) for all the parameters were obtained and were all close to number one. Linear calibration curve ranges were not obtained for fluoride as element one and for chloride as element number three, a linear range from 0 to 100 mg/l was obtained for sulphate as element two. The R^2 value for element one was 0.9975, for element two was 0.9995 and for element three was 0.9975. Overall, very good correlations were obtained for all elements with R^2-values ranging from 0.9975 to 1.0000 during a calibration process.

Cadmium and lead working range from 0 to 20 μg/l, magnesium, and sodium range from 0 to 50 mg/l, and copper, iron, manganese & zinc working range is between 0 to 500 μg/l.Table 3.1 shows the quality assurance parameters that were used during the analyses, which include the working ranges, detection limits, R^2-values, and % recovery results.

Table 3.1 Quality assurance for chemical parameters

Elements	Working range	Detection limits (DL)	R^2 values
Fluoride	N/A	0.2	0.9975
Sodium	0-50mg/L	0.03	0.9997
Magnesium	0-50 mg/L	0.04	0.9998
Chloride	N/A	0.5	0.9975
Calcium	0-50 mg/L	0.05	0.9999
Manganese	0-500 mg/L	0.25	1.0000
Iron	0-500 mg/L	0.88	1.0000
Copper	0-500 mg/L	0.44	0.9999
Zinc	0-500 mg/L	0.57	1.0000
Cadmium	0-2 mg/L	0.2	0.9999
Lead	0-20 mg/L	0.11	1.0000
Nitrate nitrogen	N/A	0.2	0.9994
Sulphate	0-100 mg/L	5.0	0.9995

Table 3.2 presents electrical conductivity values ranging between 84 μs/m and 2764 μs/m, while the pH values ranged between 4.0 and 10. All parameters were found to bewithin acceptable detection limits.

Table 3.2 Physical parameters working range and detection limits.

Elements	Working range	Detection limits (DL)
Colour	n/a	5.0
Electrical conductivity	84-2764	1.0
pH	4-10	1.0
Total hardness	n/a	0.29
Turbidity	n/a	0.2

3.3.2 Pilot study

On 20 August 2015, the City of Tshwane (CoT) appointed a service provider to conduct surface and groundwater monitoring at CoT landfill facilities including the Onderstepoort landfill site. Therefore, the groundwater monitoring conducted by CoT was regarded as a pilot study for this research project (Aqua Earth Consulting, 2015).

The three boreholes, designated BH1, BH2, and BH3, were located at the Onderstepoort landfill facility during the site inspection. Unfortunately, BH3 was dry and could not be sampled but BH1 and BH2 were sampled during a pilot study. Single samples were collected from each borehole and transported to SGS South Africa (Pty) Ltd, SANAS accredited laboratory in Randburg for quality analysis (Aqua Earth Consulting, 2015).

3.4 Sampling collection

On 12 August 2016, the composite samples were taken during the extended study and transported inside a cooler box with ice to maintain a temperature of around $4^{o}C$ to an accredited laboratory at the CSIR Meiring Naude Road Campus, Pretoria for analysis. The samples were then prepared, treated, and analysed for physical, chemical, and microbiology parameters following standard laboratory methods before being compared to SANS 241: 2015 and WHO (2017) water quality standards.

The CoT drilled another borehole to replace the dry BH3. The three boreholes constitute the sample collection sites for the current study (Figure 3.4). Groundwater samples were taken once a week during the dry period and again during the wet period to cover eight days of sample collection spread over two months. Sampling took place on 4, 12, 18, and 25 August 2016 (dry season) and on 28 October and 3, 18 November 2016 during the rainy season. The first rains came in October 2016, hence samples were not collected in September month and so sample collection was delayed until after the first rains in August and September of 2016.

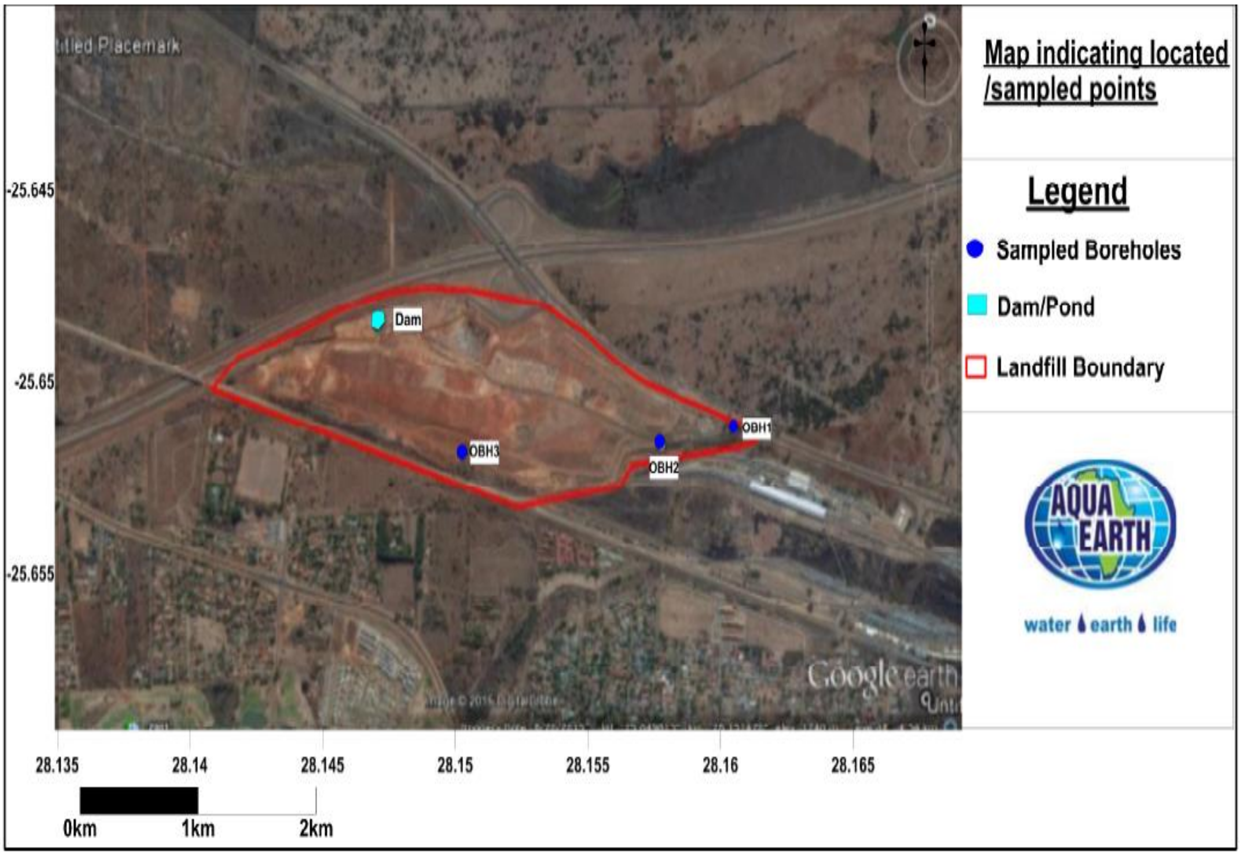

Figure 3. 4: Map indicating sampled boreholes (Aqua Earth Consulting, 2015)

Due to financial constraints, composite samples were collected from the site into a sterilized plastic bottle and stored in a refrigerator and prepared a day before being transported and taken to an accredited laboratory for analysis. The samples were collected every two consecutive weeks to generate a total of three samples each day and reported using the dates of every second alternative week (on 12 and 25 August for the dry season, as well as 28 October, 3 November, and 18 November representing the wet season).

The sterilized water sampling bottles and caps were collected from the laboratory before sampling. Plastic bottles sized 250 ml, were used to collect water samples for microbiological analysis, and sterile 500 ml plastic bottles were used to collect water samples for physical and chemical parameters. The sampler wore latex examination gloves during sample collection and when handling the cooler box containing ice packs used to store the samples after collection and during transportation to the laboratory.

3.4.1 Groundwater collection method

The groundwater sampling began with a one-week pilot study that involved the collection of samples from the existing two boreholes on 20 August 2015 and the categorization of the samples according to physical, chemical, and microbiological analysis. Minimum requirements for waste disposal by medium-size landfill sites demand three monitoring boreholes for water monitoring purposes (Department of Water Affairs and Forestry (DWAF, 1998). After the third borehole was drilled, an extended study was undertaken with samples collected as described in section 3.1 (Page 23).

Sample collection involved submerging each of the sterilized water sampling bottles into the borehole with a string tied around each bottleneck and body area and with a small rock attached to the string at the bottom of the bottle to add weight to sink the bottle Figure 3.5 (page 26) Tshibalo (2017).

Sample water was used to rinse each bottle three times before the final sample was collected. Each bottle was then tightly closed with a cap and labelled, stored in the cooler box with ice packs to maintain a low temperature before transportation to the laboratory for further analysis.

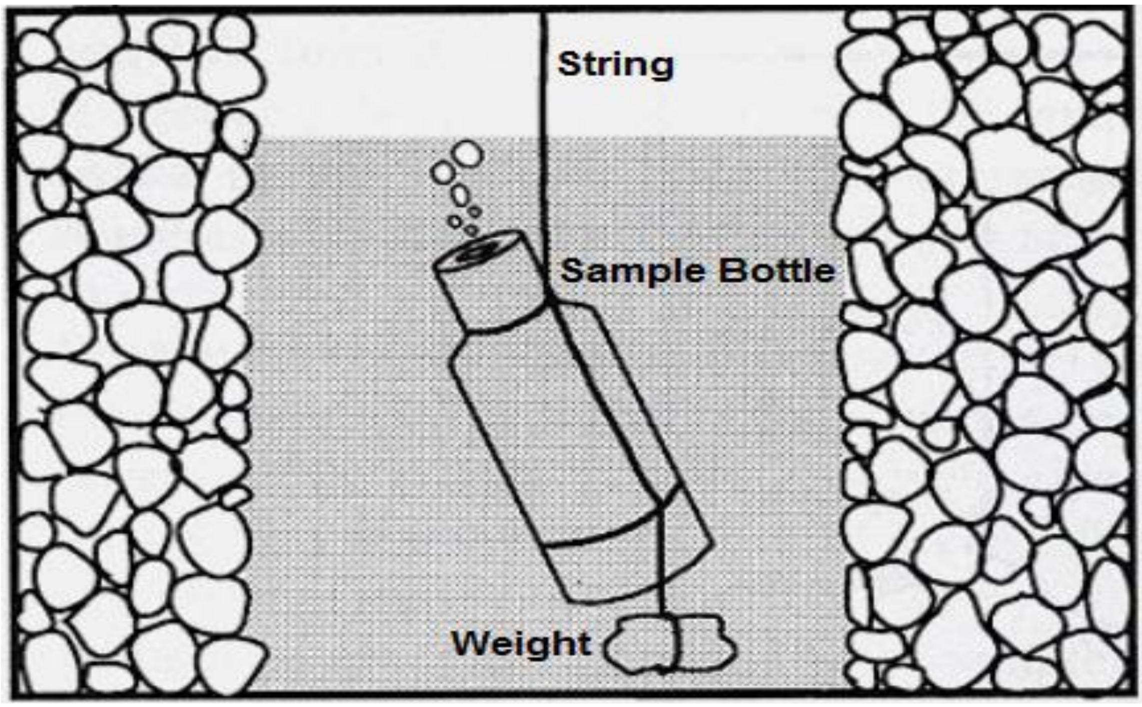

Figure 3.5 Sampling procedure demonstration (Tshibalo, 2017)

3.5 Sample collection tests

Due to the high analysis costs, three groundwater samples from BH1, BH2, and BH3 were not collected every week but rather were collected on the first and last weeks of the month. Thus, a total of nine single samples were obtained in 250 ml plastic bottles during the wet period (4 November) and another sample was collected during the wet period on 28 October and 18 November 2016.

After each collection, a total of twenty-seven (HPC, *E coli* and Total coliforms) labelled sample bottles were transported to the accredited laboratory within 24 hours for quality analysis. On each day of the fieldwork, three samples were collected and mixed to produce one composite sample per borehole. Therefore, water samples were taken during the dry period (12 & 25 August 2016), and other groundwater samples were taken during the wet period (3 November & 18 November 2016).

The results for analyses were all compared against one another from the same borehole in different seasons. The data were also compared across the different boreholes and against SANS: 241, 2015 as well as World Health Organisation (2017) water quality standards.

3.6 Types and sources of data

Primary and secondary data were considered during this study. Primary data were collected from a field study, which included groundwater sampling from three boreholes within the Onderstepoort landfill facility.

The chemical, microbiological and physical analytical data were obtained after laboratory analysis of the study samples designated as BH1, BH2, and BH3 at the landfill site. The secondary data information comprised data obtained from textbooks, paper articles, and journals as well as other publications (Oyiboka, 2014).

3.7 Sampling analysis methods

All the collected groundwater samples were transported to the Council of Scientific Industrial Research (CSIR) Meiring Naude Road, Pretoria laboratory for further analysis. The analysis was carried out for physical, chemical, and microbiological analysis.

3.8 Drinking water quality standards

The South African National Standards (SANS:241, 2015) was approved by the National Committee of the SABS/TC 147 in March 2015. The main purpose of the national standards is to specify contamination limits and the possibility of risk to human well-being (SANS: 241, 2015). The World Health Organisation (WHO) water quality standards were recommended by water quality guidelines to manage the risks of making drinking water unsafe.

Table 3.3 (page 29) shows water quality variables and water quality standards limits. The parameters listed are used to determine the chemical, physical, and microbiological status of groundwater quality. Ideally, the water quality standards and guidelines are developed to quantify the level of constituents present and are used to determine whether water is of good quality.

Water quality guidelines indicated that pH; zinc, sodium, sulphate, and manganese were not given a guiding value as per the WHO, (2017) water quality standards indicating that there were no health concerns at any levels found in drinking water (WHO, 2017).

Table 3.3 Water quality variables and water quality standards limit SANS: 241 (2015) and WHO (2017).

Parameter	Units	SANS 241: 2015	WHO (2017)
Fluoride	mg/l	<=1.5	1.5
Sodium	mg/l	200	200
Magnesium	mg/l	70	0.01
Chloride	mg/l	300	250
Calcium	mg/l	150	200
Manganese	mg/l	400	0.5
Iron	mg/l	<=2000	0.03
Copper	mg/l	<=2000	0.5
Zinc	mg/l	5	n/a
Cadmium	mg /l	<=3	0.003
Lead	mg/l	<=10	0.01
Colour	mg/l	<=15	n/a
Electrical conductivity	mS/m	<=170	1000
Nitrate nitrogen	mg/L	<=12	<1
pH	pH units	>= 5 to <=9.7	6.5-8.5
Sulphate	mg/L	<=500	250
Total hardness	mg/L	n/a	100
Turbidity	NTU	<=5	n/a
Escherichia coli	Colony forming units/100 ml	0 cfu/100 ml	0 cfu/100 ml
HPC	Counts/ml	<=1000 counts/ml	n/a
Total Coliforms	Colony forming units/100 ml	<=10 cfu/100 ml	<=10 cfu/100 ml

3.8.1 Sampling frequency and seasonal variances

The literature review indicates that groundwater pollution at landfill sites generally considers seasonal variation differences where most of the researchers collected samples during various (wet and dry) seasons Chavan and Zambare (2014) studied the leachate filtration impact on groundwater quality by gathering water samples during September month (wet season).

Patil and Kumar (2014) conducted a study to analyse parameters for chemical, physical and bacteriological analyses in a laboratory within 24 hours. Other methods were used such as a flame atomic absorption spectrophotometer and the results were compared to those of the WHO and Bureau of Indian standards for drinking water quality.

To assess groundwater contamination Hossain et al. (2014) explained the method as water samples were taken from a 500 ml plastic bottle after abstraction of the water by hand pump or tube well. The samples were taken to a laboratory at a cold temperature for analysis. All the other samples were analysed for physicochemical analysis within 48 hours.

3.9 Instrumental Methods of Analysis

3.9.1 pH and electrical conductivity parameters

The pH value of the water and wastewater is determined by electronic measurement at 25°C. The conductimetric measurement at 25°C determines the electrical conductivity of all types of water and use by the laboratory in the range of 0.5 mS/m to 4000 mS/m (APHA, 1992).

3.9.2 Color parameter

The platinum-cobalt method applies to determining color in the water and wastewater from light transmission characteristics in comparison with standard solutions of known color (APHA, 2014).

