Quality of drinking water sources in the Bloemfontein area of the Mangaung Metropolitan Municipality

By

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Declaration

The experimental work described in this dissertation was conducted at the Central University of Technology, Free State under the supervision of Professor Annabel Fossey.

The results have not been submitted in any other form to another University and except, where the work of the other is acknowledged in text, are the results of my own investigation.

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Mosepeli Ratikane

April, 2013

I certify that the above statement is correct.

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Professor Annabel Fossey

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Abstract

Introduction: Drinking water of poor quality can cause a variety of diseases and may even result in death. The impact of poor drinking water is a course for concern even in South Africa. Therefore, the physical, chemical and microbiological drinking water quality was investigated in the peri-urban area of Bainsvlei and the Woodlands Hills Estate in Bloemfontein, Free State.

Materials and Methods: The water quality was assessed in 20 identified sampling sites for three series with ten weeks apart. These sites use treated municipal and untreated borehole water for drinking. The determinants analysed for were pH, electrical conductivity (EC), turbidity, temperature, Ca, Mg, Na, F, Cl, N, SO_4,N, Free chlorine, Al, As, CN, Fe, Mn, Pb, Hg, total coliforms and *E. coli*. The water samples were collected and analysed on site and in the laboratory. Both the physical and chemical determinants were measured using standard methods whereas the microbiological determinants were measured using the Defined Substrate Technology (DST) method. The measurements were first compared to the SANS 241 (2011) for compliance. The ANOVA tests were used to investigate if any seasonal variations existed in the water quality as well as to compare the levels of the determinants between borehole and municipal water. In the assessment of the overall drinking water quality of different water sampling sites the water quality index (WQI) was used.

Results and Discussions: Significant effects were believed to exist if the p-values of the ANOVA and Scheffe tests were at a significance level of 5% ($p < 0.05$). The study results revealed that of the four physical determinants that were measured turbidity exceeded the standard in many sampling sites in the three series. Of all the chemical determinants, nitrates exceeded the standard. In the same way coliforms exceeded the standard in a number of sampling sites while *E. coli* was found in a few sampling sites in the first series. ANOVA tests revealed

that seasonal variations existed between pH, EC, temperature, cyanide and iron at a significant level of 5% ($p < 0.05$) while the Post-hoc Scheffe test further revealed the series in which the effect existed. Similarly, the ANOVA tests revealed that the levels of the determinants between municipal versus borehole varied in pH, EC, Ca, Mg, Na, F, Cl, N, and SO_4 at a significant level of 5% ($p < 0.05$). The WQI showed that in all the series when combining the good and excellent category season 2 had the highest percentage of 80%, followed by season 3 with 79% and season 1 with 70%. Only borehole sampling sites were found in the poor, very poor and unsuitable categories. Similarly all the highest WQI values were found in borehole sampling sites.

Conclusion: This study revealed that the water quality is of good quality in the Bainsvlei and Woodlands Hills Estate of the Mangaung metropolitan municipality in Bloemfontein, in the Free State, South Africa. The presence of *E. coli,* though found in a few sampling sites and the high levels of turbidity, nitrates and coliforms are of concern to public health.

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Chapter 1

Introduction

1.1 Introduction

Water is an essential, fundamental human need and a basic right for all citizens of our country. Water is needed to grow food, generate power and run industries, but most importantly water is a vital nutrient of the human body and is critical to sustain human life (Kleiner, 1999; Sabo et al., 2013). Water is used for many purposes in a household, including for drinking, the preparation of food, washing of clothing and bathing. Furthermore, water supports the digestion of food, absorption, transportation and use of nutrients and the elimination of toxins and wastes from the body (Kleiner, 1999). For the safe use of water by all living organisms on the planet, the quality of water needs to be acceptable; free of toxins and disease causing organisms (WHO, 2008).

Drinking water quality refers to the suitability of the water for drinking and other domestic purposes. Drinking water quality is defined in terms of physical, chemical and microbiological parameters. In South Africa, the South African National Standards for drinking water (SANS) 241 (2011), which is prescribed by the Water Services Act, No 108 of 1997, dictates the acceptable levels of these parameters. The SANS 241 (2011) specifies the acceptable quality of drinking water determinants at the point of delivery. Physical water quality refers to determinants, such as electrical conductivity, pH and turbidity, which in general are of no direct public health concern but affect the aesthetic characteristics of water (WHO, 2008). Chemical water quality refers to the acceptable levels of dissolved substances in water according to SANS 241 (2011). Microbiological water quality refers to the presence of pathogenic organisms as determined by indicator organisms in drinking water (SANS 241, 2011). Therefore, the

microbiological quality of drinking water is typically determined by monitoring the presence of microbiological organisms, in particular *Escherichia coli* (*E. coli*) and faecal coliform bacteria (DWAF, 1996).

The quality of drinking water may be affected by chemical contaminants. These contaminants reach drinking water supplies from various sources, including municipal and industrial discharges, urban and rural runoff, natural geological formations, drinking water distribution materials and the drinking water treatment process (Koplin, 2004). Consequently, chemical contamination of drinking water may pose health risks to consumers (Abrams, 2001). Health effects include various cancers, adverse reproductive outcomes, cardiovascular disease and neurological disease (Koplin, 2004). Similarly, the quality of water may be affected by salinization, which could be because of excessive clearance of natural, deep-rooted vegetation from catchments, rising saline groundwater, discharge of saline agricultural wastewater and increasing climatic aridity (Rao Prakasa & Puttanna, 2000).

Drinking water of poor microbiological quality can cause a variety of diseases and may even result in death (Ashbolt, 2004). World Health Organization stated that the "infectious diseases caused by pathogens are the most common and widespread health risk associated with drinking water" (Gadgil, 1998). These are waterborne diseases such as diarrhoea, typhoid and dysentery. More than 1.1 billion people in the world lack access to safe drinking water sources, which represents approximately 17% of the global population (WHO & UNICEF, 2006). Two thirds of these people live in Africa. In Sub Saharan Africa, 42% of the population is still using water of poor quality (WHO & UNICEF, 2006). Similarly, 2.4 billion people lack access to basic sanitation. Consequently, approximately 1.8 million people die every year from diarrhoeal diseases (including children); 90% are children under the age of five, mostly in developing countries (WHO, 2004). Of all these diarrhoeal diseases, 88% are caused by unsafe water supply, inadequate sanitation and poor hygiene (WHO, 2004).

In South Africa, a water scarce country, nearly 80% of the population relies upon surface water as the main source of domestic water (Zamxaka et al., 2004). This indicates that many of the people still utilise groundwater for domestic purposes. Rural communities, especially in urban fringe areas, are particularly susceptible to the dangers from polluted water, because such communities often do not have access to treated water (municipal water) and have to rely solely upon groundwater. Groundwater is gaining importance in the supply of water to rural communities in the drier regions of South Africa, mostly because of unreliable and insufficient piped water sources especially during times of drought (WRC, 1993). Data from 1998 showed that in the Free State province of South Africa, 0.12 million people are dependent on groundwater resources (DEAT, 2002).

The Department of Water Affairs introduced in 2008 the Blue Drop incentive-based water quality regulation strategy (DWA, 2011). This regulatory strategy requires that municipal service providers be certified with a Blue Drop if they fulfill certain water quality management requirements, which include compliance with water quality standards, the existence of a water safety plan, process controlling and the credibility of sample results, among others (DWA, 2011). The Mangaung Metropolitan Municipality (MMM) failed to qualify for the 2011 Blue Drop assessment, as the score dropped from 95.0% in 2010 to 84.69 % in 2011 (DWA, 2011). One of the main reasons for this drop in the Blue Drop score can be attributed to the deterioration of water in the distribution network from Welbedacht dam which supplies the urban users in Bloemfontein (DWA, 2011).

This study investigates the quality of drinking water in the Mangaung Metropolitan Municipality (MMM) of the Free State, in particular, the Bainsvlei area and the Woodlands Hills Estate in Bloemfontein. The Bainsvlei area is served by municipal water and groundwater through boreholes. The Woodlands Hills Estate, on the other hand, is served by the municipality. However, the management of the estate has constructed four boreholes which they wish to connect to their water supply in the future (personal communication, C Louw).

The boreholes in the Bainsvlei area are used extensively for agricultural purposes. The potential agricultural pollutants can in turn impact negatively on the quality of the water. In addition, the boreholes serve a number of smallholdings that are engaged in commercial activities, including, chicken abattoirs, sunflower seed oil extraction plant, a rusk baking factory and stores. Furthermore, water quality testing of these boreholes by the MMM is infrequent, mostly because of financial and logistical constraints (personal communication, C Louw). Therefore, it is suspected that many of the boreholes that serve this region are at a risk of being polluted and may pose a risk to consumers residing on the farms and smallholdings.

1.2 Aims and Objectives

The study explores the status of the water quality in the vicinity of Bloemfontein, Free State, particularly in the Bainsvlei and the Woodlands Hills Estate region, with the aim of determining the levels of pre-identified water quality determinants; physical, chemical and microbiological, selected according to SANS 241 (2006). Recommendations will be made if necessary.

To meet this aim the following objectives were developed:

- To identify the drinking water sources in the Bainsvlei area and the Woodlands Hills Estate area and sample the different drinking water sources;
- To analyse the water of the sample sites in terms of physical, chemical and microbiological characteristics as specified by the SANS 241 (2006) level 4; which include levels 1, 2, 3 as well as organoleptic and more chemical determinants.
- To compare the quality assessments of the drinking water with the SANS 241 (2011) specifications; and
- To make recommendations if necessary.

Chapter 2

Literature Review

2.1 Introduction

"The quality, quantity and availability of water are one of the most important environmental, social and political issues around the world" (Dahiya et al., 2007). This is evidenced by goal seven of the Millennium Development Goals. Contaminated water according to World Health Organization (WHO) (2003) endangers the physical, mental and social health for people and is an insult to human dignity (Momba et al., 2006). "Infectious diseases caused by pathogenic bacteria, viruses and protozoa or by parasites are the most common and widespread health risk associated with drinking water" (WHO, 1993). The wide variety of waterborne diseases and their public health impact are important concerns with far-reaching implications (Low, 2001). Approximately 3.4 million people, mostly children, die annually from water related diseases, of which 2.2 million people die from diarrheal diseases (WHO, 2001).

In South Africa, the health impact of poor quality drinking water is well recognised and has resulted in the development of substantial legislation which include the constitution (section 24 of the Bill of Rights, Constitution of the Republic of South Africa (Act No. 108 of 1996), the National Water Act (36 of 1998), the Water Services Act (108 of 1997) and the National Health Act (61 of 2003). This recognition has also culminated in the appointment of one of the largest government departments, Water Affairs to regulate drinking water quality (Wright, 2006).

The quality of natural (raw) water intended for drinking and other uses varies both temporally and spatially. This variation changes substantially in different seasons (Vega et al., 1998). For example, the concentration of

dissolved oxygen in a river may vary as a result of input from runoffs, which may transport different types and concentrations of contaminants such as metals and petroleum products from urban storm water or chemicals from agricultural fields (WRI, 1992; USEPA, 1999a). Water quality may also differ depending on the location, origin and the climate in a particular area (Nash, 1993).

On a global scale, major problems of drinking water pollution are characterized by pathogenic agents, organic pollution, sanitation, nitrate pollution, heavy metals, industrial organics and acid mine drainage (Aydemir et al., 2005). In Africa the major concerns in order of importance are, nitrate pollution, pathogens, organic agents' pollution, salinization and acid mine drainage (Xu & Usher, 2006). In South Africa, over application of sewage sludge, irrigation by wastewater, deforestation and intensive animal husbandry are the major pollution problems (Tredoux, 2000 in Xu & Usher, 2006).

Diseases caused by polluted drinking water pose a health risk to consumers of the water. In South Africa, more than seven million people, which constitute approximately 17% of the population, do not have access to good quality drinking water (Zamxaka et al., 2004). The impact of water-borne diseases in South Africa is substantial. For example, it was estimated that 43,000 people die yearly because of diarrhoeal diseases. Of these deaths, 20% include young children up to the age of five years (Mackintosh & Colvin, 2003), hence the need for interventions to improve the quality of drinking water through a holistic approach and proper management (DWAF, 2005a).

2.2 Drinking water

2.2.1 Introduction

Water results from precipitation in the form of rain, hail, fog or snow. Water covers approximately 70% of the earth, although most of it is saline occurring in the different oceans of the world (Africa Bio, 2002). Although many African countries along the equator receive a great amount of rainfall and possess a dense hydrographic network, the situation is different in other parts of the continent. For instance, South Africa is largely a semi-desert country which is prone to erratic and unpredictable rainfall affecting the reliability and variability of river flow (GCIS, 2004 in Wright, 2006). In South Africa the average annual rainfall amounts to approximately 500 mm, compared with a world average of approximately 860 mm. Apart from this, the average annual potential evaporation is higher than the rainfall in all but a few isolated areas where rainfall exceeds 1 400 mm per year (Africa Bio, 2002).

In many countries in other parts of the continent and including South Africa (Yongsi & Blaise, 2010), access to safe drinking water for domestic use has become a major challenge for contemporary societies with its increased demand (USEPA, 1999b; UNPF, 2007). This demand for clean and safe drinking water has become more acute in the context of growing global population, particularly in developing countries (Cohen, 2006).

2.2.2 Drinking water types

Drinking water is sourced in two major ways. These are; surface water which occurs as wetlands, rivers, streams, dams and lakes, including the solid forms of water, namely, snow and ice (Winter et al., 2002) and groundwater which is water that percolates into the ground and accumulates in both unconsolidated sediments and hard rock formations (aquifers). Most African groundwater occurs in the folded zones of the African platform (Xu & Usher, 2006). The groundwater sources include springs, wells and boreholes (Wright et al., 2004). People living in urban areas mostly have access to surface water, which is treated and supplied by local municipalities. Municipal treated water is distributed through a network of pipes to the consumers (Jagals et al., 1997). However, groundwater is

gaining increasing importance in the supply of water to rural communities such as in the drier regions of South Africa and in Botswana where surface water is very scarce (Adams et al., 2001).

2.2.3 Urban and rural drinking water

In developing countries, a large proportion of households are deprived of treated municipal water (Rufener et al., 2010). For instance, in Botswana in 2000, 52.1% of all urban households had access to municipal water in their homes, or were able to access municipal water from public standpipes. In contrast, only 9.1% of rural households had access to municipal water in their homes and had to rely mostly upon surface water and groundwater in the immediate vicinity (Desert, 2007). Globally, the World Health Organization and United Nations Children's Fund (WHO & UNICEF, 2006) announced that access to treated drinking water had risen to 95% in urban areas, while in rural areas access had remained at approximately 73% in developing countries (WHO & UNICEF, 2006). A similar pattern was encountered in South Africa, the latest available data demonstrated that the proportion of the population with access to treated drinking water in urban areas had risen from 81% in 1990 to 99% in 2008 (UNICEF SA, 2008). In rural areas, access to treated drinking water had improved to 78% in 2008 (UNICEF SA, 2008).

2.2.4 Drinking water treatment

The primary goal of public drinking water utilities is to produce and deliver safe drinking water to consumers through appropriate treatment technologies (Charrois & Jeffrey, 2010). Safe drinking water is viewed as water which does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages (WHO, 2008). Safe water is mostly supplied from regulated public

municipal systems, which is usually treated before being supplied to the consumer. The amount and type of treatment applied, as well as the technologies used in drinking water treatment facilities, vary according to the quality of the raw water which depends mostly on whether the water source is surface or ground (DWAF, 2005a). A wide variety of treatment processes are commonly applied to remove contaminants from drinking water (Bellamy et al., 1993; Grabow, 1996), usually in a particular sequence. The most regularly applied order of water treatment processes are; coagulation and flocculation, sedimentation, filtration and disinfection (Schutte, 1995).