3.9.3 Turbidity parameter

Nephelometric method using HACH-2100Q turbidity meter (Hach company Loveland, Colorado, United States of America) was used to determine the turbidity of water and wastewater. The measurement is based on the intensity of light scattered by the sample under the defined condition when compared to the intensity of light scattered by a standard reference suspension under the same conditions. The higher the intensity of the scattered light higher the turbidity (APHA, 2012).

3.9.4 Chloride, sulphate, nitrite-nitrate ions

Thermo Scientific Gallery plus discrete photometric analyzer method of analysis is applicable for determined of the chloride, sulphate, and nitrite-nitrate parameters

(Thermo Fisher Scientific, Waltham, Massachusetts, United States). The discrete analysis technology is relatively new and was mostly used in clinical market and also in industrial markets in mid year 2000.

The samples and reagents are mixed in reaction wells and or cuvettes. The method consists of two different analysers, the system analyses the sample mixed with reagents in a reaction cup, and then the sample were analyses in a separate optical well and cell and other method mixes samples and reaction in the same cup that the system uses to analyses (APHA, 2012).

3.9.5 Calcium, magnesium, cadmium, lead, manganese, magnesium, zinc, and total hardness parameters

The Inductively coupled plasma mass spectrometry (ICP-MS) measurement of metals under acidic conditions following digestion of total metals using MARS microwave digestion. This method applies to the determination of calcium, magnesium, cadmium, lead, manganese, magnesium, zinc, and total hardness parameters (APHA, 2012).

3.9.6 Escherichia coli

Escherichia coli is a member of the feacal coliform group of bacteria which yields a positive indole reaction at 44.5ºC, this method applies to the confirmation of feacal coliforms bacteria isolated on m-FC medium colonies from the membrane that are picked and inoculated into tubes containing tryptone water. The tubes or bottles are incubated at 44.5ºC or 1ºC for 24 hours. After incubation, Kovac's reagent is added, and the tubes producing a red layer are positive for *E.coli* (APHA, 2012).

3.9.7 Total coliform count

The total coliform method involves the counting of dark green colonies with a green metallic sheen that develops within 24 hours at 35°C on an endo-type medium containing lactose This iridescent green coating forms over the growing colonies following the production of an acid-aldehyde complex that is a fermentation by-product which combines with the Schiff's reagent in the m-Endo media (APHA, 2012).

3.9.8 Heterotrophic Plate Count (HPC)

The HPC uses the pour plate method that is performed in a biological safety cabinet. Volumes of 1 ml of the water or ten-fold dilutions are mixed with a non-selective nutrient-enriched agar medium. The agar plates are incubated at 35°C for 48 hours after which all the colonies are counted. The HPC is reported per 1 ml of the original sample (APHA,1992).

This method quantifies viable aerobic bacteria in potable water, untreated sewage, and industrial effluents as well as the fresh or salted water surface. These bacteria do not represent the total number of microorganisms in water but only those that form visible colonies in nutrient media under specified culture conditions WHO (2017). The test for the HPC is used together with total coliforms and feacal coliforms as an indication of the sanitary quality of water and it is used to test the efficiency of water treatment processes (ISO:8199, 2018).

3.10 Data Statistical Analysis

All chemical, microbiological and physical data obtained from laboratory analysis of the study samples (BH1, BH2, and BH3) were subjected to analysis of variance using the Statistica version 12 software. For intra and inter-borehole sample comparisons, specifically, a 1-way ANOVA was used for comparing mineral composition among borehole water samples including their physical and microbiological characteristics. All parameters and measurements were tested at $p<0.05$ significance level and the Duncan multiple range tests were used for the separation of means among treatments.

The results (pH, turbidity, electrical conductivity, colour, total hardness, *E. coli*, total coliforms, HPC, and elements (Cl, Fl, N, Cd, Cu, Fe, Pb, Mg, Na, Ca, Mn & Zn)) are presented in graphical representations but without errors bars and mean separation shown because some data were missing for one of the boreholes as the water dried up during sample collection.

CHAPTER 4: RESULTS

This chapter consists of the results of the research study, which have been discussed and presented. It also discusses the water sample methods used to determine the water quality analysed during the sample testing in order to investigate environmental geohydrology at the Onderstepoort landfill facility.

The samples were prepared, treated, and analysed for physical, chemical, and microbiological characteristics following standard laboratory methods. The following water quality parameters were assessed and measured to achieve the project's objectives:

- Physical parameters
  pH, electrical conductivity (EC), total hardness (TH), turbidity and colour,
- Chemical parameters
  Cadmium (Cd), calcium (Ca), chloride (Cl-), copper (Cu), fluoride (F), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), nitrate nitrogen, sodium (Na) sulphate (SO_4^{2-}), and zinc (Zn).
- Microbiological parameters

Escherichia coli (E. coli), total coliforms, and heterotrophic bacteria count (HPC).The results from all boreholes in this study were compared to each other to determine the three-dimensional and sequential profiles of water quality The comparisons of these results were made with those of the local and international water quality standards, the outcomes of similar studies undertaken in South Africa and other countries were done.

4.1. Physical Data and Interpretation

4.1.1 pH

The pH of the water samples was measured during both the pilot and the extended study, and the variance was determined between the samples from the three boreholes. The pilot study indicated that pH levels varied between 8.5 and 8.7 for water from BH1 and BH2.

The pH levels were then measured from all three boreholes and the results for the pilot and extended study is illustrated in Figure 4.1a (page 35). This figure indicates that the pH values varied between 7.0 and 7.9 at BH1, between 7.6 and 8.1 at BH2, and between 7.2 and 8.1 at BH3. These pH results were acceptable when compared to SANS 241: 2015 lower and upper limits (pH 5 – pH 9.7) of water quality standards.

Figure 4.1b (page 36) illustrates the pH levels obtained that varied between the upper and lower limits (6.5 - 8.5) in comparison to the World Health Organisation water quality standards (WHO, 2017) and shows that the pH recorded in water collected from the different borehole sampling sites exceeded the WHO water quality standards.

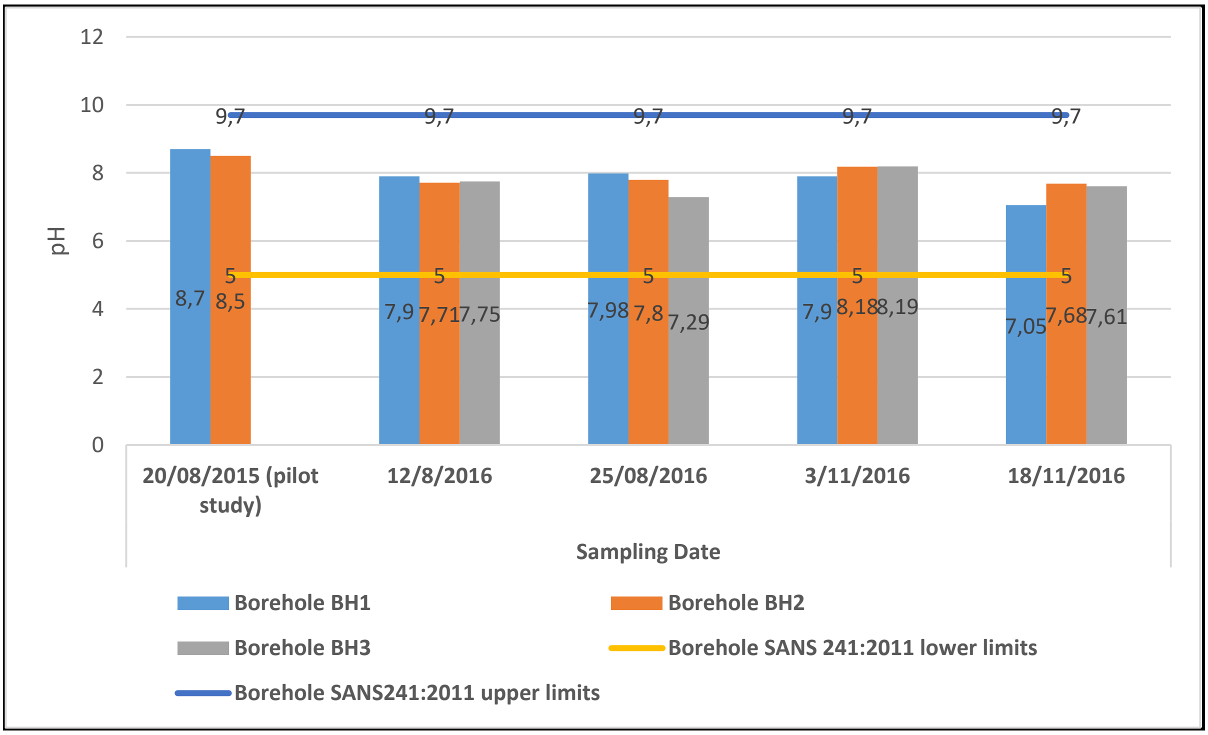

Figure 4.1a: pH concentration in water samples collected from sites BH1, BH2, and BH3 sampling sites relative to SANS 241: 2011 upper and lower water quality standard values.

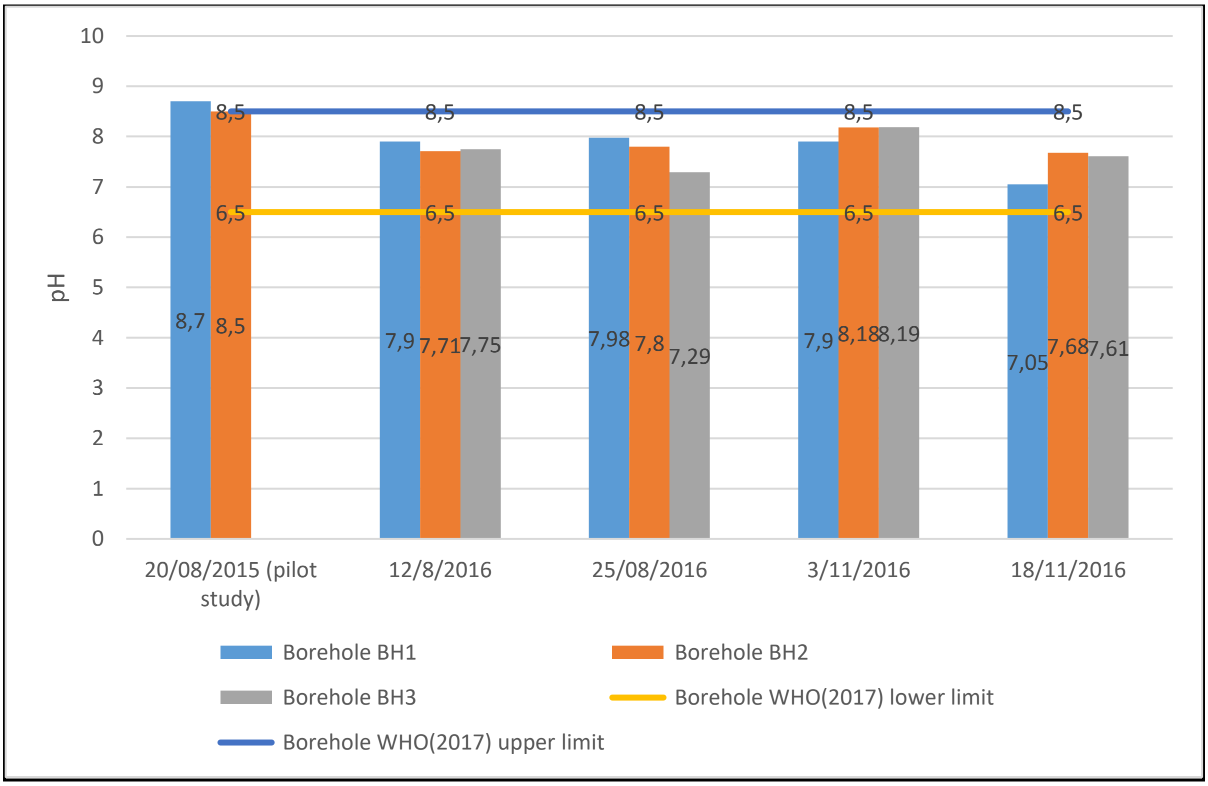

Figure 4.1b: pH concentration in water samples collected from sites BH1, BH2 and BH3 sampling sites relative to WHO (2017) upper and lower water quality standards values.

4.1.2 Turbidity

Water samples were not analysed for turbidity during the pilot study and so this parameter was only measured during the extended study. Thus, Figure 4.2 (page 37) indicates four sets of analytical results that were high between twice and nearly 60 times greater than the SANS quality standard limit.

This was particularly evident in BH3 water which showed turbidity at least twice as high as the turbidity in three of the four water samples from BH1 or BH2. The highest turbidity value for water from BH3 was 291 NTU, a figure obtained just after the rainy season in samples collected on 3 November 2016. The lowest turbidity levels were 8.9 NTU and 22 NTU measured in BH2 on 25 August 2016 and 18 November 2016.

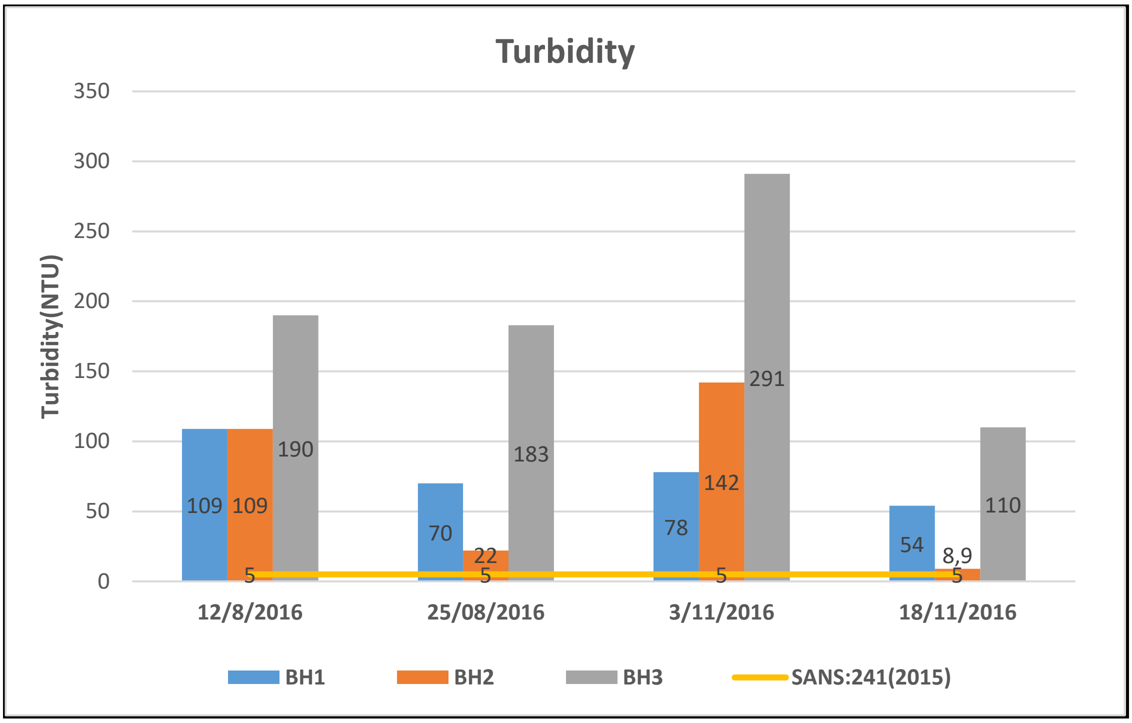

Figure 4.2: Turbidity concentration in water samples collected from BH1, BH2 and BH3 sampling sites.

4.1.3 Electrical Conductivity (EC)

Figure 4.3 (page 38) indicates the electrical conductivity (EC) in water samples collected during the pilot and extended studies. The EC data from the pilot study is shown on the far left of the figure and indicates 60 µS/m in BH1 and 103 µS/m in water collected from BH2.

The highest EC level was measured at BH3 as 291 µS/m on 3 November 2016, but this was reduced to 110 µS/m by 18 November 2016. The EC levels in BH2 fluctuated more in comparison to the other two boreholes but all the EC figures measured were within the WHO (2017) standard limit and only BH3 water exceeded the SANS 241: 2015 water standard limit.