Coagulation and flocculation constitute the backbone processes in most advanced water treatment plants. The objective of these two processes is to enhance the separation of particulate species in downstream processes such as sedimentation and filtration (Amirtharajah & O'Melia, 1999; USEPA, 1999c). In coagulation and flocculation, colloidal particles and other finely divided matter are brought together and agglomerated to form larger sized particles that can subsequently be removed in a more efficient manner (Sawyer et al., 1994). Alum and iron salts or synthetic organic polymers, used alone or in combination with metal salts, are generally used to promote coagulation. In the earlier days, coagulation was used to remove turbidity (cloudiness) from potable water. However, more recently, coagulation has been shown to be an effective process for the removal of a wide variety of contaminants, such as metals, toxic organic matter, viruses, and radionuclides that can be adsorbed by colloids (Shammas, 2002). These coagulated particles tend to settle or sediment to the bottom during sedimentation.

Settling or sedimentation is a natural process whereby the combined weight of the dirt and the alum (floc) become heavy enough to sink to the bottom of the sedimentation tank. These heavy particles settle to the bottom as the clear water moves to filtration (Shammas, 2002).

Filtration is a process of passing water through a medium such as sand to remove turbidity. Sand filters can either be of rapid or slow type. Both types are effective in reducing turbidity of the water which interferes with the effectiveness of disinfection (Letterman & Cullen, 1985). However only slow sand filters reduce bacterial and viral contamination, as well as larger biological contaminants such as *Cryptosporidium, Giardia*, amoebae and parasite eggs (USEPA, 1991).

Drinking water is disinfected to remove, deactivate or kill pathogenic microorganisms, which is one of the main objectives for the protection of public health (Galal-Gorchev, 1996). The destruction of microbial pathogens is essential and commonly involves the use of reactive chemical agents such as chlorine (WHO, 2008). Chlorine in its various forms, chlorine, chloramine or chlorine dioxide, is the most commonly used disinfectant worldwide, whereas in developing countries, the use of chlorine is often the only affordable means of disinfecting drinking water. Chlorine treatment is effective in killing most pathogens including bacteria, viruses and protozoa which cause diseases such as typhoid fever, dysentery and cholera (Gadgil, 1998). However some viral waterborne outbreaks have been reported because of consumption of contaminated water that met bacteriological standards. For example, an outbreak of infectious hepatitis occurred among a military community (Bosch, 1998). During surveillance rotaviruses and enteroviruses were detected in water samples that were consistently free of indicator bacteria while levels of free chlorine were found to meet the standard and had eliminated bacteria but were unable to remove pathogenic viruses from the same water (Hebert et al., 1985). When added to the water chlorine rapidly hydrolyses, yielding hypochlorous acid (HOCl), a weak acid which dissociates partially into hypochlorite ion (OCl-) and hydrochloric acid (HCl). Hypochlorous acid is a considerably more efficient disinfectant than hypochlorite ion (Morris, 1982).

The major advantage of treating water with chlorine is its ability to leave a residual disinfection concentration in the drinking water supply. This residual or free chlorine is the available chlorine left in the water after a specified contact period, which can further disinfect any newly introduced biological contamination (Gadgil, 1998). However, it is less effective against oocysts of the waterborne protozoan *Cryptosporidium parvum* and *Giardia lamblia* (Clark et al., 1993).

The disinfection of drinking water using chlorine has saved many lives through the destruction of microbiological pathogens which are responsible for waterborne diseases. The introduction of this process resulted in the dramatic decline of typhoid and cholera cases in Europe and North America in the early 1900s (Galal-Gorchev, 1996). However, the use of chemical disinfectants, including chlorine, in water treatment usually results in the formation of chemical by-products, some of which are potentially hazardous (Hebert et al., 1985). Various studies have shown that these by-products may be carcinogenic for humans (Legay et al., 2011). However, the risks to health from these by-products are extremely small in comparison with the risks associated with inadequate disinfection. Therefore, it is important that disinfection should not be compromised when attempting to control such by-products (WHO, 1993).

2.2.5 Household water treatment (HWT) technologies

In situations where drinking water supply is not microbially safe, HWT technologies have the potential to have rapid and positive health impacts (WHO, 2008). HWT technologies are also effective where stored water becomes contaminated because of unhygienic handling during transportation or in the home (Nala et al., 2003). There are a number of these methods which always have to be used in combination with safe storage of the treated water to minimize contamination after treatment (Wright et al., 2004 in WHO, 2008). The use of these HWT technologies

differs from country to country and depends highly on economic status of individuals (Sobsey et al., 2008). Technologies that are available include bringing water to a full rolling boil for one minute to kill most microbes (Sattler & Lipscomb, 2003), use of household bleach or high-test hypochlorite (HTH) granules and exposure to sunlight, which are all used in South Africa (DWAF, 2005a). However, not all HWT technologies are highly effective in reducing all classes of waterborne pathogens such as bacteria, viruses and protozoa. For example, some filtration methods, such as ceramic filters, are ineffective in removing enteric viruses. Hence priority must be given to the targeted pathogens in a particular water source when choosing a HWT technology to be used (WHO, 2008)

In the Bolivian village Aymara, where the Indian community was at risk of cholera, a narrow-mouthed, plastic, water storage vessel used with 5% calcium hypochlorite solution for home disinfection of stored water was introduced. Through the use of this vessel and chlorine solution, poor quality drinking water from non potable sources eventually met World Health Organization standards for microbiological quality (Quick et al., 1996). Currently in Nepal, the most commonly treatment system involves the use of a ceramic candle filter. Communities filter their drinking water using a ceramic candle filter before drinking (Sagara, 2000). However, the candle filter displays inadequate water flow rates and is ineffective in the removal of microorganisms from the raw water (Howard, 2003). Therefore, such a filter system is used in combination with a disinfection process such as boiling, to ensure that the water is sufficiently treated before it is consumed (Low, 2001). In countries such as the Philippines, Guatemala, Uganda, Chad, Botswana and Zimbabwe a powder containing ferric sulfate and calcium hypochlorite is used in households to render the water safe for drinking. However, all these technologies must be promoted and used following stringent precautions to avoid poisoning through over dosage of the chemicals involved (Elimelech, 2005).

2.3 Drinking water pollution

2.3.1 Introduction

Water pollution refers to changing of the physical, chemical and biological properties of water from a beneficial state to one that is dangerous to organisms relying upon water for their wellbeing (Baumgartner, 1996). Water pollution comes in many forms and from a wide range of sources (Nogueira et al., 2003). Water pollution is influenced by factors such as environmental, physical and anthropogenic which affect or alter the water quality parameters (Aydemir et al., 2005). Physical factors that may have an influence on water quality include: geology and soils while environmental factors comprise climate (temperature and rainfall), vegetation and runoff (Wright, 2006). Anthropogenic factors include agricultural activities which may contaminate water from feedlots, pastures and croplands. Mining of different commodities such as gold, pollute water as well as industries such as pharmaceutical factories. Human settlements play a major role in water pollution through various forms such as sanitary and storm sewers (Yadav et al., 2002; Davies & Mazumder, 2003). However, not all water sources are polluted by similar pollution activities. For instance, in the USA, pollution of surface water is mostly by agricultural activities. Groundwater on the other hand is contaminated by agricultural activities, drinking water storage tank leaks, sewer and septic leakage, leaching from landfills, mining, industrial waste, and many other activities (USEPA, 1999b).