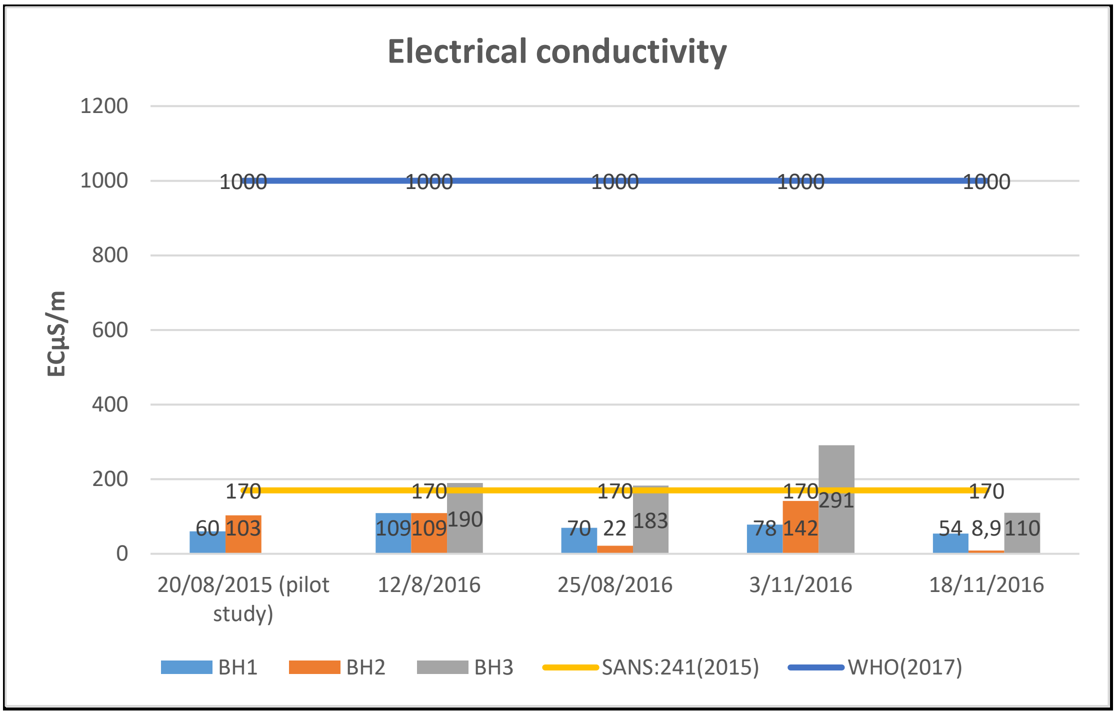

Figure 4.3: Electricity conductivity concentrations in water samples collected from sites BH1, BH2 and BH3.

4.1.4 Colour

The colour parameter was not analysed during the pilot study and data are presented in Figure 4.4 (page 39) following an analysis of water collected from the three boreholes in 2016. Prior to the rains, the colour of the water samples was 5 mg/l, well within the SANS 241: 2015 quality standard limit of 15 mg/l.

Trends indicated that water colour increased in samples from BH1 and BH2 following the rains to a maximum of 14 mg/l and 7 mg/l, respectively. The colour of the water from BH3 was consistent at 5 mg/l across the study.

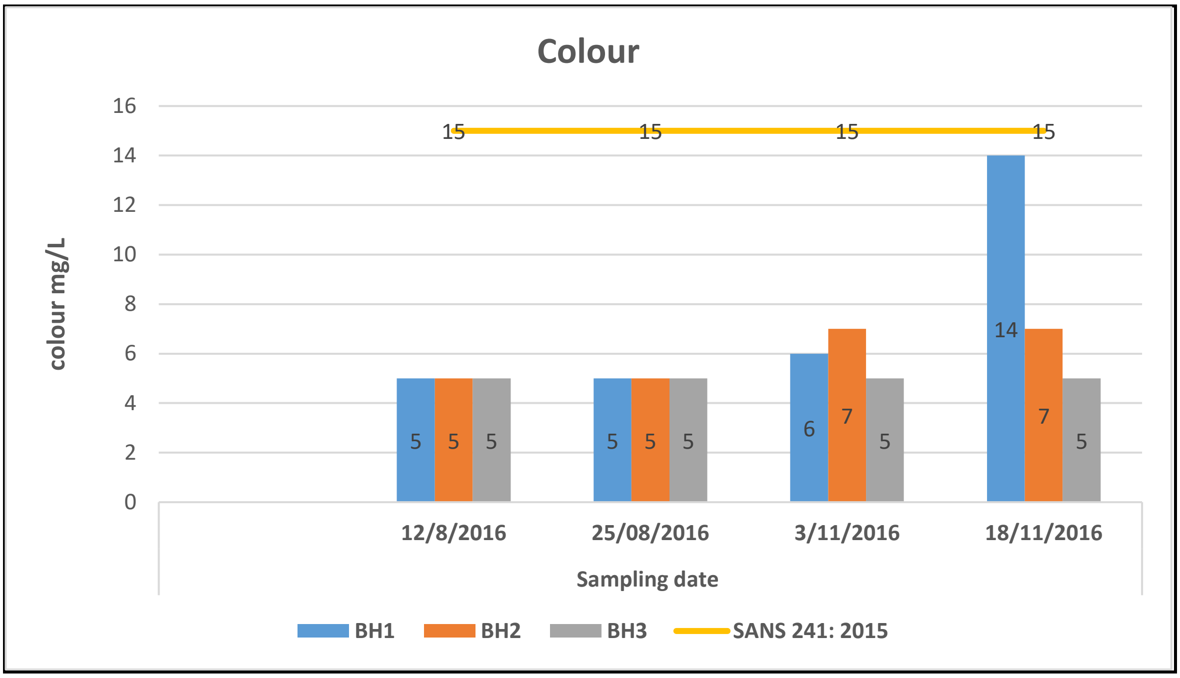

Figure 4.4: Water colour concentration in water collected from BH1, BH2 and BH3 sampling sites.

4.1.5 Total hardness data

Total hardness data from the extended study samples are graphically represented in Figure 4.5 (page 40). The WHO (2017) standards for water hardness are 0 to 60 mg/l (soft), 61 to 120 mg/l (moderate), 121 mg/l to 180 mg/l (hard) and >180 mg/l (very hard).

Figure 4.7 indicate that water hardness was consistently very hard prior to the rainy season and immediately thereafter but that samples collected from BH2 on 18 Nov 2016 were relatively elevated to over 600 mg/l while the lowest hardness levels were measured as 179 mg/l at BH1 and 131 mg/l from BH3 on 18 November 2016

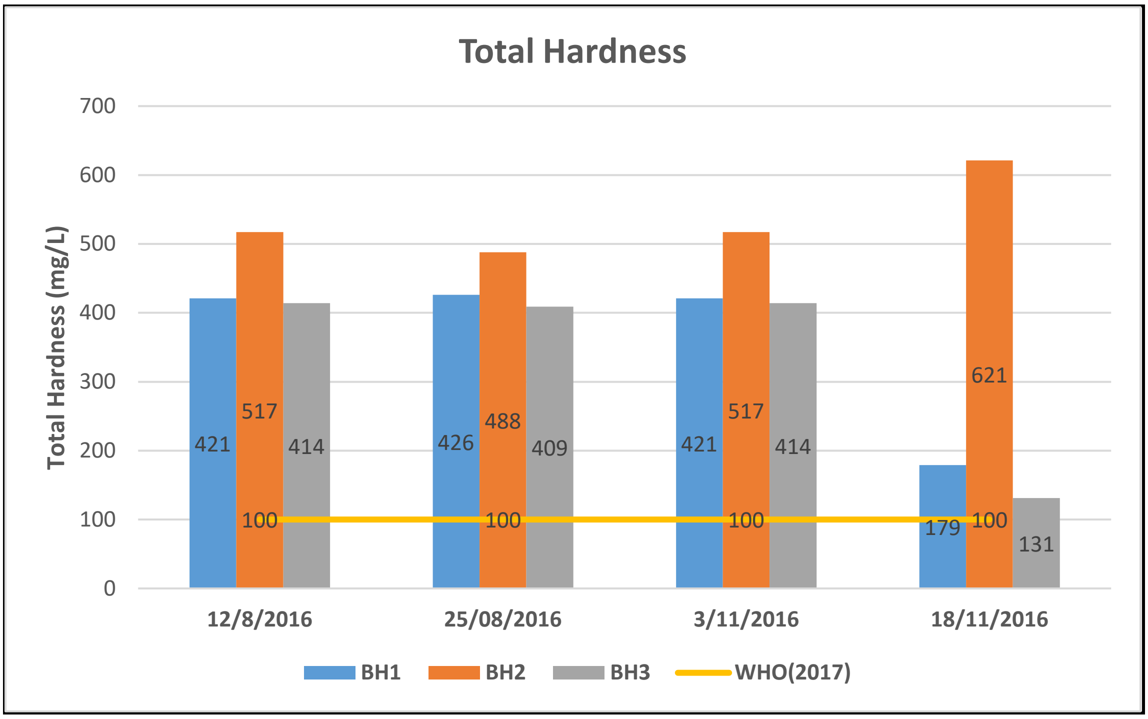

Figure 4.5: Total water hardness concentration in water samples collected from BH1, BH2 and BH3 sampling sites.

4.2 Microbiological data and interpretation

4.2.1 Escherichia coli (E. coli)

As indicated in Figure 4.6 (page 41), the pilot study focused only on *E. coli* and total coliform counts from BH1 and BH2 while the extended study involved count analysis of *E. coli*, HPC and total coliform.

The highest Escherichia Coli levels measured were 4200 in borehole 01 on 18 November 2016 and borehole 01 was 400 on 04 August 2016 and 258 in borehole 02 and 10 in borehole 01 on 28 October 2016. The lowest levels were measured in BH1 and BH3 on 28 October and 04 August 2016. *E. coli* levels were not specified under SANS 241: 2015 and in the WHO (2017) water quality standards.

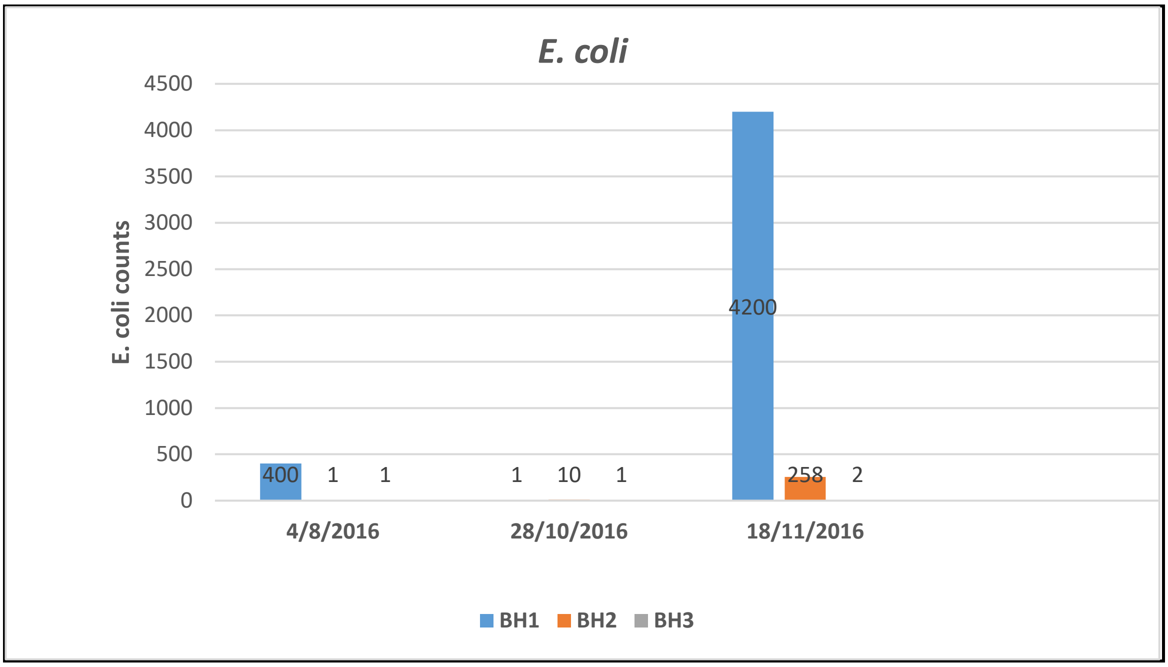

Figure 4.6: Escherichia coli counts in water samples collected from BH1, BH2 and BH3 sampling sites

4.2.2 Total Coliforms

Figure 4.7 (page 42) shows the highest levels of Total Coliforms between 10 000 in borehole 03 and 70 000 in borehole 02, on 28 October 2016. Borehole 01 levels measured 6200 on 18 November 2016.

Borehole 03, 01 levels were measured between 4000 – 4200. The lowest level of Total Coliforms was measured in borehole 01 and borehole 03 on 28 October and 04 August 2016. The concentration level of Total Coliforms was high than acceptable limits as compared to SANS 241: 2015 and WHO (2017) water quality standards.

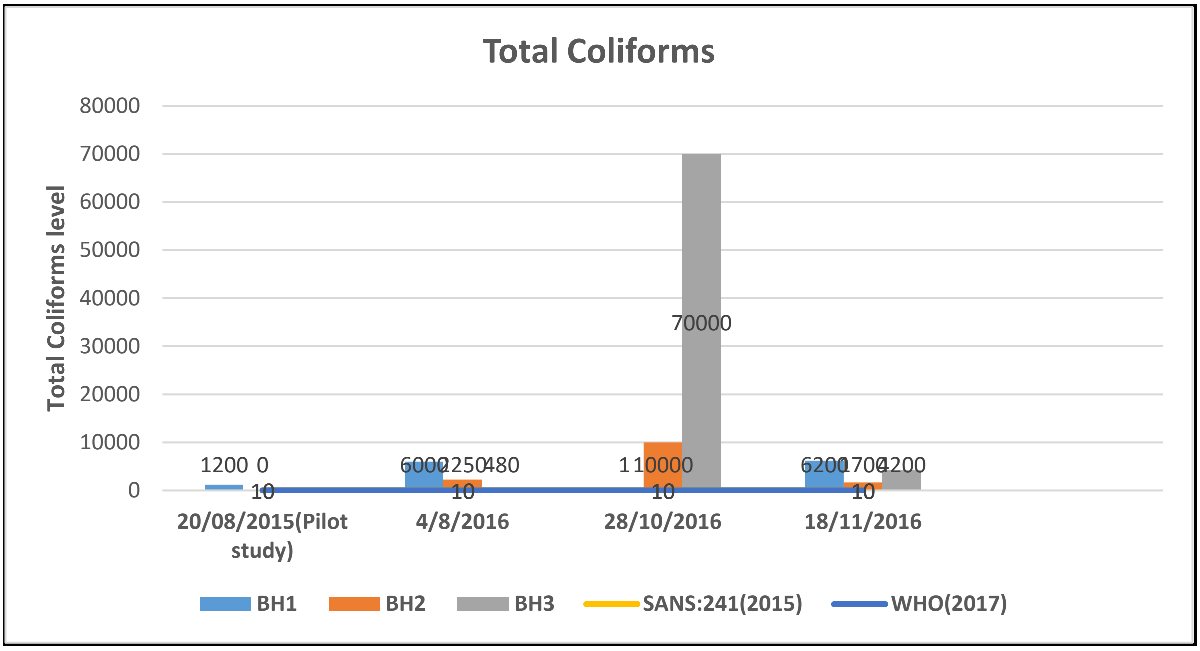

Figure 4.7: Total Coliform concentrations in water samples collected from BH1-BH3 sampling sites

4.2.3 Heterotrophic Plate Count (HPC)

The HPC parameter was not sampled during the pilot study, and it was only measured during the extended study Figure 4.8, (page 43). The highest HPC levels measured were 95250 on 28 October 2016 in borehole 01, and 12500 in borehole 01 on 18 November 2016.

Borehole 03 measured 19475 on 18 November 2016. The lowest level was 480 measured in borehole 03 on 04 August 2016. The HPC level was higher than acceptable limits as compared to SANS 241: 2015 and WHO (2017) water quality standards levels were not specified.