2.3.2 Physical factors

Geology

The availability and quality of water, especially of groundwater, depends primarily on the geology of the environment where the water occurs (MacDonald & Davies, 2001). Groundwater is stored within pore spaces and fractures in rocks and where the pores or fractures are interconnected, the rocks are viewed as being permeable allowing the easy flow of groundwater (MacDonald & Davies, 2001). However, changes in the water quality may arise from the chemical composition of groundwater when trace constituents make up approximately 1% of the solute content (Edmunds & Smedley, 1996). For example, in the crystalline basement of Sub Saharan Africa (SSA), which covers 40% of the landmass and supports 220 million rural inhabitants, groundwater is generally of good quality with occasional elevated sulfate, iron or manganese (Chilton & Foster, 1995). In volcanic rocks, which cover only 6% of the landmass of the SSA, but underlie drought prone and poverty stricken areas in East Africa of 45 million rural people, groundwater quality may be poor because of elevated fluoride concentrations. Similarly, consolidated sedimentary rocks cover 32% of the landmass of SSA with 110 million rural people living on the rocks. The groundwater quality on these rocks is generally good, but saline at depth, or may have localised elevated sulfate, iron or manganese (Foster et al., 2000).

Soils

Soils are heterogeneous mixtures of air, water, inorganic and organic solids and microorganisms (Sparks, 2003). Chemical reactions between soil solids and soil solutions influence both plant growth and water quality (Vasanthavigar et al., 2010). There are a number of reactions which take place in the soil. These reactions include precipitation, polymerization, oxidation-reduction and adsorption and they affect the solubility, mobility, speciation (form), toxicity and bioavailability of contaminants in soils, surface and groundwater (Hassert, 1992). For example, soil adsorption, which is known as the tendency of materials to attach to soil particle surfaces, determines

movement of substances such as pesticides into the water system unless soil erosion occurs (O'Day, 1999). This adsorption is measured by Koc (the octonal water partition coefficient) (Hassert, 1992). Koc values that are greater than 1000 indicate strongly attached substances which are not likely to move while values less than 500 indicate those that move easily into the water systems (Vasanthavigar et al., 2010). Substances with values in between these two may rely on other influences such as runoff to determine whether they move or not (Aydemir et al., 2005). Similarly, the variability of the soil which is highly characterized by soil's texture, structure, moisture and organic matter content may influence movement of attached substances by leaching and runoff (Zalidis et al., 2002). Consequently, as water seeps through the soil it carries with it polluting substances applied to the land, such as fertilizers and pesticides. This polluted water moves through water bearing formations known as acquifers and eventually surfaces, discharging the pollutants into streams and rivers (Sparks, 2003).

2.3.3 Environmental factors

Climate

Changes in the climate (precipitation and temperature) may have a substantial effect on the quality of both surface and groundwater. For instance, heavy rainfall may lead to changes in the direction of flow of water systems and flow through channels that would normally not occur (Murdoch et al., 2001). These new channels may flood grazing fields causing sewage and agricultural chemicals to enter surface waters such as rivers, borehole heads and dams. For example, during October of 1992 a large outbreak of bloody diarrhoea affected thousands of individuals in South Africa and Swaziland resulting in fatalities (Hunter, 2003). In some areas men were mostly affected because men drank surface water in the fields while women and children drank borehole water at home. The source of the illness upon investigations was found to be Enterohaemorrhagic *Escherichia coli* (EHEC) O

157:H7 which was isolated from water samples and cattle dung that was washed into surface water by heavy rains after a period of drought (Hunter, 2003). Heavy rainfall events are often followed by coliform re-growth in water distribution systems, presumably because of increased nutrients in water (LeChevallier et al., 1991). Temperature increases tend to stimulate blooms of planktonic species such as the toxin producing Cyanobacteria (Blue–green algae) (Hunter, 1998). Exposure to these toxins through the consumption or through contact with toxin containing water or blooms during bathing has been implicated in causing various clinical symptoms such as dermatitis, respiratory problems and hepatitis (Hunter, 1998; Codd, 2000). In cases where rainfall decreases, wetlands tend to disappear and water tables decline, thereby threatening water security, which may give rise to water washed diseases such as scabies and trachoma (Abrams, 2001).

Seasonal variations also have a strong effect on flow rates and hence on the concentration of pollutants in water sources (Vega et al., 1998). In the warmer seasons the effects of acid precipitation is exacerbated in poorly buffered lakes and streams. Warm climates also decrease dissolved organic carbon, which causes increased penetration of ultraviolet radiation in fresh waters (Schindler, 2001). During the colder and dry seasons the physico-chemical properties such as pH, TDS and dissolved oxygen (DO) as well as trace metals of water decrease far below the WHO standards (Agbaire & Oyibo, 2009).

Vegetation

The presence of vegetation in a particular area may affect the quality of water (Wright, 2006). Contamination of drinking water may result in several ways including fertilization of crops such as tobacco, vegetables and flowers (Rao Prakasa & Puttanna, 2000). Nitrogen fertilizers are usually applied in higher doses than what plants can take up, leaving a residue in the soil. These superfluous nitrogen nutrients in the soil subsequently enter the water

resources through irrigation and runoff from rainfall (Logsdon, 1985). Another form of contamination may be caused by deforestation. When trees are removed from a site leaving the soil surface disturbed, this may lead to soil erosion (detachment and movement of soil particles) affecting nearby water resources (Dissmeyer, 2000).

Runoff

Runoff is water from rain, irrigation, or any other water released onto the surface and flows downhill until it meets with a barrier, a body of water, or begins to percolate into the soil (Aydemir et al., 2005). Runoff is the prime vehicle for pollutant delivery, where contaminants from agricultural, industrial and residential areas are conveyed to storm water drains and water bodies (Wright, 2006). The volume of runoff is governed primarily by infiltration characteristics and slope of the land, the soil type, as well as the type of vegetative cover (Leopold, 1968). Mountainous regions, areas with steep gradients or areas with poor vegetative cover are also more susceptible to increased runoff (Wright, 2006). Runoff movement is highly mobilized by the erosion of soil and sediment which transport considerable amounts of nutrients such as organic nitrogen, phosphorus and pesticides to rivers and streams (Sparks, 1994).

2.3.4 Anthropogenic factors

Agricultural activities

Agricultural activities may contribute to drinking water pollution through a number of activities. These activities include intensive animal husbandry (feedlots), land grazing, dry land cultivation, on-site sanitation and diffuse agricultural activities. Through these activities, over 140 million tons of fertilizers and several million tons of

pesticides are applied each year (Tredoux et al., 2000; Schricks et al., 2010). Contaminants from these activities enter the water sources through leaching and runoff of chemicals. Similarly the number of microorganisms is increased in drinking water (Elhatip, 2003; Xu & Usher, 2006). A study on organophosphate pesticide (OPP) residues in drinking water from Artesian wells and health risk assessment of agricultural communities was conducted in Thailand by Jaipieam et al., in 2009. The study suggested that people in agricultural communities may be exposed to substantial levels of pesticides when compared to non-agricultural communities (Jaipieam et al., 2009). Data were collected from these wells during both wet and dry seasons. The average OPP concentrations in the agricultural communities were 0.085 and 0.418 μg/L for the dry and wet seasons respectively, which were substantially higher than 0.004 μg/L for both seasons in the non-agricultural communities. Thus, the ingestion of OPPs in contaminated water in the agricultural communities were estimated to be 0.187 and 0.919 μg/L per day during the dry and wet seasons, respectively, and 0.008 μg/L per day during both seasons in the non-agricultural communities.

Another study in Hertzogville in the Free State, South Africa, also revealed increased levels of nitrates in groundwater caused by wheat farming activities (Xu & Usher, 2006). The nitrate levels in water were between 17 to 22 mg/L, exceeding the SANS 241, (2011) standard of 11 mg/L. The highest concentration was in the immediate vicinity of the agricultural area and lowest in the town borehole, which was some distant from the farming activity. The fertilizer contribution to the nitrate pollution was found to be low, while tilling of the soil played a major role in mobilizing leaching of natural nitrates from the soil to the subsurface.

Studies in the Hex river and Elands Bay areas of South Africa, also confirmed groundwater pollution by nitrates from agricultural activities (Xu & Usher, 2006). Schoeman & Steyn (2003) found in a study of borehole water in the

rural areas of South Africa in 2003 that many boreholes were unfit for human consumption. In these boreholes it was found that the nitrate-nitrogen levels were greater than 6 mg/L and salinity exceeded l000 mg/L TDS.

Industrial and mining activities

Industrial effluent causes pollution through leaching of chemicals into groundwater while surface water is contaminated by effluent discharges with incompletely removed organic contaminants (Snyder et al., 2001; Koplin et al., 2004). These chemicals, which include mercury (Hg) cadmium (Cd) and arsenic (As) are mostly a byproduct of industrial activities, are introduced through indiscriminate solid waste dumps and wastewater (Nickson et al., 2005). Consequently the chemicals may be consumed with water, or taken up by plants and aquatic organisms (Zhe et al., 1991). When taken up by aquatic organisms, the chemicals are passed through the food chain, known as bioaccumulation, and continue to accumulate until lethal levels are reached (Aydemir et al., 2005).

Pollution of groundwater by mining is caused mostly by abandoned mining waste (Naicker et al., 2003). These wastes, known as tailings, often contain elevated heavy metals. The tailings are abandoned in pits or as heaps. During heavy rains leaching is enhanced, resulting in contamination and acidification of groundwater by pyrite (FeS_2) containing waste (Schreck 1997). Similarly salt mining gives rise to an increased load of chloride in water by the natural leaching of salt rock and the discharge of waste brines (Theile 1996 in Schreck 1997). Salinization of the groundwater becomes a problem where these rocks surrounding aquifers are used for drinking water abstraction.

In South Africa, Johannesburg, consultants, Steffan, Robertson and Kirsten Inc. were contracted by the Water Research Commission in the early 1980s to investigate the contribution of mine tailings to the steadily rising

dissolved solid load in the principal water supply to Johannesburg, the Vaal River (Naicker et al., 2003). The river's catchment includes the gold mining districts (Naicker et al., 2003). The consultants revealed and concluded that the dumps were indeed a source of a serious pollution, especially the older sand dumps. Although the cause of pollution was found to be erosion of dump material into water courses, the consultants also found and concluded that the major contribution came from rain water which had percolated through the dumps, creating polluted groundwater beneath the dumps, which was emerging as surface water in streams (Winter et al., 2002). The surface water was highly acidic as a result of oxidation of pyrite (FeS_2), had a high metal content and was low in pH (Naicker et al., 2003).

Human settlements

As populations grow and demands for water and other services expand, pollution levels will also rise, causing a reduction in the availability of safe water for human consumption (Abrams, 2001). The disposal of excreta using land-based systems is a key issue for groundwater quality and public health protection, mostly in rural areas (WHO, 1996). Similarly, in peri-urban areas the use of inappropriate water supply and sanitation technologies leads to severe and long-term public health risks. The use of poorly constructed sewage treatment works and land application of sewage close to drinking water supplies in urban areas can lead to groundwater contamination (Pedley & Howard, 1997). In urban areas overloading of the water and sanitation infrastructure is a major challenge as it causes rapid deterioration of urban living conditions. The situation is worsened by informal settlements which erupt because of urban influx (Nash, 1993). In areas of informal settlements, treated water might be scarce hence the use of other unsafe sources (Pedley & Howard, 1997). In an informal settlement in Zimbabwe, treated water was not available and residents had to depend on groundwater for their domestic needs (Chidavaenzi et al., 2000). Zimbabwean informal settlements are characterized by poor drainage, minimal solid

waste management, poor housing and overcrowding (Makoni, 2001). Residents are compelled to use on-site sanitation systems, particularly pit latrines and ventilated improved pit latrines. These unsewered disposal systems caused severe groundwater contamination by pathogenic microorganisms and other contaminants. Consequently, residents were prone to diseases (Zingoni et al., 2005).

2.4 Effects of water pollution

2.4.1 Introduction

The United Nations declared 1981 to 1990, as "The International Drinking Water and Sanitation Decade", (UN Resolution 35/18, November 10, 1980), with the goal of full access to water supply and sanitation to all people. Despite the efforts made, the countries of the world are still faced with the reality of having 1.1 billion people who lack access to safe water, 2.4 billion that are without adequate sanitation resulting in 2 to 4 million deaths a year all attributable to unsafe water (Gleik 2002). The failure to provide safe drinking water and adequate sanitation services to all people is perhaps the greatest development failure of the 20th century. The most serious consequence of this failure is the high rate of mortality among young children from preventable water-related diseases (Pedley & Howard, 1997 in Hunter, 2003). Waterborne diseases and sanitation-related infections are one of the major contributors to disease burden and mortality which are felt by the poorest societies and children under the age of five (Pru¨ss & Havelaar, 2001). WHO estimated in the 2000 assessment that there are four billion cases of diarrhoea each year in addition to millions of other cases of illness associated with the lack of access to clean water (Gleik, 2002). Diseases caused include typhoid and dysentery. In South Africa, it has been estimated that 9.7 million (20%) of the people do not have access to an adequate water supply and 16 million (33%) lack proper sanitation services (Info, 2006). Among the top twenty causes of death in children under the age of five in South

Africa, diarrhoea was ranked at number three (WRC, 2000) at 10 786 deaths (10.2%), thus demonstrating the high impact of waterborne diseases. There are a number of effects of polluted water namely health, agricultural as well as environmental (Changhua et al., 1998).

2.4.2 Health effects

Disease causing microorganisms in drinking water are predominantly of faecal origin (Ashbolt, 2004). Waterborne diseases are typically caused by enteric pathogens which are mainly excreted in faeces by infected individuals and ingested by others in the form of faecally contaminated water or food. These pathogenic organisms include many types of bacteria, viruses, protozoa and helminths, which differ widely in size classification, structure and composition. Pathogenic organisms are highly infectious and disease-causing (Low, 2001). For example, in France a large waterborne outbreak of infection that occurred during August 2000 in a local community was investigated (Gallay et al., 2006). Those who had drunk tap water had a threefold increased risk for illness (95% CI 2.4–4.0). Investigations revealed that a groundwater source to this community had probably been contaminated by agricultural runoff and specifically a *Campylobacter coli*, group A rotavirus and norovirus were detected and a failure in the chlorination system was identified (Gallay et al., 2006). Chemicals such as nitrates and nitrites in water and food may cause methemoglobinaemia in babies, while arsenic is toxic and may be carcinogenic even in small amounts resulting in skin lesions, hyper-keratosis, skin cancer and liver disease. In Bangladesh alone the risk of arsenic poisoning is increasing. The number of patients seriously affected by arsenic in drinking water has now risen to 7000 (Karim, 2000).

2.4.3 Environmental effects

Apart from being unaesthetically looking, polluted water may also affect the environment during its treatment and distribution in Municipal Drinking Water Distribution Systems (MDWDSs). MDWDSs consume a significant quantity of energy to transport water (Arora & LeChevallier, 1998). In the US where MDWDSs supply more than 85% of the drinking water (Vickers, 2001), the electric cost necessary for water processing and distribution in municipal water systems was found to account for up to 80% of the total cost (EPRI 2002 in Santosh et al., 2010). This energy consumption poses a challenge to the world's environmental health by exacerbating green house gas emissions and global climate change, a challenge not only in the US (Levin et al., 2002) but to all countries of the world. Thus, the reduction of energy use associated with MDWDSs is globally critical to achieving the United Nations' Millennium Development Goal (MDG) of environmental sustainability (MDG 2000). A sensitivity analysis of seven diverse municipal water distribution systems was performed by Santosh et al., (2010). The three system-properties analysed were system-wide water demand, storage tank parameters (tank maximum water level, tank diameter, and tank elevation), and pumping station (pump horsepower and boosters and their location). The findings of the analysis revealed that a 50% reduction in water demand, main pump horsepower, and booster horsepower resulted in an average energy savings of 47, 41, and 9.5% respectively, for the seven systems analysed while other properties examined showed insignificant savings (Santosh et al., 2010).