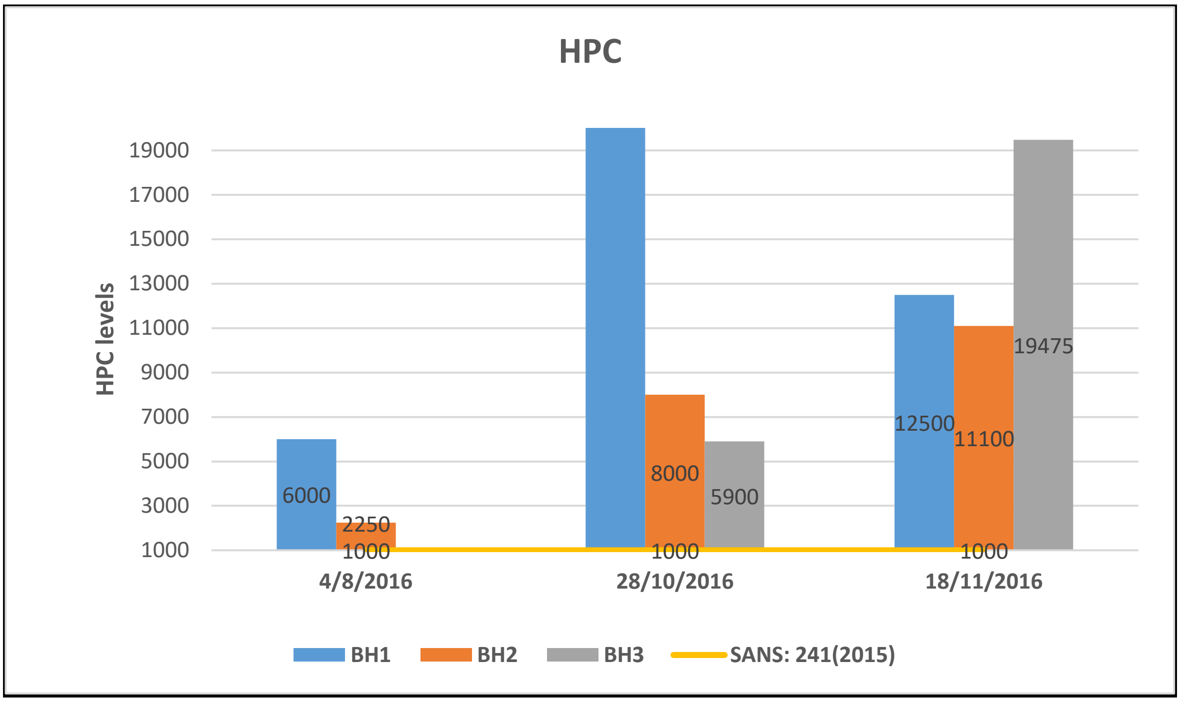

Figure 4.8: Heterotrophic Plate Count concentrations in water samples collected from BH1, BH2 and BH3 sampling sites.

4.3 Chemical data and interpretation

An overview of the results of chemical analysis in relation to SANS or WHO standard limits reflects general trends allowing specific (groups of) chemicals to be categorized as present in water samples at minimal, intermediate, and high levels.

Thus, the halogen chloride and fluoride ions were present at low to intermediate concentrations, nitrate-nitrogen was low while sulphate was high while most metals were absent or detected at a low level except for calcium (intermediate to high) and manganese and magnesium.

4.3.1 Chloride

Figure 4.9 (page 44) demonstrates that even though the concentrations of chloride in the water samples were well below that of the SANS 241:2015 limit, a consistently high concentration of chloride was recorded during the pilot, as well as the extended study from BH2 compared to BH1 and BH3.

BH2 was measured 101 mg/l on 20 August 2015 during the pilot study. BH3 was measured at 29 mg/l on 12 August 2016 and 27 mg/l on 03 November 2016 during an extended study. The lowest level was measured in borehole 03 as 27 mg/l on 03 November 2016. Borehole 03 measured 28 mg/l on 25 August 2016. The chloride levels measured lower and within acceptable limits as compared to water quality standards in SANS 241: 2015

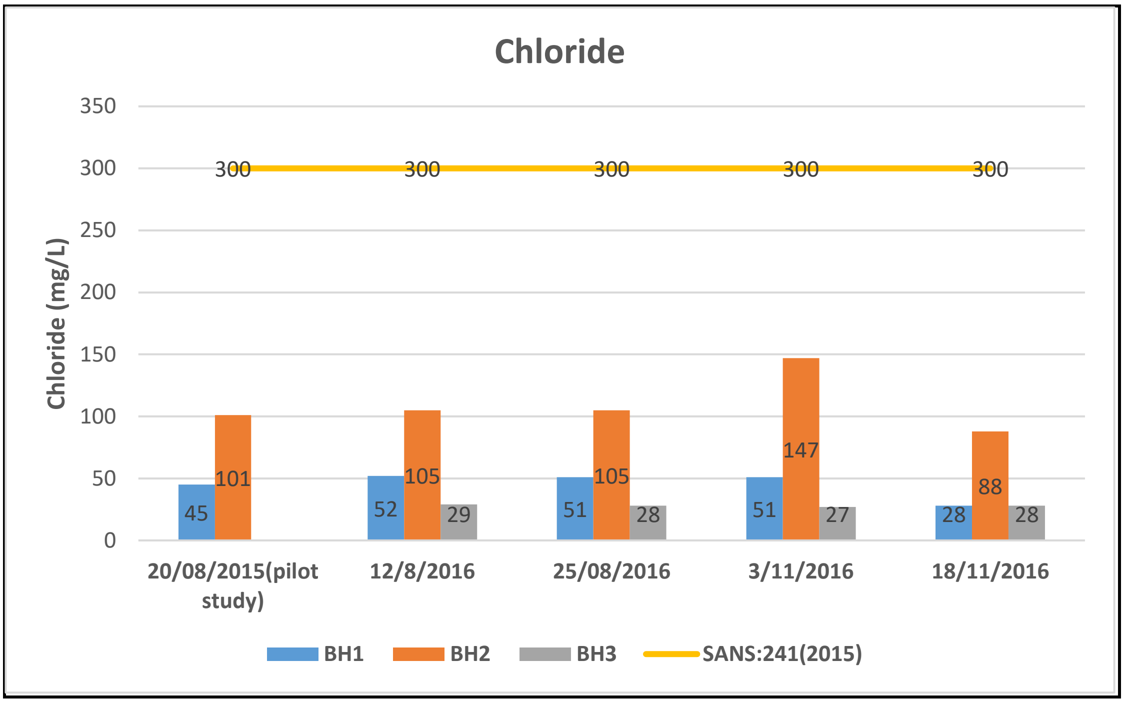

Figure 4.9: Chloride concentrations in water samples collected from at BH1, BH2 and BH3 sampling sites.

4.3.2 Fluoride

Figure 4.10 (page 45) indicates that the concentrations of fluoride in the 2016 water samples were consistently higher compared to those in the 2015 water samples. Apart from water samples collected on 3 November 2016, higher concentrations of fluoride were detected in water samples collected from BH2.

The highest concentration of fluoride (0.95 mg/l) was determined in water from BH2 on 3 November 2016 followed by water collected from BH3 on the same date and from BH2 on 18 November 2016, these two latter concentration figures were 0.89 mg/l. The lowest fluoride level was measured as < 0.05 mg/l during the pilot study. Fluoride concentrations were within the acceptable limits (1.5 mg/l) as compared to SANS 241: 2015 water quality standards.

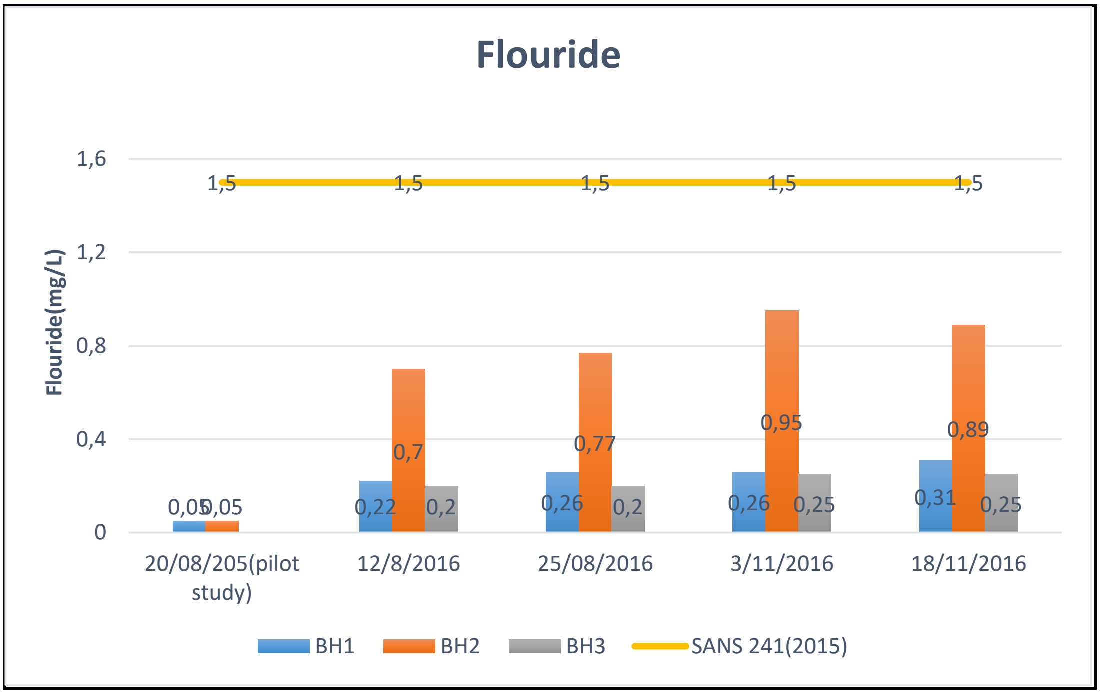

Figure 4.10: Fluoride concentrations in water samples collected from BH1, BH2 and BH3 sampling sites.

4.3.3 Nitrate Nitrogen

Figure 4.11 (page 46) indicates the highest level of nitrate-nitrogen measured 1705 mg/l in borehole 03 on 03 November 2016. Borehole 02 measured 1.7 mg/l on 03 November 2016 and 1.1 in borehole 03 on 18 November 2016.

The lowest level was measured between 0.20 – 0.93 mg/l in borehole 01, borehole 02, and borehole 03 on 12 August and 25 August 2016. During the pilot study, the parameter was not measured. The nitrate-nitrogen levels were low as compared to the SANS 241: 2015 drinking water quality standards of 12 mg/l nitrate nitrogen. The WHO (2017) water quality standards levels for nitrate-nitrogen were not specified.

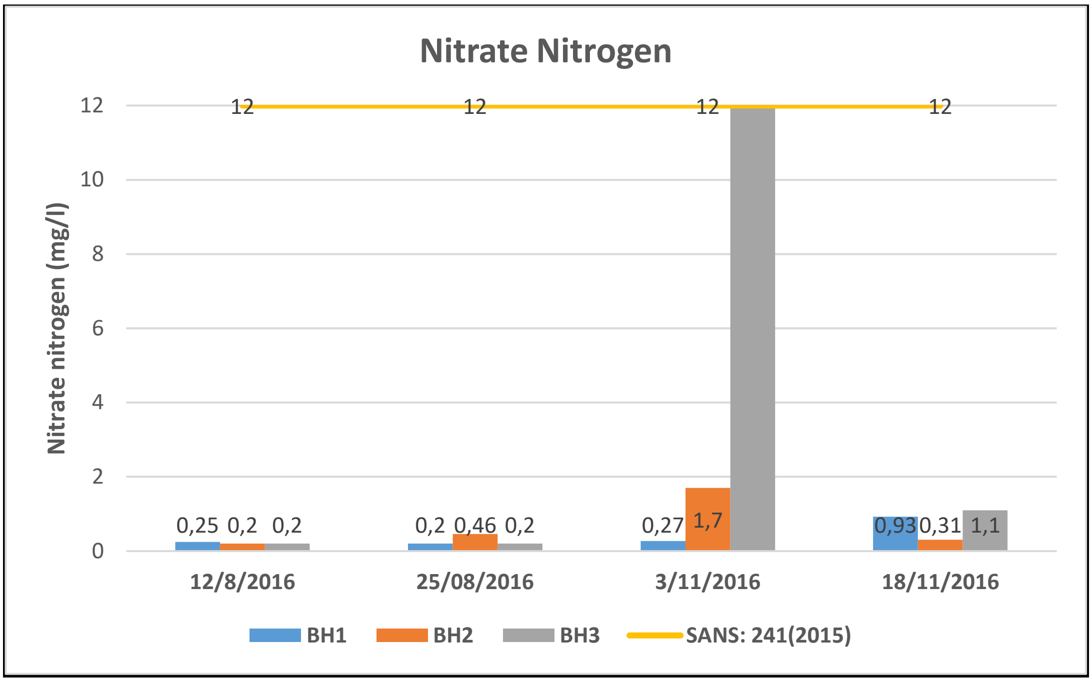

Figure 4.11: Nitrate nitrogen concentrations in water samples collected from BH1, BH2 and BH3 sampling sites.

4.3.4 Sulphate

During the sampling period, the concentration of sulphate in the water samples was close to the SANS 241: 2015 aesthetic upper limit (250 mg/l). Figure 4.12 (page 47) indicates that the highest concentration of sulphate (281 mg/l) was determined in water collected from BH2 on 3 November 2016.

The lowest concentrations of sulphate were measured in 2015 and prior to the rainy season in 2016. The concentration of sulphate is not specified in the list of WHO (2017) water quality standards.

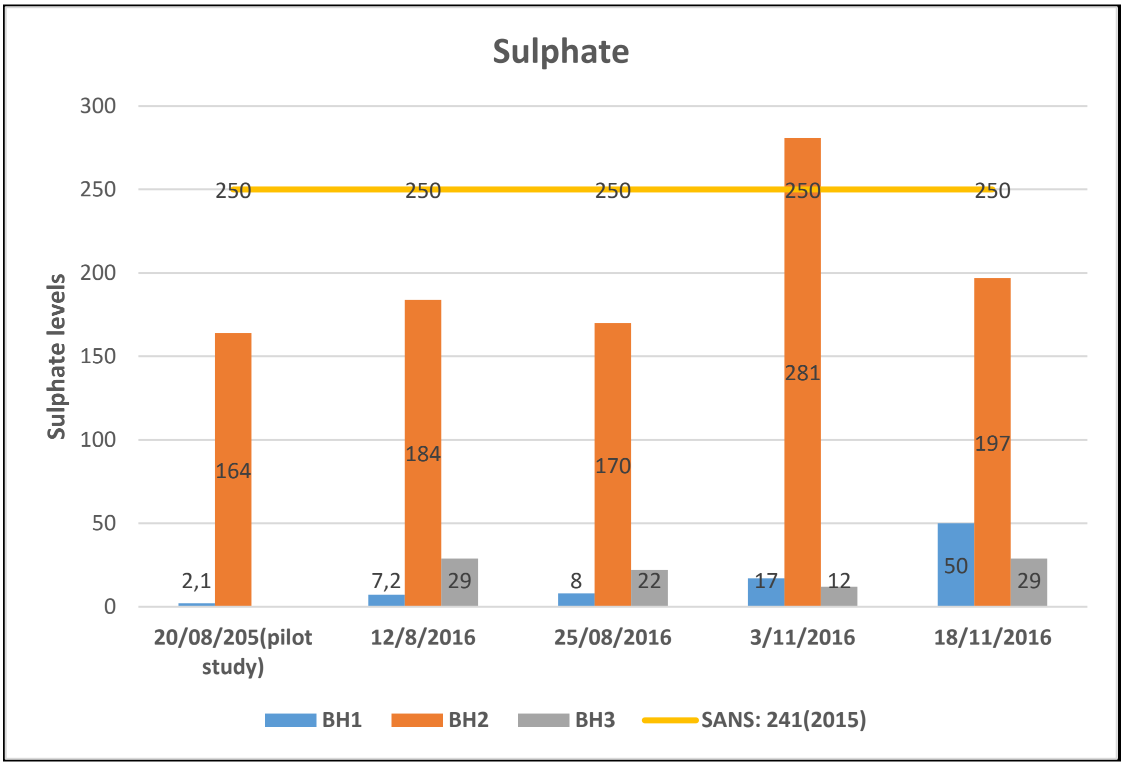

Figure 4.12: Sulphate concentration in water samples from BH1, BH2 and BH3 sampling sites.

4.3.5 Cadmium

The concentration of cadmium was not determined during the pilot study. Figure 4.13 (page 48) indicates that an identical concentration of cadmium (<0.02 µg/l) was determined in each collected water sample. These results compared to the cadmium concentration limit (3 µg/l) in both SANS 241: 2015 and WHO (2017) drinking water quality standards.