2.4.5 Agricultural effects

Agricultural production may be affected by polluted water whereby nitrate in water is capable of inducing methemoglobinaemia in a wide range of species such as cattle, sheep, swine, dogs, guinea pigs, rats, chickens and turkeys (Fewtrell, 2004). The various effects of nitrate on different animals such as intestinal disorders in pigs, pregnancy-related disorders in rats, depression, muscle tremors and in coordination in goats, loss of body weight and reduced water consumption in broiler chicken, sexual disorders in sheep and hyperthyroid in foals have been

reported (Haman & Bottcher, 1986). In 1985, the collapse of the tailing dam in Chenzhou lead/zinc mine (Hunan, southern China) led to the spread of mining waste spills on the farmland along the Dong River where precautions such as soil cleaning were taken in some places. Seventeen years later, cereal (rice, maize, and sorghum), pulses (soybean, Adzuki bean, mung bean and peanut), vegetables and the rooted soils were sampled and found to be contaminated with metals such as lead and cadmium. Generally the edible leaves or stems of crops were more heavily contaminated than seeds or fruits. The bioaccumulation factors (BAFs) of crops were in the order: cadmium, zinc, copper, lead and arsenic. BAF was typically lower in the edible seeds or fruits than in stems and leaves. Thus crop farming was affected and consequently food security was threatened (Liua et al., 2004). All these effects of polluted water discussed above have direct bearing on overall health as defined by WHO (2003) such as food security, lost work days, missed educational opportunities, health care costs, as well as the draining of family resources (Gleik, 2002).

2.5 Drinking water quality

2.5.1 Introduction

In South Africa, drinking water quality is described as water with acceptable physical, chemical, and microbiological properties. Many of these properties are represented by constituents that are either dissolved or suspended in the water (DWAF, 1996).

The physical quality of drinking water is influenced by aesthetic properties, namely, taste, odour, and the colour or cloudiness of water (DWAF, 2005b). These properties do not have a direct public health risk but usually indicate potential problems such as the presence of dissolved organic carbon (DOC) which shows the organic material

content in the water (WHO, 2008). This DOC may pass through the water treatment process to the disinfection stage. If DOC combines with chlorine, trihalomethanes (THMs) may be formed. Some THMs such as chloroform have been implicated as a cause for cancer (DWAF, 1996). To determine the physical quality of drinking water aesthetic determinants that should be frequently tested for include; pH, turbidity, dissolved solids and electrical conductivity (SANS, 2011).

Chemical quality of drinking water is influenced by the nature and concentrations of dissolved substances such as salts, metals and organic compounds, many of which may be detrimental to health in high concentrations (Aydemir et al., 2005). The SANS 241 (2011) specifies acceptable daily intake levels of a range of chemicals which have been listed in three categories as macro, micro and organic determinants. The effects of these chemical determinants may be either aesthetic, operational and or health (Zhe et al., 1991; SANS 241, 2011). Aesthetic chemicals are chloride and manganese while those that are operational include ammonia and calcium. Chemicals that may pose a health risk include arsenic (As), nitrate (N) and fluoride (F). These chemicals may cause diseases such as cancer, methemoglobinaemia and mottling of teeth respectively (DWAF, 1996; WHO, 2008), if the limits specified by SANS 241 (2011) are exceeded.

Microbiological quality is influenced by the presence of disease causing organisms (pathogens) in drinking water. These pathogens, which are predominantly of faecal origin (enteric pathogens), include bacteria, viruses and protozoa, which cause a variety of waterborne diseases, for example, gastroenteritis, infectious hepatitis and dysentery (Ashbolt, 2004), most of which present diarrhoea as the main symptom of infection (WRC, 2000). Diarrhoeal diseases remain one of the leading causes of illness and death in the developing world (Abrams, 2001). Hence, the magnitude of the morbidity and mortality from waterborne diarrhoeal diseases, conclusively remain the major environmental health hazard to humans globally (Gadgil, 1998). Therefore, it is important to

monitor drinking water quality on a regular basis. SANS 241 (2011) recommends the use of the microbiological indicators, *E. coli* and total coliforms (rod shaped, gram-negative, non-spore forming, lactose fermenting bacteria), to indicate the presence of faecal pollution in domestic water supplies.

2.5.2 Drinking water legislation

The WHO, as the premier and most prestigious international health organization, has developed drinking water quality guidelines with the purpose of protecting public health. However, these guidelines are intended for the use by countries to develop their own standards, regulations and mandatory limits that can readily be implemented. When adapting and adopting WHO guidelines, local or national environmental, social, economic and cultural conditions in a particular country have to be considered. Thus, each country should review its needs and capacities when formulating national regulations and standards (WHO, 2008).

In Europe, a water management tool called EU Drinking Water Directive (98/83/EC) has been developed using the WHO guidelines as the basis. This tool which is being used in all the EU countries sets quality standards for drinking water at the tap looking at microbiological, chemical and organoleptic parameters and the general obligation within the member states that drinking water must be wholesome and clean. The directive requires member states to monitor drinking water quality regularly and to provide consumers with adequate and up-to-date information on their drinking water quality status. The member states may translate the Drinking Water Directive into their own national legislation by either adding new parameters which exists in their locality or increasing the limit of parameters in the existing standard (ECE, 2011).

In the USA, the Safe Drinking Water Act (SDWA) of 1974 is the governing act with a purpose of regulating contaminants in drinking water. This act uses a multiple barrier approach through the use of a water safety plan (Blackburn et al., 2002). In pursuant to the act, the Environmental Protection Agency (EPA) is required to set standards for drinking water quality by the 1996 amendment to the act and oversee that all states, localities and water suppliers implement these standards (USEPA, 1999b). The standards are divided into national primary standard which is legally enforceable with limiting amounts for each contaminant in drinking water. The second division is the national secondary standard which regulates contaminants that may cause cosmetic or aesthetic effects in drinking water. This secondary standard is not federally forceable, although some states have chosen to enforce it (Sattler & Lipscomb, 2003).

In Australia, drinking water quality is governed by the Drinking Water Standards, which are subject to the Australian Drinking Water Guidelines of 1996 (Stein, 2001). These guidelines were developed by the National Health and Medical Research Council (NHMRC) and the Agriculture and Resource Management Council of Australia and New Zealand. These documents are used alongside with the relevant WHO 1993 guidelines (Stein, 2001).

In the African country Botswana, where both surface and groundwater resources are scarce, the National Conservation Strategy (1990) and the Water Master Plan of 1991 are implemented to safeguard natural resource (UNDP, 2002). The Botswana Standards, which were developed by the Bureau of Botswana Standards (BOBS), stipulates the water quality standards and penalties for breach of such standards. The Ministry of Minerals, Energy and Water Resources (MMEWR) is responsible for all policies relating to the water sector. Within MMEWR, the Department of Water Affairs (DWA) is responsible for groundwater investigations, protection and monitoring of resources and water supply development in rural areas (Desert, 2007).

South Africa, similar to many other countries, has also promulgated a number of acts and regulations to safeguard water quality. The National Water Act (36 of 1998), which is the principal legal instrument relating to water resources management in South Africa, contains comprehensive provisions for the protection, use, development, conservation, management and control of South Africa's water resources. The National Health Act (61 of 2003) mandates water quality monitoring as a municipal health service. The Water Services Act (108 of 1997) stipulates requirements with respect to access, national norms and standards and the institutional framework for the provision of water services. Another important tool is the South African Drinking Water Guidelines of 1996, which provides information required to make judgments as to the fitness of water to be used for domestic purposes. The guidelines contain similar information to what is available in the international literature (DWAF, 1996) such as the WHO drinking water guidelines.

The various South African documents, specifically “Regulation 5 of Water Services Act Compulsory National Standards for the Quality of Potable Water (2001)”, have resulted in the development of the South African National Standards (SANS) 241 (2011) for drinking water quality to ensure the protection of public health. The SANS 241 (2011) is the definitive reference on acceptable numerical limits for drinking water quality at the point of delivery in South Africa in terms of physical, microbiological, aesthetic and chemical quality.

2.6 Water quality assessment

2.6.1 Introduction

The quality of drinking water is typically determined by assessing the levels of some physical, chemical and microbiological water quality properties (USEPA, 2003). The assessment is achieved by monitoring the presence

of physico-chemical properties and microbial organisms, especially faecal coliform bacteria (Gray, 1994; USEPA, 2008). Monitoring of drinking water is achieved by using a representative drinking water sample which has been collected from a place that represents the water at the point of concern (Muhammad et al., 2010). Therefore, sampling is an integral factor of the entire water quality assessment process (Burlingame & O'Donnell, 1993). It directly affects the accuracy of drinking water quality results, which depend upon good sampling field techniques (DWAF, 2006). Sampling procedures are well described by various water quality agencies, including the World Health Organization (WHO, 2004). For results to be accurate there are certain requirements to be met such as frequency of sampling, location of sampling sites, sampling equipment to be used as well as the use of correct sampling techniques (DWAF, 2006).

When considering the frequency of sampling, the risk of contamination is of primary importance (Bridgman et al., 1995). Furthermore, the frequency of testing for individual constituents will depend upon the variability of the individual constituent as well as size and nature of the distribution network (Regli et al., 1991; SANS 241, 2011). Therefore, sampling should be frequent enough to enable the monitoring to provide meaningful information and also be statistically valid (WHO, 2008). Monitoring of microbiological constituents is undertaken more frequently than that of chemical constituents because even a brief incident of microbial contamination may cause immediate infection, illness and or death in consumers (DWAF, 2005a).

Location of sampling depends on the water quality constituent being examined, as well as the characteristics of the distribution system being managed (DWAF, 2006). For constituents where the concentration does not change greatly within the distribution system, sampling of the water at the treatment plant may be sufficient (SANS 241, 2011). However, for characteristics that vary in concentration during distribution, sampling should be undertaken throughout the distribution system from the point of supply to the point of delivery to the consumer at fixed points

(Burlingame & O'Donnell, 1993). It should be noted that the behavior of the concentrations of some constituents, such as disinfection by-products, chlorine residual, turbidity and microbiological organisms may differ from one distribution system to another (WHO, 2008).

2.6.2 Physical assessment

Physical assessment involves the analysis of water quality determinants such as electrical conductivity (EC) or total dissolved solids (TDS), pH, turbidity and temperature in drinking water. EC and TDS serve as general indicators of taste and "freshness" of the water indicating the salinity and quantity of dissolved substances. The pH of drinking water, particularly an acidic pH, affects the corrosiveness and taste of water and determines whether encrustation of pipes and fittings is likely to be an important problem. Turbidity, on the other hand, indicates the cloudiness of the water and affects the risk of infectious disease transmission as it affects effectiveness of chlorination. Temperature affects the equilibrium reactions and oxygen solubility (DWAF, 1996). All these determinants are aesthetic in nature and do not pose a health risk to consumers, but do however act as indicators of the efficiency of water treatment (SANS 241, 2011).

Measurement of physical determinants

The measurement of the various aesthetic determinants is undertaken on-site at a particular water point (DWAF, 2006). When water pH is determined, fresh water samples should be used and measured electrometrically using a pH meter. Prior to the measurement of the pH, the pH meter should first be calibrated against standard buffer solutions of known pH (WHO, 1993). Because pH measurements are influenced by temperature, it is important to report the water temperature at the time when the pH was determined. For example, the SANS 241 (2011)

requires that the water temperature should be at 25˚ Celsius. The pH of most raw waters lies within the range of 6.5 - 8.5 (WHO, 2004). Nutrient enrichment and industrial effluent discharge through biological and anthropogenic activities may give rise to pH fluctuations (Ocampo-Dugue, 2006). Notably, acid mine drainage may cause a marked lowering of the pH (Naicker et al., 2003). Furthermore, it has been demonstrated that pH measurements may be inaccurate in the presence of sodium at pH values greater than 10 (DWAF, 1996).

The measurement of TDS provides an indication of the total amount of various inorganic salts dissolved in water, while EC is a measure of the ability of water to conduct an electrical current (DWAF, 1996). The TDS concentration is directly proportional to the EC of water (WHO, 1993). Since EC is much easier to measure than TDS, it is routinely used as an estimate of the TDS concentration (WHO, 2004). Measurement criteria are given in terms of TDS concentration in mg/L, as well as the equivalent EC, which is expressed in milli-Siemens per metre (mS/m), and measured at 25˚C or corrected to a temperature of 25˚C. For most natural waters, EC is related to the dissolved salt concentration (TDS) by a conversion factor ranging from 5.5 to 7.5 with an average conversion factor for most waters as 6.5 (DWAF, 1996). The conversion equation of EC to TDS is as follows: EC (mS/m at 25˚C) × 6.5 = TDS (mg/L), where the TDS of raw waters is less than 150 mg/L (DWAF, 1996).

Turbidity is a measure of the light-scattering ability of water and indicates the concentration of suspended matter in water (USEPA, 1999a). Turbidity is characterized by the presence of suspended matter consisting of a mixture of inorganic matter (clay and soil particles) and organic matter (DWAF, 1996). Turbidity of surface water may be influenced by rainfall events and algal growth while groundwater has a stable turbidity (Payment et al., 2002). A nephelometric turbidimeter is used for the measurement of turbidity and the unit of measure is nephelometric turbidity units (NTU). The turbidity of raw water can range from less than 1 NTU in very clear water to more than 1 000 NTU in turbid, muddy water (DWAF, 1996; WHO, 2008).

2.6.3 Chemical assessment

There are a number of chemical determinants in water, both organic and inorganic, including some pesticides that are of concern to human health. These chemicals are known to be toxic to humans, or are suspected of causing cancer (Aydemir et al., 2005). However, the WHO points out that the range of chemicals differs from one country to another (WHO, 2008). In South Africa, the SANS 241 (2011) states that drinking water is deemed to have failed compliance for chemical requirements when it has been confirmed that a sample exceeds the numerical limits for lifetime consumption.

Measurement of chemical determinants

Different chemicals are measured differently using different methods. For example, chloride and ammonia are measured using colorimetric methods, while calcium, aluminium and arsenic are measured using atomic absorption spectrometry methods and cadmium is measured using absorption spectrometry (DWAF, 1996). In South Africa, the unit of measure is mg/L for all macro chemical determinants (major chemicals determinants) and µg/L for all micro chemical determinants (minor chemical determinants) as specified by the SANS 241 (2011).