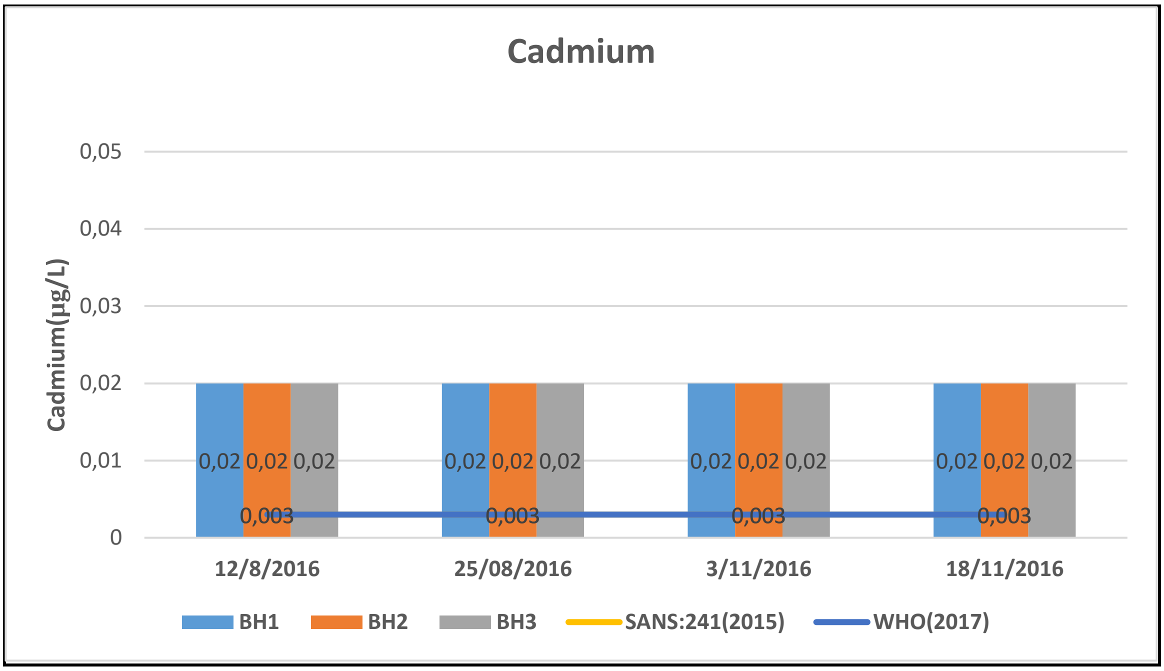

Figure 4.13: Cadmium concentrations in water samples collected from BH1, BH2 and BH3 sampling sites.

4.3.6 Copper

Figure 4.14 (page 49) illustrates that the highest copper concentration (14 mg/l) was measured in water from BH2 on 3 November 2016 and BH3 (0.94 mg/l) on 18 November 2016. The lowest copper concentrations (0.02 mg/l) were measured in BH1 and BH2 on 20 August 2015. These copper concentrations are compared to the SANS 241: 2015 and WHO (2017) acceptable limit for copper of 2 mg/l.

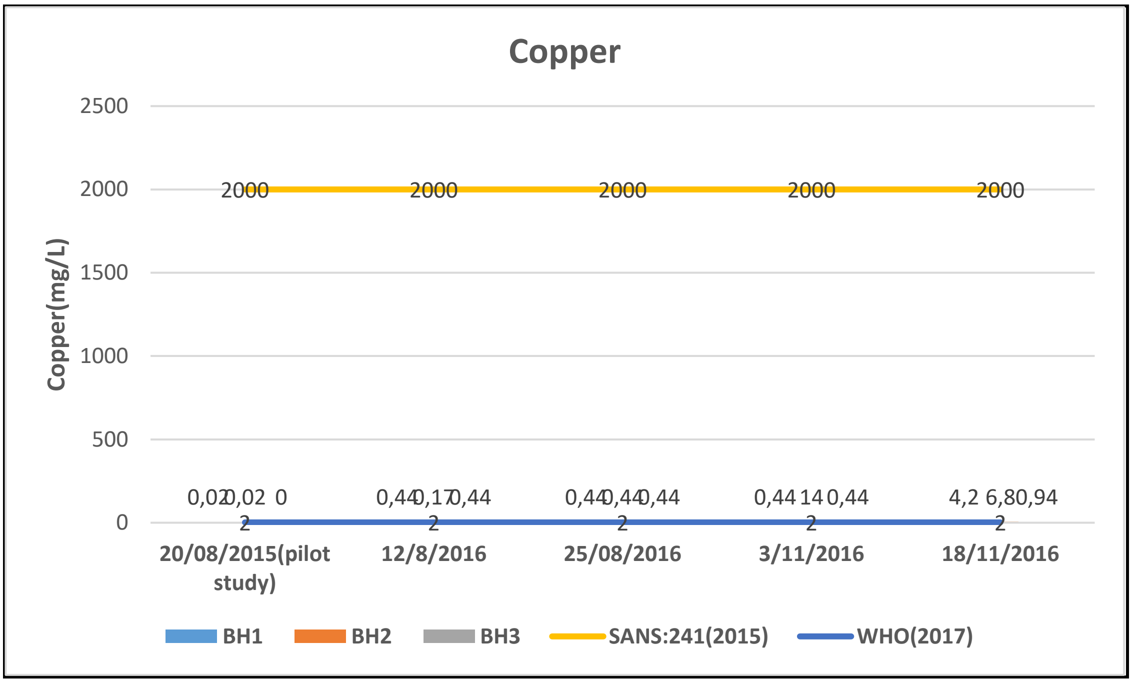

Figure 4.14: Copper concentration in water samples collected from BH1, BH2 and BH3 sampling sites.

4.3.7 Iron

The concentration of iron measured in BH1, BH2 and BH3 were within the acceptable limits of SANS 241: 2015. Figure 4.15 (page 50) indicates that the highest concentration of iron (257 mg/l) was measured in water from BH3 on 18 November 2016. This compares to the concentrations of iron in BH1 (40 mg/l) and BH2 (9,7 mg/l) measured on the same date. The lowest concentration of lead (0.05 mg/l) was measured in BH1 and BH2 on 20 August 2015 during the pilot study.

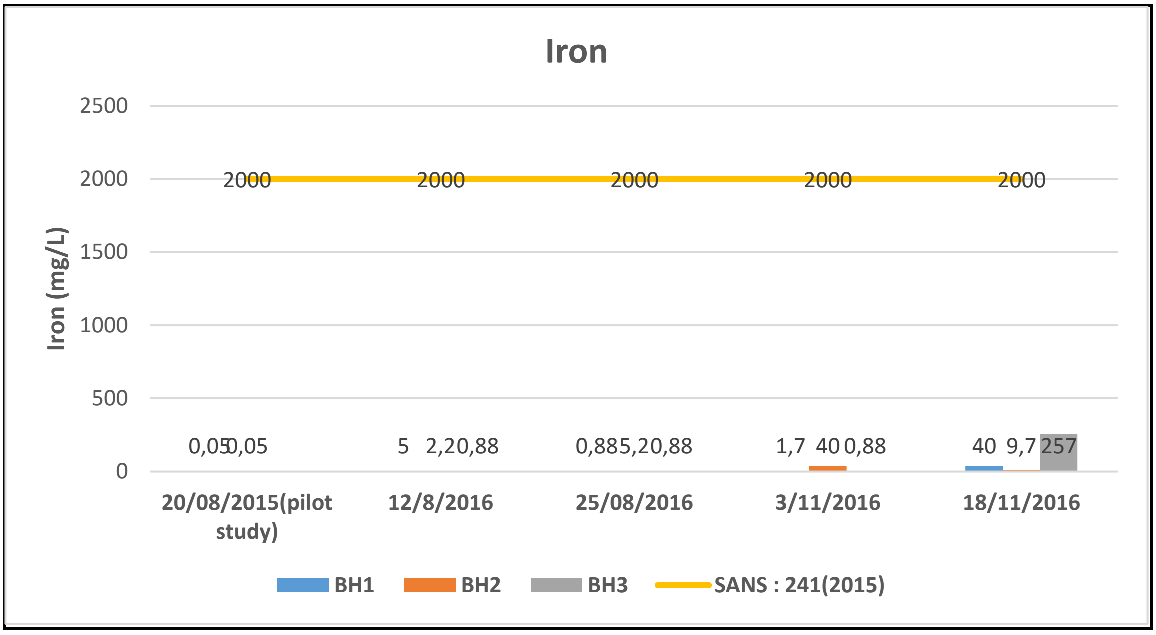

Figure 4.15: Iron concentrations in the water samples collected from BH1, BH2 and BH3 sampling sites.

4.3.8 Lead

The concentration of lead was not determined during the pilot study. An identical lead concentration (0.1 mg/l) was obtained for each water sample obtained from each of the boreholes in 2016. This is a very low concentration compared to the SANS 241: 2015 water quality standard Figure 4.16 (page 50).

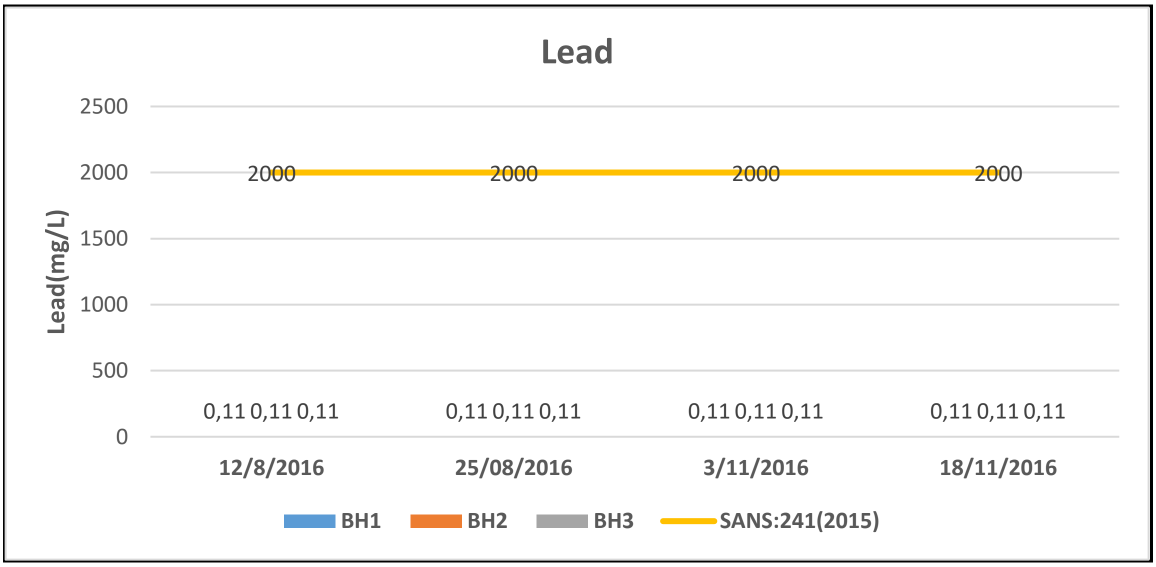

Figure 4.16: Lead concentrations in water samples collected from BH1, BH2 and BH3 sampling sites.

4.3.9 Magnesium

The level of magnesium exceeded the SANS 241: 2015 (10 mg/l) and WHO (2017) (0.1 mg/l) drinking water quality standards. Figure 4.17 (page 51) indicates that the highest concentrations of magnesium were measured on 3 November 2016 after the rains, particularly in water from BH2 (83 mg/l) and in BH1 (80 mg/l) and BH3 (79 mg/l). These 2016 figures are significantly higher than the magnesium concentrations noted in BH1 (38 mg/l) and BH2 (55 mg/l) in the 2015 pilot study.

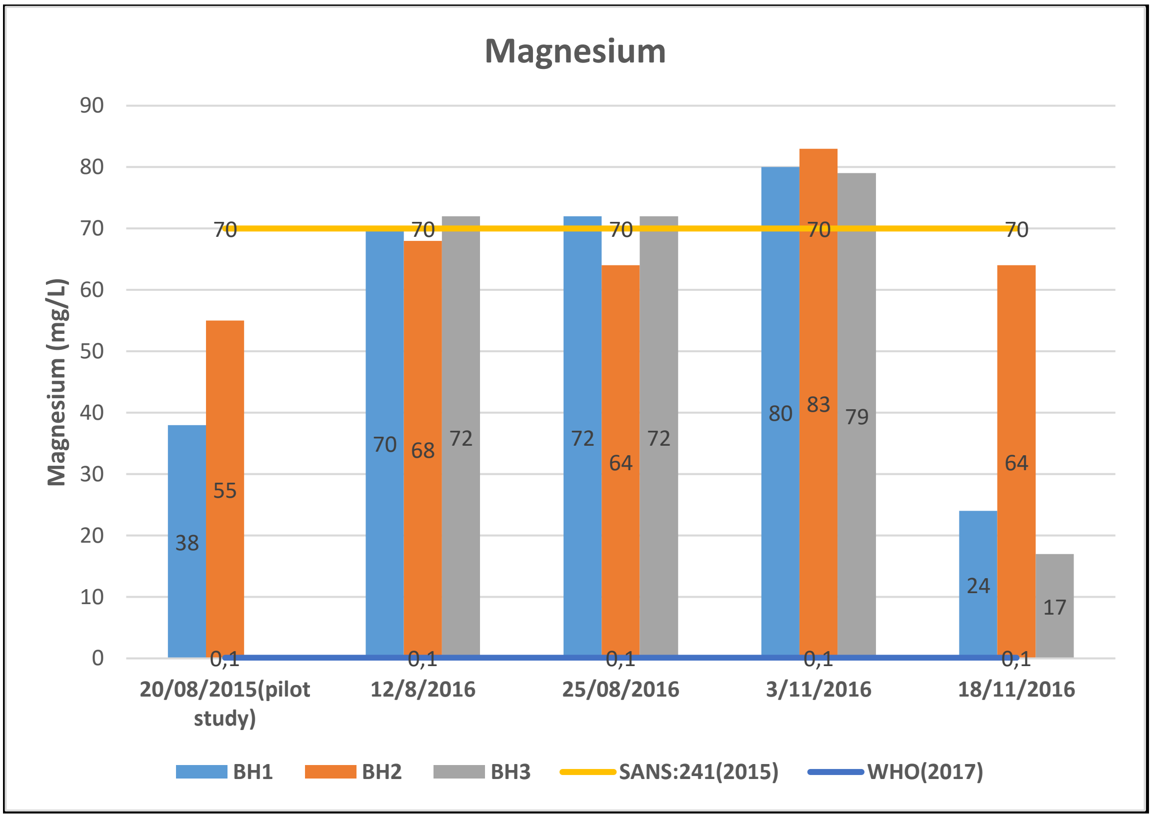

Figure 4.17: Magnesium concentrations in water samples collected from BH1, BH2 and BH3 sampling sites.

4.3.10 Sodium

Figure 4.18 (page 52) indicates a relatively low concentration of sodium ions in the water samples collected from the three boreholes. Water from BH2 showed two to three time's higher concentrations of sodium compared to the sodium concentration in water from BH1 or BH3. The lowest concentrations of sodium in water samples from BH1 and BH 3 were measured on 18 November 2016. These sodium concentration levels were within acceptable limits when compared to SANS 241: 2015 and WHO (2017) drinking water quality standards.

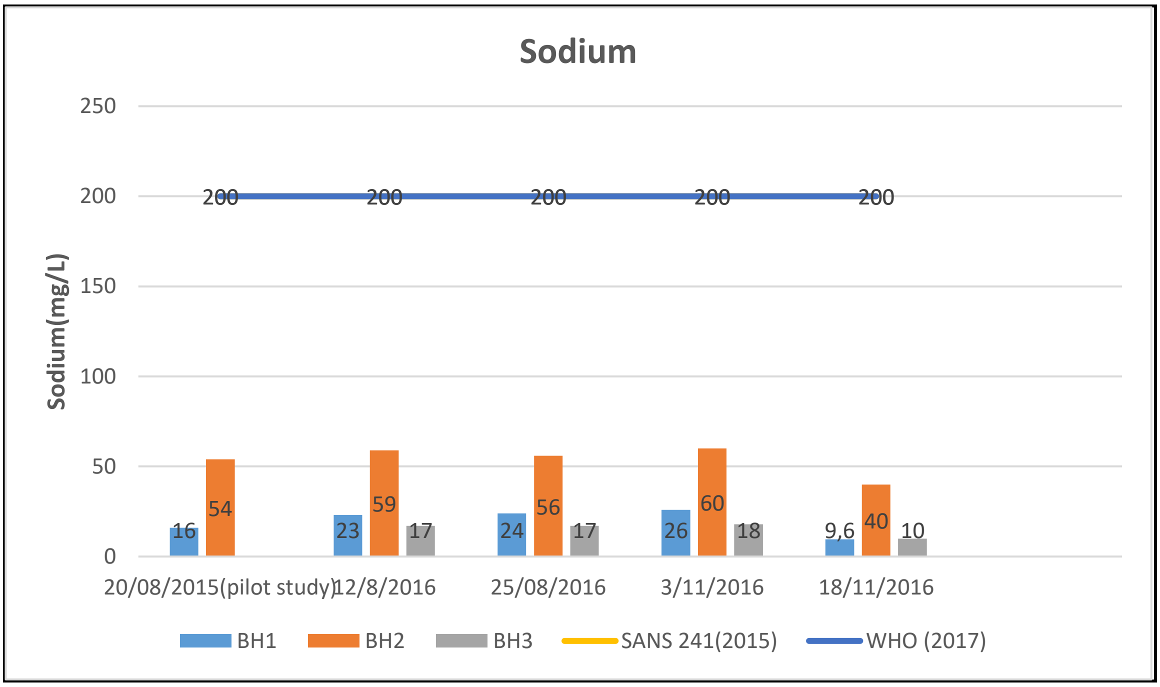

Figure 4.18: Sodium concentrations in water samples collected from BH1, BH2 and BH3 sampling sites.

4.3.11 Calcium

Figure 4.19 (page 53) indicates that calcium concentrations were relatively high during both the pilot and the extended studies but increased to nearly breaching the SANS 241: 2015 upper concentration limit of 150 mg/l. Prior to the rains, an average calcium concentration of around 90 mg/l was noted in water samples from BH2 but this increased to 143 mg/l in the November 2016 samples.

Apart from the water sample collection date during the extended study, a lower calcium concentration was noted in BH3 water compared to BH1. The lowest calcium concentrations were measured as 26 mg/l in water collected from BH3 on 18 November 2016 and for water collected from BH1 (32 mg/l) on the same date. The calcium level was within the acceptable limits as compared to SANS 241: 2015 drinking water quality standards.

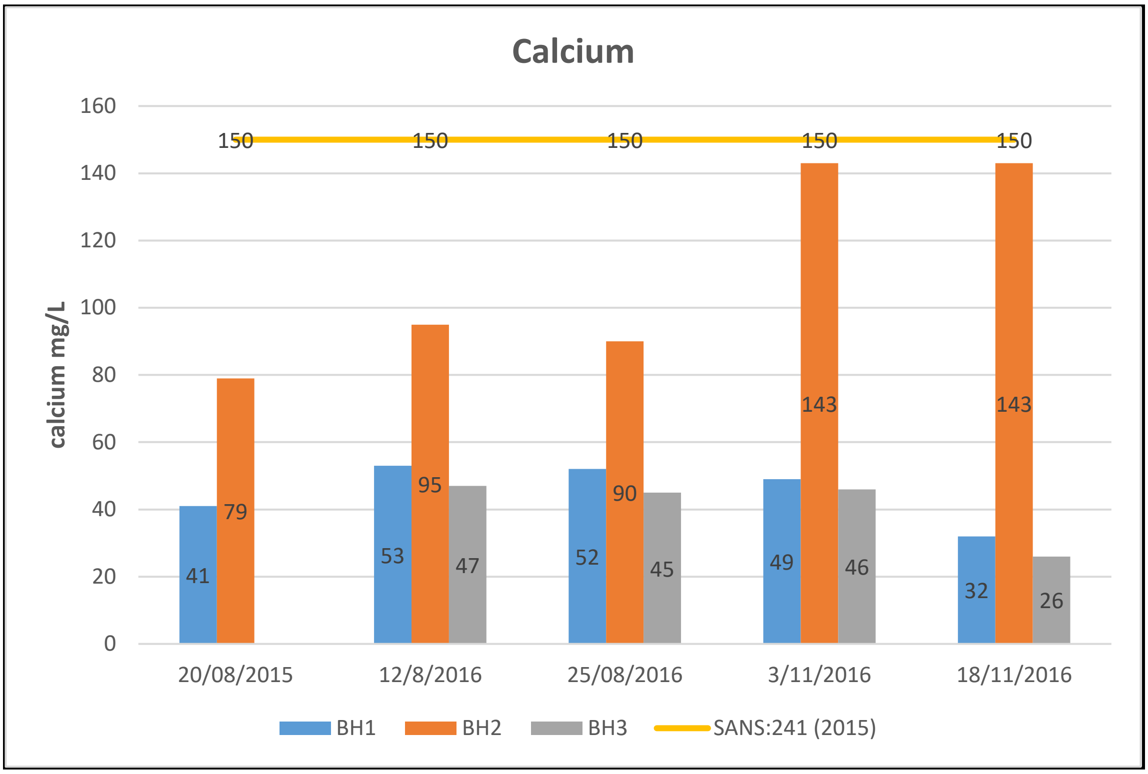

Figure 4.19: Calcium concentrations in water samples collected from BH1, BH2 and BH3 sampling sites.

4.3.12 Manganese

Figure 4.20 (page 54) indicates relatively high concentrations of manganese were noted in water samples collected from BH3 compared to water from BH1 or BH2. The highest manganese concentration (1705 mg/l) was measured in water samples collected from BH3 on 3 November 2016, a figure that is over four times higher than the upper SANS 241: 2015 water quality standard limit. The concentration of manganese in water samples collected from BH1 and BH2 was all lower that the water quality standard limit set by SANS 241: 2015.

The concentration of manganese in water samples collected from all three boreholes on 18 November 2016 was relatively low compared to the manganese concentrations noted in samples collected from corresponding boreholes during the extended study in 2016. The lowest concentrations of manganese were measured in BH1 and BH2 during the pilot study.

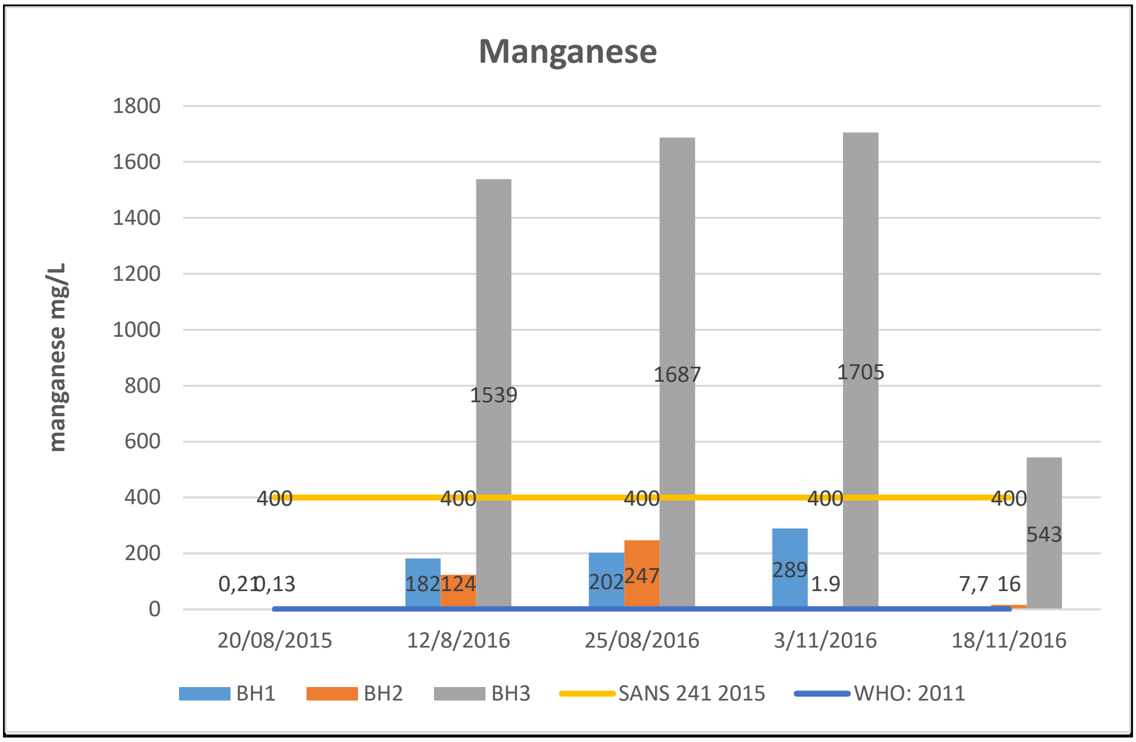

Figure 4.20: Manganese concentrations in water samples collected from BH1, BH2 and BH3 sampling sites.

4.3.13 Zinc

Figure 4.21 (page 55) indicates the highest zinc concentration levels measured at 5 mg/l in water samples collected from BH3 on 18 November. The measured zinc concentration in all water samples collected in August 2016 and BH3 collected on 3 November 2016 were equal (0.57 mg/l). Water collected from BH1 and BH3 on 3 November 2016 measured3.0 mg/l and 0.88 mg/l respectively. The zinc concentration was within the SANS 241: 2015 drinking water quality standard.

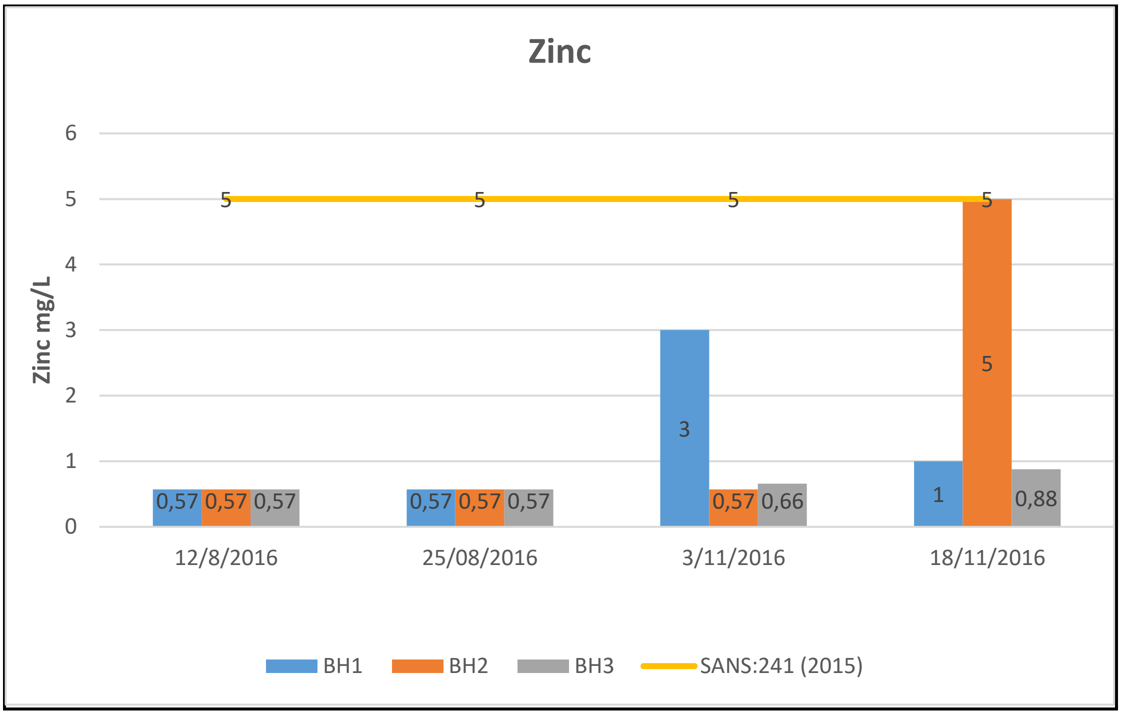

Figure 4.21: Zinc concentrations in water samples collected from BH1, BH2 and BH3 sampling sites.

CHAPTER FIVE: DISCUSSION

This chapter discusses the research findings based on the groundwater quality data undertaken within the Onderstepoort landfill site study area. The research study focused on analysing the data obtained from the pilot study in August 2015 and the extended study was undertaken in August and late 2016 respectively. Table 3.3 (page 30) lists the limits of water quality parameters that were prepared by the WHO (2017) and the SANS 241: 2015 drinking water quality standards.

The collected water samples were transported on ice to an accredited CSIR laboratory for water quality parameter analysis. Water samples were analysed for physical parameters such as pH, electrical conductivity (EC), and total water hardness, for inorganic components of groundwater including fluoride, nitrate nitrogen, chloride, sulphate, phosphate, sodium, potassium, calcium, and magnesium. The analysed microbiological parameters included *E. coli*, total coliforms, and heterotrophic plate count (HPC).

5.1 Physical parameters

Tiwari (2015) describes the pH as an indicator of the existence of biological life in water. For organismal survival in an aquatic environment, the pH should ideally be between 6.0 and 9.0 (DWAF, 1996). In some cases, acidic pH is influenced by metals such as copper, zinc, or lead dissolving in the water (DWAF, 1996).

The pH of the water samples obtained during the pilot and extended study at the Onderstepoort landfill site varied between 7.0 and 7.8 from BH1, between 7.6 and 8.1 from BH2, and between 7.2 and 8.1 from BH3 (Figures 4.1a page 35 and 4.1b page 36). The pH of the water samples analysed in this study remained within acceptable limits as compared to water quality standards.

According to Tiwari (2015), turbidity is determined by the organic and or inorganic constituents whereas Mathetsa (2015) reported that turbidity indicates a lack of sufficient light that can influence the survival of aquatic organisms such as fish and plants. The turbidity levels obtained in borehole 03 varied between 190 NTU, 183 NTU, 291 NTU, and 110 NTU on 12, 26 August 2016, and 18 November 2016 in borehole 03 as compared to the levels measured in borehole 01 and 02 Figure 4.2 (page 37). The lowest turbidity levels varied between 8.9 and 22 NTU in borehole 02 on 18 and 25 August 2016. This is a cause of concern when the turbidity levels are above 5 NTU, it reduces the efficiency of chlorine in the water. The turbidity levels were above the acceptable limits as compared to SANS 241: 2015 water quality standards and World Health Organisation (WHO) (2017) acceptable level limits were not specified.

The electrical conductivity (EC) represents water's ability to conduct electricity due to the presence of dissolved ions. EC parameter measured in micro siemens per meter (mS/m). According to DWAF (1996a), a high level of electrical conductivity in the water is caused by pollution sources such as industrial discharges, mining, and agriculture activities.

The electrical conductivity concentrations were recorded as 60 mS/m in borehole 01 and 103 mS/m in borehole 02. The highest level obtained in borehole 02 was 144 mS/m on 03 November 2016, and 127 mS/m on 18 November 2016. The concentration level of 117 mS/m was recorded on 25 August 2016. The EC concentration level on sampled boreholes is not a concern since the results were below the acceptable limits as compared to WHO (2017) and SANS 241: 2015 water quality standards Figure 4.3 (page 38).

The colour concentration levels varied between 14 mg/l from borehole 01 on 12 August 2016 and 7.0 mg/l from boreholes 02 and 03. The concentration level of 5.0 mg/l was obtained on 12 August 2016 in borehole 03. The colour of the water is more vital for most water users and the colour is preferred to be colourless. During the sampling period, colour concentrations level is not of concern as it is below acceptable limits as compared to SANS 241: 2015 water quality standards. The WHO (2017) acceptable limits for colour parameters were not specified.

During the extended study, borehole 02, as shown in Figure 4.5 (page 40), the total hardness concentration level varied between 131 mg/l and 517 mg/l. The lowest levels obtained an average of 131 mg/l and 179 mg/l concentrations. The total hardness parameter acceptable limits levels were not specified in WHO (2017) water quality standards. The total hardness concentration levels were above the SANS 241: 2015 water quality standards limit.Oyiboka, (2014) emphasised the water is classified on the basis of hardness into soft (0-75 mg/l) moderately hard (75150 mg/l) and hard (151-300 mg/l).The presence of high calcium and magnesium in the water can reacts with soap to form scum.

5.2 Microbiological Parameters

Mathetsa, (2015) highlighted that the microorganisms such as bacteria, viruses, and protozoa can be found in the water and the consumption of polluted water with microorganisms could lead to diseases such as gastro intestines, cholera, typhoid, and salmonella. Figure 4.6 illustrates the *E. coli* results undertaken during the pilot and extended studies. The *E. coli* concentration levels were not specified under SANS 241: 2015 and WHO (2017) water quality standards.

The high levels were measured in borehole 02(6000), borehole 01 (4200), and borehole 03 (4000). The lowest levels were in borehole 1, as compared to other boreholes. The highest counts of bacteria observed in borehole 01 may originate from the agricultural activities undertaken nearby the landfill site.

Total coliform counts were determined at all the sampling sites during the pilot and extended study. The counts were higher than the acceptable limits of SANS 241: 2015 and WHO (2017) water quality standards Figure 4.7 (page 42).

The total coliforms consist of a diverse group of bacteria from the genera *Escherichia coli, Citrobacter, Enterobacter, Klebsiella, Serratia, and Rahnella* DWAF (1996*).* The total coliform is used to assess the general hygiene of the water quality and evaluation of the efficiency of the drinking water treatment process DWAF (1996).

Heterotrophic Plate Counts (HPC) represent the general microbial quality of the water (DWAF, 1996a). This is, however, to assess the general bacterial content in the water but does not necessarily represent the total bacterial population in the water DWAF (1996).

During sampling, the HPC was determined in all the sampling sites during extended studies. The HPC was not measured during the pilot study. The concentration level was higher than acceptable limits as compared to SANS 241: 2015 and WHO (2017) levels were not specified in Figure 4.8 (page 43). The high HPC may result in acute gastrointestinal illness.

5.3 Chemical Parameters

The chloride concentration level during the pilot study varied between 45 mg/l in borehole 01 and 101 mg/l in borehole 02. The lower concentration obtained during the extended study was 0.5 mg/l in borehole 01. and the higher concentration was 105 mg/l in borehole 02 (Figure 4.9). According to DWAF (2011), the higher concentration of chloride in water gives water a salty taste. The chloride concentration level for the whole sampling period was within acceptable limits as compared to WHO (2017) and SANS 241 2015 water quality standards.

The lowest concentration level of fluoride was recorded as 0.005 mg/l and the highest level was 0.4 mg/l during the pilot study Figure 4.10 (page 45). The lowest concentration of fluoride in the water may strengthen teeth in mammals while the high concentration increases tooth enamel (DWAF, 1996).

Tshibalo (2017) emphasized that the possible source of fluoride within the study area could be the geological creation of the groundwater. The fluoride concentration level was within acceptable limits as compared to SANS 241: 2015 water quality standards. The acceptable limits for WHO (2017) values were not specified.

The nitrate-nitrogen concentration level obtained during the extended study varied between 0.20 mg/l and 1705 mg/l. The nitrate-nitrogen parameter was not measured during the pilot study. The nitrate-nitrogen parameter concentration level was high as compared to SANS 241: 2015 water quality standards. The WHO (2017) acceptable limits were not specified Figure 4.11 (page 46).

The sulphate concentration level was high as compared to drinking water quality SANS 241: 2015. The acceptable limits for WHO (2017) water quality standards were not specified Figure 4.12 (page 47). Sulphate contains a combination of sulphur and oxygen. According DWAF (1996) indicate that consumption of the excess amount of sulphate in drinking water may result in diarrhoea. Whereas Mahmood et al. (2013) elaborate that excessive amounts of sulphate in the water can cause scale build-up in pipes and a bitter taste to drinking water that could lead to laxative effects in livestock and human beings.

The presence of cadmium in the water poses a serious health impact as it accumulates in the liver and kidney tissues of mammals DWAF (1999). The concentration level of cadmium was 0.02mg/l in boreholes 01, 02, and 03 on 12 and 25 August 2016. Borehole 03 on 18 November 2016. The cadmium concentration levels at the sampled boreholes are not a concern since the acceptable level limits were below as compared to SANS 241: 2015 and WHO (2017) water quality standards Figure 4.13 (page 48).

According to DWAF (1996) indicate that copper is toxic if present in the water even in small quantities, on the other hand, high concentrations can cause gastrointestinal discomfort which can lead to liver, kidney, and red cell damage. The copper lowest concentration level obtained was 0.05 mg/l in boreholes 01 and 02 on 20 August 2015 during the pilot study. The highest copper concentration level was 14 mg/l in borehole 02 on 13 November 2016, 6.8 mg/l in borehole 03 on 18 November 2016, and 0.9 mg/l in borehole 02 on 12 August 2016 during an extended study (Figure 4.14 (page 49). The copper concentration level is within the acceptable limits as compared to SANS 241:2015 and higher concentrations were observed as compared to WHO (2017).

The iron concentration level varied from 0.05 to 297 mg/l (Figure 4.15). The presence of iron in water plays an important role as part of the respiratory enzymes in all organisms and it can also form a basic component of hemoglobin in humans and animals DWAF, (1996). The iron concentration levels are not of concern since the level was within the acceptable limits of SANS 241: 2015. The WHO (2017) water quality standards levels were not specified in Figure 4.15 (page 50).

The lead parameter was not sampled during the pilot study for water quality purposes. The lead concentration levels were constant at 0.11 mg/l during the extended study in boreholes 01, 02, and 03 on 12 August and 25 August 2016 and borehole 03 on 18 November 2016 Figure 4.16 (page 50).According to DWAF (1996) lead in lower concentration may cause neurological impairment in the foetus and young children. The disposal of waste materials such as batteries, paints, and plastic within the landfill site can have an impact on the level of lead in the water. The lead parameter concentration level was within acceptable limits as compared to SANS 241:2015. The WHO (2017) acceptable limits were not specified.

The magnesium concentration levels during the pilot study varied from 38 mg/l to 55 mg/l. During the extended study, the magnesium concentration level varied between 17 mg/l and 83 mg/l Figure 4.17 (page 51). DWAF, (1996) highlighted that magnesium occurs as a mineral such as magnesium carbonate or silicate. The water with excessive magnesium levels is exposed to high temperatures. The high level of magnesium in water may lead to a laxative effect. The magnesium concentration level was a concern since the level was high as compared to SANS 241:2015 and acceptable limits for WHO (2017) water quality standards were not specified.

According to Mathetsa (2015) sodium occurred naturally in the water from geological rock formations. Figure 4.18 (page 52) presents the concentration levels of the sodium recorded as 60 mg/l in borehole 02 on 03 November 2016. Borehole 02 was 59 mg/l on 12 August 2016, 56 mg/l in borehole 02 on 25 August 2016 and 54 mg/l in borehole 02 on 20 August 2016 and 40 mg/l in borehole 02 on 18 November 2016.The sodium concentration level obtained at the sampling boreholes is not of concern since the levels are within acceptable limits as compared to SANS 241: 2015 and WHO (2017) water quality standards.

The highest concentration level of calcium was recorded as 143 mg/l in borehole 02 on 03 and 18 November 2016. On 12 August 2016, 95 mg/l was obtained in borehole 02, 90 mg/l in borehole 02 on 18 August. Borehole 02 recorded 79 mg/l on 20 August and 53 mg/l & 52 mg/l on 12 & 18 August 2016 Figure 4.19 (page 53). The calcium is liable for water hardness, and this could lead to a decrease in the water pipe system lifespan.

The lowest calcium concentration levels were obtained as 26 mg/l on 18 November, and 32 mg/l in borehole 01 on 18 November. Borehole 03 was measured at 45 mg/l, 46 mg/l, and 47 mg/l on 12 and 18 August and 03 November. The calcium concentration level is not of concern since the levels were within the acceptable limits as compared to WHO (2017) and SANS 241: 2015 acceptable limits were not specified.

The levels of manganese concentration level were higher than acceptable limits as compared to the acceptable limits of SANS 241: 2015 and WHO (2017) water quality standards. The concentration level of manganese varied between 1705 mg/l in borehole 03 on 03 November 1687 mg/l in borehole 03 on 25 August 1539 in borehole 03 on 12 August, and 543 in borehole 03 on 18 November Figure 4.20 (page 54). The presence of manganese in the water gives the beverage an unpleasant taste and is also liable for staining plumbing fixtures.

The zinc parameter refers to a metallic element. The presence of zinc in the water arises from the leaching of galvanized plumbing and fittings (DWAF, 1996a). The lowest levels of zinc were obtained in boreholes 01, 02, and 03 at 0.57 mg/l on 12 and 25 August, borehole 01 measured 1.0 mg/l borehole 02 measured 5.0 mg/l and borehole 03 was 0.88 mg/l on the 03 November 2016 Figure 21(page 55). The zinc concentration level was within acceptable limits as compared to SANS 241: 2015 water quality standards. The acceptable limits for WHO (2017) water quality standards limits were not specified.

5.4 Conclusion

The physical data parameters such as pH, turbidity, electrical conductivity,color, and total hardness were measured during the dry season. Most of the levels obtained were lower. The highest level was obtained during the rainy season where the turbidity parameter measured 29l mg/l presented in Figure 4.4 (page 39). Color measured a maximum of 14 mg/l following the rainy season while total hardness was classified as very hard prior rainy season.

The microbiological data parameter such as E *coli*, total coliforms, and HPC were sampled during the dry season and rainy season. During the pilot study, the E *coli* highest level measured was 400 mg/l in Figure 4.8 (page 43) and the total coliform levels obtained between 10 000 during the rainy season and the lowest level measured during the pilot study. The HPC parameter was measured as the highest during the rainy season and lowest during the dry season.

The chemical data parameter such as chloride, fluoride, nitrate nitrogen, sulphate, cadmium, iron, lead, magnesium, sodium, calcium, manganese, and zinc parameters was measured during the dry and rainy seasons. During the pilot, study chloride was measured at high levels during the dry and lowest during the rainy season. Sulphate was measured at the highest level during the rainy season and the lowest during the rainy season in 2016. Magnesium obtained the highest level during the rainy season and the lowest levels were measured during the pilot season. Manganese levels were extremely high during both seasons. The following parameters nitrate nitrogen, cadmium, iron, lead, sodium, calcium, and zinc levels were measured the lowest during both seasons.

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This last chapter of the research study summarises the main research findings to develop conclusions. This research study aimed to assess the groundwater quality within the Onderstepoort landfill site, using selected chemical, physical and microbiological parameters.

In 2015, the city undertook a study to monitor the groundwater at the Onderstepoort landfill site. The results of the pilot study were compared to the current study. The findings of the physical parameter analysis determined that the parameters such as colour and electrical conductivity concentration level are within WHO (2017) and SANS 241:2015 water quality standards. The pH concentration level is within the SANS water quality standard, but a higher concentration was observed as compared to WHO (2017) water quality standard. The pH decreased slightly since the study was undertaken in 2015.

The parameters such as turbidity concentration level were determined as high compared to water quality standards and slightly decreased since the 2015 study. The total hardness, turbidity, and colour parameter's acceptable limits were not specified by the water quality standards.

The microbiological parameters were analysed to discover the level of pollution in the water. The HPC and *E Coli* were not sampled during the pilot study. The findings indicated a high level of total coliforms and *E. Coli* during the extended study, whereas HPC acceptable limits were not specified in both water quality standards. The total coliform parameters extremely increased since 2015. The presence of total coliforms, *E Coli*, and HPC determined groundwater pollution by human faeces Tiwari (2015).

The chemical parameter analysis results indicated the levels of parameters within the acceptable limits, as compared to water quality standards such as chloride, fluoride, cadmium, calcium, lead, sodium, and zinc. The highest level was observed in parameters such as lead, copper, sulphate, nitrate nitrogen, magnesium, and manganese. The City, therefore, needs to continuously monitor the groundwater. The sulphate, copper, and iron parameters are within acceptable limits since 2015 and slightly increased during the current study.

The aim of the research study was achieved as the groundwater quality was sampled to assess the level of pollution at the Onderstepoort landfill site. The chemical, physical and microbiological parameters were taken for analysis at an accredited laboratory at CSIR, Meiring Street in Pretoria, South Africa. The test results were compared to SANS 241 (2015) and WHO (2017) drinking water quality standards.

It is, therefore, confirmed that the results obtained from this study, indicate that there is a pollution of groundwater within the Onderstepoort landfill site. The activities that are undertaken on-site contribute to the pollution of groundwater quality.

6.1.1 Study hypothesis

The following conclusions were made after analysing the results and discussions:
Hypothesis (**H0**) is accepted. The Onderstepoort landfill site water quality levels were above the recommended levels of SANS 241:2015 and WHO (2017) water quality standards.

6.2 Recommendations

To control and manage groundwater vulnerability to pollution through landfill activities, there is a need for appropriate planning, design, and construction of landfill sites. The Onderstepoort landfill site is currently in the process of being closed. A proper closure plan should be developed and continuous monitoring of the groundwater quality within the site should be executed.

According to the permit condition of the Onderstepoort landfill site, groundwater monitoring should continue for a period of 30 years after the decommissioning of the site. According to Aljaradin and Persson, 2015 to minimize groundwater pollution within the landfill site, the municipality must properly design and install a leachate control system.

It is a requirement that the landfill sites be operated within the measures in place, to avoid pollution of groundwater or surface water quality. It is also important to establish a surface drainage system in the landfill site to limit the infiltration of the water through the landfill body. The closure and rehabilitation plan should be developed to ensure proper closure of the site and continuous monitoring of the groundwater should take place to monitor groundwater quality over time, and even after the closure of the landfill site.

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LIST OF APPENDICES

Appendix A: Ethical Clearance

UNISA university of south africa

CAES RESEARCH ETHICS REVIEW COMMITTEE

Date: 10/11/2014

Ref #: **2014/CAES/155**
Name of applicant: **Mr DR Mapholo**
Student #: **45424799**

Dear Mr Mapholo,

Decision: Ethics Approval

Proposal: Environmental geohydrological investigation: Focusing on Townlands landfill site in Rustenburg, South Africa

Supervisor: Mr R Mulaudzi

Qualification: Postgraduate degree

Thank you for the application for research ethics clearance by the CAES Research Ethics Review Committee for the above mentioned research. Final approval is granted for the duration of the project.

Please consider point 4 below for further action.

The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Research Ethics Review Committee on 06 November 2014.

The proposed research may now commence with the proviso that:

1) *The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.*
2) *Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the CAES Research Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.*
3) *The researcher will ensure that the research project adheres to any applicable*

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.

4) *The approval is based on the understanding that the municipality will do the drilling of the boreholes as part of their daily tasks, and that it would have been done irrespective of the researcher's project. The researcher must clarify whether this assumption is correct in a memorandum to the Committee.*

Note:

The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the CAES RERC.

Kind regards,

Signature
CAES RERC Chair: Prof EL Kempen

Signature
CAES Executive Dean: Prof MJ Linington

Please note point 4.

University of South Africa
Preller Street, Muckleneuk Ridge, City of Tshwane
PO Box 392 UNISA 0003 South Africa
Telephone: +27 12 429 3111 Facsimile: +27 12 429 4150
www.unisa.ac.za

Appendix B: City of Tshwane approval letter

CITY OF
TSHWANE
IGNITING EXCELLENCE

Office of the Deputy City Manager
Governance and Support Services

20th Floor Isivuno House | 143 Lillian Ngoyi Street | Pretoria | 0001
PO Box 440 | Pretoria | 0001
Tel: 012 358 6251/4869 | Fax: 086 2148421
Email: FransBos@tshwane.gov.za | www.tshwane.gov.za | www.facebook.com/CityOf Tshwane

My ref:	Research Permission	Tel:	012 358 4559
Contact person:	Pearl Maponya	Email:	PearlMap3@tshwane.gov.za
Section/Unit:	Integrated Research Services	Date	09 November 2016

Re: Ms.Dineo R Mapholo
PO Box 71012
Die Wilgers
0014

Dear Ms. D Mapholo,

RE: Approval to Conduct Research within the City of Tshwane Metropolitan Municipality

I have the pleasure to inform you that your request to conduct research on the topic " ***Environmental geo-hydrological investigation: focusing on City of Tshwane landfill site in Pretoria, South Africa"*** has been reviewed and permission is hereby granted for you to conduct research in the City of Tshwane Metropolitan Municipality.

It is noted that your research is aiming to understand the underlying geo-hydrological surrounding and assess the potential impacts of landfill site on ground water within the vicinity of the landfill site and to ensure compliance with National Water Act. In addition, please be informed that as a researcher you are required to sign the Confidentiality Agreement Form with the City prior to conducting research. Research and Innovation Department will be facilitating the whole process; therefore communication should be directed to this department.

Once you complete your research in the City, you will be requested to present your findings and submit the final report/copy of your dissertation.

Yours faithfully

Frans Boshielo (Mr)
Deputy City Manager
Governance and Support Services

10/11/2016
Date

IT'S MY RESPONSIBILITY TO PAY MY MUNICIPAL ACCOUNT IN FULL, ON TIME

Office of the Deputy City Manager

Appendix C: Language editing letter

THOTHI
WRITING AND EDITING SOLUTIONS

Registration Number:2018/1578658/07

19 Felica Street, Karenpark .0118 *Cel No: 082 -439- 3521*

Certificate

This serves to certify

that:

MAPHOLO DINEO RANGWATO

Has written a Dissertation titled:

Environmental Geo-hydrological Investigation: The case of Onderspoort landfill site,

As a requirement for_____

MASTERS DEGREE

at the

College of Agriculture and Environmental Science (UNISA)

She has requested the editorial services of Thothi Writing and Editing Solutions (Pty) Ltd to edit this document, which has been edited to the standard required by an institution of Higher Learning. The company confirms that the content has not been tampered with and guarantees that the standard of English Language in the document as acceptable.

………………………………

Date:27…/…07…/…2022……

Appendix D: Statistician Letter

Proof of Data Analysis

LEFEZ EDITORIAL SERVICES
Flat 101 Zethushof
620 Park Street
Arcadia
E-mail: statshelp66@gmail.com

Date: 26 July 2022

This is to certify that I have statistically analysed data for the following postgraduate (MSc.) candidate:

Surname and Name: Mapholo Dineo Rangwato

Title*:* ENVIRONMENTAL GEOHYDROLOGICAL INVESTIGATION: FOCUSING ON THE ONDERSTEPOORT LANDFILL SITE, GAUTENG, SOUTH AFRICA.

Dr. S. Sargu
Acting Director
Lefez Edotinial Services

Appendix E: Turn it in Report

Turnitin Originality Report

MSc Environmental Management dissertation by Dr Mapholo

From DES 2022 (DES 2022)

- Processed on 02-Aug-2022 11:01 SAST
- ID: 1878037208
- Word Count: 19067

Similarity Index

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Similarity by Source

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24%

Publications:

13%

Student Papers:

14%

Appendix F: Physical and chemical laboratory results

our future through science

T0007

CSIR: Implementation Unit
P.O.Box 395, Pretoria
Building 10, Room A048
Meiring Naude Road, Brummeria, Pretoria
VAT NO: 4470114283

Tel (+27) 012 841 4145
Fax (+27) 012 841 4653/3691
Email MGovenderKirkpatrick@csir.co.za

Inorganic Laboratory- Pretoria

Certificate Of Analysis

Report NO: I-2016-17859

Sample Description: Composite Borehole

Customer: Dineo Mapholo

Address: No.25 Grenadine1131 Libenas Avenue
Equestria Pretoria

No of Samples: 3

Date Received: 12-Aug-2016

Sample Condition: Room Temperature

Date Completed: 30-Aug-2016

Phone: 0721202678

Contact: Dineo Mapholo (dineomapholo@gmail.com)

Analysis	Unit	Lab No / Sample ID / Method	I-16-142869 Onderstepoort Composite Borehole 114:45	I-16-142870 Onderstepoort Composite Borehole 2 14:49	I-16-142871 Onderstepoort Composite Borehole 3 14:40
Cadmium	µg/L Cd	CMP 33	<0.20	<0.20	<0.20
Calcium	mg/l Ca	CMP 33	53	95	47
Chloride	mg/l Cl	CMP 27 A	52	105	29
Colour	mg/l Pt	CMP 12 A	<5.0	<5.0	<5.0
Copper	µg/L Cu	CMP 33	<0.44	0.71	<0.44
Electrical Conductivity	mS/m [25°C]	CMP 31	64.5	86.0	58.5
Fluoride	mg/l F	CMP 27 A	0.22	0.70	0.20
Iron	µg/L Fe	CMP 33	5.0	2.2	<0.88
Lead	µg/L Pb	CMP 33	<0.11	<0.11	<0.11
Magnesium	mg/l Mg	CMP 33	70	68	72
Manganese	µg/L Mn	CMP 33	182	124	1539
Nitrate Nitrogen	mg/l N	CMP 27 A	0.25	<0.20	<0.20
pH	pH units [25°C]	CMP 31	7.79	7.71	7.75
Sodium	mg/l Na	CMP 33	23	59	17
Sulphate	mg/l SO4	CMP 27 A	7.2	184	29
Total Hardness	mg/l	CMP 4	421	517	414
Turbidity	NTU	CMP 13 A	109	109	190
Zinc as Zn	µg/L Zn	CMP 33	<0.57	<0.57	<0.57

J. Dikobe - Technical Signatory A M Bester - Technical Signatory

Date Printed 30-Aug-2016
Page 1 of 1

CSIR
our future through science

Tel (+27) 012 841 4145
Fax (+27) 012 841 4653/3691
Email MGovenderKirkpatrick@csir.co.za

sanas Testing Laboratory T0007

CSIR: Implementation Unit
P.O.Box 395, Pretoria
Building 10, Room A048
Meiring Naude Road, Brummeria, Pretoria
VAT NO: 4470114283

Inorganic Laboratory- Pretoria

Certificate Of Analysis

Report NO:	I-2016-17936	Sample Description:	Water Sample
Customer:	Dineo Mapholo	No. of Samples	3
Address:	No.25 Grenadine1131 Libenas Avenue	Sample Condition:	Room Temperature
	Equestria Pretoria	Sample Identification:	Water Sample in 1L and 500ml Plastic Bottle
Contact:	Dineo Mapholo		
Phone:	0721202678 Fax:		
Order No:		Date Received: 25-Aug-2016	Date Completed: 13-Sep-2016

Analysis	**Unit**	**DL**	**Uncertainty %**	**Lab No / Sample ID / Specification****	I-16-143571 Onderstepoort Borehole 1 10:15 25/08/16	I-16-143572 Onderstepoort Borehole 2 10:35 25/08/16	I-16-143573 Onderstepoort Borehole 3 10:25 25/08/16
Cadmium(CMP 33)	µg/L Cd	0.2	6.36	<=3	<0.20	<0.20	<0.20
Calcium(CMP 33)	mg/l Ca	0.05	5.47		52	90	45
Chloride(CMP 27 A)	mg/l Cl	0.5	6.88	<=300	51	105	28
Colour(CMP 12 A)	mg/l Pt	5	15.91	<=15	<5.0	<5.0	<5.0
Copper(CMP 33)	µg/L Cu	0.44	4.9	<=2000	<0.44	<0.44	<0.44
Electrical Conductivity *(CMP 31)	mS/m [25°C]	1	4.02	<=170	85.8	117	77.5
Fluoride(CMP 27 A)	mg/l F	0.2	13.15	<=1.5	0.26	0.77	<0.20
Iron(CMP 33)	µg/L Fe	0.88	8.94	<=2000	<0.88	5.2	<0.88
Lead(CMP 33)	µg/L Pb	0.11	12.48	<=10	<0.11	<0.11	<0.11
Magnesium(CMP 33)	mg/l Mg	0.04	7.16		72	64	72
Manganese(CMP 33)	µg/L Mn	0.25	6.23	<=400	202	247	1687
Nitrate Nitrogen(CMP 27 A)	mg/l N	0.2	9.47	<=11	<0.20	0.46	<0.20
pH(CMP 31)	pH units [25°C]	1	0.14	>= 5 to <= 9,7	7.98	7.80	7.29
Sodium(CMP 33)	mg/l Na	0.03	8.29	<=200	24	56	17
Sulphate(CMP 27 A)	mg/l SO4	5	7.96	<=500	8.0	170	22
Total Hardness(CMP 4)	mg/l	0.29			426	488	409
Turbidity(CMP 13 A)	NTU	0.2	4.59	<=5	70	22	183
Zinc as Zn(CMP 33)	µg/L Zn	0.57	11.52	<=5000	<0.57	<0.57	<0.57
Escherichia coli(MMP 8)	count per 100ml		2.1	Not detected	<1	500	<1
HPC(MMP 1)	count per 1ml		1.7	<= 1 000	4350	8550	850
Total Coliforms(MMP 2)	count per 100ml		1	<= 10	<1	500	<1

Remarks: * This is not SANAS accredited and is not included in the SANAS Schedule of accreditation for this laboratory. ** : SANS 241-1:2015 STANDARD # Subcontracted Analysis

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Inorganic Laboratory- Pretoria

Certificate Of Analysis

Report NO:	I-2016-18318	Sample Description:	Ground Water
Customer:	Dineo Mapholo	No. of Samples	3
Address:	No.25 Grenadine1131 Libenas Avenue	Sample Condition:	Room Temperature
	Equestria Pretoria	Sample Identification:	Water Samples in 1L Plastic Bottles
Contact:	Dineo Mapholo		
Phone:	0721202678	Fax:	
Order No:	Paid EFT	Date Received:	03-Nov-2016
		Date Completed:	17-Nov-2016

			Lab No	I-16-146621	I-16-146622	I-16-146623
			Sample ID	Borehole 1 Composite Onderstepoort	Borehole 2 Composite Onderstepoort	Borehole 3 Composite Onderstepoort
Analysis	**Unit**	**DL**	**Specification****			
Cadmium(CMP 33)	µg/L Cd	0.2	<=3	<0.20	<0.20	<0.20
Calcium(CMP 33)	mg/l Ca	0.05		49	143	46
Chloride(CMP 27 A)	mg/l Cl	0.5	<=300	51	147	27
Colour(CMP 12 A)	mg/l Pt	5	<=15	6.0	7.0	5.0
Copper(CMP 33)	µg/L Cu	0.44	<=2000	<0.44	14	<0.44
Electrical Conductivity(CMP 31)	mS/m [25°C]	1	<=170	81.5	144	72.7
Fluoride(CMP 27 A)	mg/l F	0.2	<=1.5	0.26	0.95	0.25
Iron(CMP 33)	µg/L Fe	0.88	<=2000	1.7	40	<0.88
Lead(CMP 33)	µg/L Pb	0.11	<=10	<0.11	<0.11	<0.11
Magnesium(CMP 33)	mg/l Mg	0.04		80	83	79
Manganese(CMP 33)	µg/L Mn	0.25	<=400	289	1.9	1705
Nitrate Nitrogen(CMP 27 A)	mg/l N	0.2	<=11	0.27	1.1	0.32
pH(CMP 31)	pH units [25°C]	1	>= 5 to <= 9,7	7.90	8.18	8.19
Sodium(CMP 33)	mg/l Na	0.03	<=200	26	60	18
Sulphate(CMP 27 A)	mg/l SO4	5	<=500	17	281	12
Total Hardness(CMP 4)	mg/l	0.29		452	699	440
Turbidity(CMP 13 A)	NTU	0.2	<=5	78	142	291
Zinc as Zn(CMP 33)	µg/L Zn	0.57	<=5000	3.0	<0.57	0.66

** : SANS 241-1:2015 STANDARD # Subcontracted Analysis

J. Dikobe - Technical Signatory

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Inorganic Laboratory- Pretoria

Certificate Of Analysis

Report NO:	I-2016-18386	Sample Description:	Ground Water
Customer:	Dineo Mapholo		
Address:	No.25 Grenadine1131 Libenas Avenue	No of Samples	3
	Equestria Pretoria	Date Received:	18-Nov-2016
Phone:	0721202678	Sample Condition:	Room Temperature
Contact:	Dineo Mapholo (dineomapholo@gmail.com)	Date Completed:	29-Nov-2016

Analysis	Unit	Lab No / Sample ID / Method	I-16-147113 Borehole 1 Composite Onderstepoort	I-16-147114 Borehole 2 Composite Onderstepoort	I-16-147115 Borehole 3 Composite Onderstepoort
Cadmium	μg/L Cd	CMP 33	<0.20	<0.20	<0.20
Calcium	mg/l Ca	CMP 33	32	143	26
Chloride	mg/l Cl	CMP 27 A	28	88	28
Colour	mg/l Pt	CMP 12 A	14	7.0	<5.0
Copper	μg/L Cu	CMP 33	4.2	6.8	0.94
Electrical Conductivity	mS/m [25°C]	CMP 31	44.2	127	33.9
Fluoride	mg/l F	CMP 27 A	0.31	0.89	0.25
Iron	μg/L Fe	CMP 33	40	9.7	257
Lead	μg/L Pb	CMP 33	<0.11	<0.11	<0.11
Magnesium	mg/l Mg	CMP 33	24	64	17
Manganese	μg/L Mn	CMP 33	7.7	16	543
Nitrate Nitrogen	mg/l N	CMP 27 A	0.93	0.31	1.1
pH	pH units [25°C]	CMP 31	7.05	7.68	7.61
Sodium	mg/l Na	CMP 33	9.6	40	10.0
Sulphate	mg/l SO4	CMP 27 A	50	197	29
Total Hardness	mg/l	CMP 4	179	621	135
Turbidity	NTU	CMP 13 A	54	8.9	110
Zinc as Zn	μg/L Zn	CMP 33	1.0	5.0	0.88

J. Dikobe - Technical Signatory

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Appendix G: Microbiological laboratory results

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Microbiology Laboratory - Pretoria

Certificate Of Analysis

Report NO: M-2016-02402
Customer: Dineo Mapholo
Address: No.25 Grenadine1131 Libenas Avenue
Equestria Pretoria
Phone: 0721202678 Fax:
Contact: Dineo Mapholo (dineomapholo@gmail.com)
Order No: EFT

Sample Description: Water
No of Samples: 3
Date Received: 04-Aug-2016
Sample Condition: Cold
Date Completed: 10-Aug-16

Analysis	Escherichia coli	HPC	Total Coliforms
Unit	count per 100ml	count per 1ml	count per 100ml
Method	MMP 8	MMP 1	MMP 2
Sample Identification			
M-16-07007 Borehole 1	400	6000	4000
M-16-07008 Borehole 2	<1	2250	2600
M-16-07009 Borehole 3	<1	480	<1

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<1 cfu is defined as Not Detected

Tshidi Setati - Technical Signatory

Prudence Maroga - Technical Signatory

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Certificate Of Analysis

Report NO:	M-2016-02506	Sample Description:	Water		
Customer:	Dineo Mapholo				
Address:	No.25 Grenadine1131 Libenas Avenue	No of Samples	3	Sample Condition:	Cold
	Equestria Pretoria	Date Received:	18-Nov-2016	Date Completed:	22-Nov-16
Phone:	0721202678 Fax:				
Contact:	Dineo Mapholo (dineomapholo@gmail.com)				
Order No:	EFT				

Analysis	Escherichia coli	HPC	Total Coliforms
Unit	count per 100ml	count per 1ml	count per 100ml
Method	MMP 8	MMP 1	MMP 2
Sample Identification			
M-16-07419 Borehole 1	4200	12500	6200
M-16-07420 Borehole 2	258	11100	1700
M-16-07421 Borehole 3	2	19475	4200

<1 cfu is defined as Not Detected

Tshidi Setati - Technical Signatory

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Certificate Of Analysis

Report NO:	M-2016-02482	Sample Description:	Water		
Customer:	Dineo Mapholo				
Address:	No.25 Grenadine1131 Libenas Avenue	No of Samples	3	Sample Condition:	Cold
	Equestria Pretoria	Date Received:	28-Oct-2016	Date Completed:	31-Oct-2016
Phone:	0721202678 Fax:				
Contact:	Dineo Mapholo (dineomapholo@gmail.com)				
Order No:	EFT Payment				

Analysis	Unit	Lab No / Sample ID / Method	M-16-07308 Borehole 1	M-16-07309 Borehole 2	M-16-07310 Borehole 3
Escherichia coli	count per 100ml	MMP 8	<1	10	<1
HPC	count per 1ml	MMP 1	95250	8000	5900
Total Coliforms	count per 100ml	MMP 2	<1	10000	70000

<1 cfu/100ml is defined as Not Detected.

Prudence Maroga - Technical Signatory

Date Printed 31-Oct-2016

Appendix H: Aqua Earth consulting laboratory results

Table 7: Groundwater quality from borehole at Ondersetpoort Site as compared to the SANS standards (August 2015)

Determinand	pH	EC	TDS	Ca	Mg	Na	K	Cl	SO_4	NO_3-N	F	Fe	Mn	NO_2	Cu
Risk	Operational	Aesthetic	Aesthetic	NS	NS	Aesthetic	NS	Aesthetic	Aesthetic	Acute health	Chronic health	Aesthetic	Aesthetic	NS	Chronic Health
Unit		mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
OBH1	8.7	60	350	41	38	16	5.4	45	2.1	1.5	<0.05	<0.05	0.21	<0.5	<0.02
OBH2	8.5	103	690	79	55	54	11	101	164	<0.1	<0.05	<0.05	0.13	<0.5	<0.02
OWCD	8.2	60	320	43	41	19	1.8	37	12	<0.1	<0.05	<0.05	0.32	3.6	<0.02

Standard Limit (SANS 241:2011)	≥5 to ≤ 9.7	≤ 170	≤ 1200	NS	NS	≤ 200	NS	≤ 300	≤ 250	≤ 11	≤ 1.5	≤ 0.3	≤ 0.1	<0.9	≤ 2
NS	Not Specified			mg/l	milligrams per litre					(yellow)	Above SANS 241: 2011 Limits				

Table 8: **Bacteriological Results as compared to SANS 241:2011 (August 2015)**

Site ID	Total Coliforms (cfu/100ml)	Escherichia Coli (E.coli) (cfu/100ml)
OBH1	1200	0
OBH2	0	0
OWCD	1820	3100

SANS 241; 2011		
CLASS I: Recommended Operational Limit	<10	0
ABOVE Recommended Operational Limit	>10	>0