2.6.4 Microbiological assessment

Microbial assessment of drinking water is achieved by the use of bacteria as indicators of the sanitary quality of drinking water though the use of bacterial indicators does not guarantee drinking water to be free from enteric viruses such as hepatitis A virus (Bosch, 1998). The indicator organisms commonly monitored for are coliform bacteria and thermotolerant coliforms (Kempster et al., 1997). Detection of individual microorganisms is difficult

hence the use of indicator organisms (Gadgil, 1998). Presence of indicator organisms in drinking water is indicative of either environmental contamination, faecal contamination or inadequate water treatment depending on the species monitored for (Zamxaka, 2004). For example, other thermotolerant genera, such as *Klebsiella*, which are widely distributed in the environment, might also trigger a positive total coliform result, but might not be related to faecal contamination or human health risks (Soller et al., 2010). Similarly coliforms (Gram-negative, non-spore forming, oxidase-negative, rod-shaped facultative anaerobic bacteria) are used to indicate environmental pollution fermenting lactose to acid and gas within 24 to 48 h at 36 ± 2°C with the enzyme β-galactosidase (WHO, 2004). In the event of a positive coliform result, an additional test is required to assess if the positive coliform is *E. coli* (ODH, 2004). *E. coli* is a thermotolerant coliform and is generally considered an indicator of fecal contamination when found in drinking water. Faecal coliforms and more especially *E. coli* are the most commonly used indicators of faecal pollution. The presence of *E. coli* indicates and confirms the presence of faecal pollution by warm blooded animals (often interpreted as human faecal pollution) (DWAF, 1996). It is therefore important to note that there is no universal indicator, as often assumed with thermotolerant (faecal) coliforms or *E. coli* (Ashbolt, 2004)

Measurement of microbiological determinants

Methods for detection, characterization, and enumeration of various indicator bacteria in water have well-defined national and international standards such as those from the International Standardization Organization (ISO) (WHO, 2001). For the detection of *E. coli* and faecal coliforms, the two standard methods are the most probable number or MPN test (ISO 9308-2:1990) and membrane filtration test (ISO 9308-1:1990) (Gadgil, 1998).

Most Probable Number (MPN) method

The MPN test is carried out by incubating an appropriate medium in multiple tubes, each inoculated with a water sample suitably diluted if necessary. Each tube receives one or more viable organs and will show a positive reaction appropriate to that medium (Nogueira et al., 2003). The most probable number of organisms in the water sample is then deduced by counting the number of tubes showing positive and negative reactions, and looking up statistical tables of probability which give confidence limits on the results (Ashbolt, 2004). Although this test is simple to perform, it is time-consuming, requiring 48 hours for the presumptive results and further testing is required for confirmation of the coliform type hence the membrane filtration was a practical alternative to the MPN approach (WHO, 2001).

Membrane Filtration (MF) method

In the MF test, the water sample is filtered through a 0.45 μm cellulose filter supported on a porous or perforated disk by applying negative pressure (or vacuum) to the other side of the disk. This draws the sample through the membrane filter, retaining coliforms and many other bacteria on its surface. The membrane filter is then incubated by placing it, face up, on an appropriate selective medium. Colonies developed on the membrane can be quickly and easily identified (for example by their characteristic color) and counted (number of colonies)/100 mL of water (WHO, 2001). By the 1950s MF was a practical alternative to the MPN approach, although the inability to demonstrate gas production with membranes was considered a major drawback (Waite 1985). This approach was questioned as it ignored *E. coli* and any related coliforms because they failed to ferment lactose, to produce gas from lactose or were indole-negative at 44.5ºC (Waite 1987). This failure and the need for selective media to

improve on recoveries and identification of target bacteria led to the introduction of other methods such as the defined substrate technologies methods (WHO, 2001).

Defined Substrate Technologies (DST) method

DST methods were introduced in the late 1980s as another water assessment tool (Edberg et al., 1988). DST simultaneously detects total coliform bacteria and *E. coli* by enzymatic hydrolysis of specific substrates. These methods screen for bacteria using selective inhibitors and elevated incubation temperatures to assess enzymatic activity (Buckalew et al., 2006). One such DST medium is the Colilert by the Idexx Laboratories, which utilizes two substrates: *0*-nitrophenyl-b-D-galactopyranoside (ONPG), which screens for β-D-galactosidase, an enzyme found in lactose-fermenting bacteria and in some coliform bacteria, and 4-methylumbelliferyl-b-D-glucuronide (MUG), which screens for β-D-glucuronidase, an enzyme found in several bacterial species, but predominantly in *E. coli* (Tryland & Fiksdal, 1998). Colilert has recently been certified by the USEPA as a viable method for bacterial assessment of surface waters (USEPA, 2003). When compared with the MF the Colilert presents a laboratory protocol that is simpler to manage, quicker to process and easier to quantify results while comparison with the MPN showed that though the Colilert was as sensitive as the MPN, it did not require confirmatory tests, was easy to inoculate, and was very easy to interpret hence showing good correlation with the traditional MF and MPN methods when used to test both fresh and marine water (Edberg, 1988, Fricker et al., 1997; Eckner 1998). The advantage of these enzyme-based methods is that they pick up traditionally non culturable coliforms (George et al*.,* 2000). These developments have therefore resulted into the recent miniature publication of MPN based methods for coliforms and *E. coli* and *enterococci* based on the defined substrate approach (ISO/FDIS 1998, 1999) by the International Standards Organization (WHO, 2001).

2.6.5 Water quality index

Water quality index (WQI) is defined as a rating reflecting the composite influence of different water quality parameters (Ishaku, 2011). WQI is calculated from the point of view of the suitability of water for human consumption (Ramakrishnaiah et al., 2009). Expressing water quality, especially to a lay person, is enormously more difficult than expressing water quantity. For instance, the latter can be expressed in precise terms such as the volume contained in a water body. On the other hand, water quality being a multi-parameter attribute (a large number of physical, chemical and biological factors together determine the water quality and is a function of the nature of water utilization) uses a number of different techniques such as WQI to communicate water quality (Sarkar & Abbasi, 2006). WQI resolves lengthy, multi-parameter water analysis reports into single digit scores (Debels et al., 2005). This index is a mathematical instrument used to transform large quantities of water characterization data into a single number, which represents the water quality level as well as allowing adequate classification of water quality. Additionally, WQI facilitates comparison between different sampling sites and or events. Consequently, it is one of the most effective tools to communicate information on the quality of water to the citizens and policy makers (Sanchez et al., 2007).

WQI was initially proposed by Horton in 1965 for use and has since been developed by several authors such as Brown et al., 1970; Prati et al., 1971; Said et al., 2004; Debels et al., 2005; Ramakrishnaiah et al., 2009; Vasanthavigar et al., 2010 and Ishaku 2011 (Alobaidy, 2010). Many different methods for the calculation of WQI have been developed. These methods consider similar physical and chemical parameters but differ in the way the values are statistically interpreted and integrated (Debels et al., 2005). Originally there was a criterion that was chosen for developing a WQI, the basis of which was that the index should handle limited number of variables to

avoid making the index unwieldy, the variables should be of significance in most areas and that only such variables, of which reliable data is available, or obtainable, should be included (Sarkara & Abbasi, 2006).

There are four steps that are followed when developing WQI though additional ones may be added (Abbasi, 2002 in Sarkara & Abbasi, 2006). The first one is the selection of parameters which must reflect the overall water quality with respect to a given water end use. The second one is the transformation of different units and dimensions of a parameter into a common scale which is achieved through development of sub-indices. The third step involves the assigning of suitable weightages to the parameters which is mostly done based on the importance of the impact of that particular parameter on water quality. However this method has been discarded by other researchers because of high level of subjectivity. Hence why the use of preexisting water quality standard was suggested (Prati et al., 1971; Sargaonkar & Deshpande, 2003). The last step is the evaluation of the final score through aggregation of the respective indices such as the weighted sum (Brown et al., 1970).

The commonly used WQIs include the British Columbia Water Quality index (BCWQI) which can be used for a variety of uses including drinking water though it has a serious limitation when comparing water bodies (Said, 2004). There is also National Sanitation Foundation Water Quality Index (NSFWQI) which uses nine parameters (Brown et al., 1970). The other frequently used is the Oregon Water Quality Index (OWQI) which was developed in the late 1970's and uses eight parameters (Cude, 2001). Lastly, is the Florida Stream Water Quality Index (FWQI) which was developed in 1995 using 12 parameters (SAFE, 1995).

2.7 Drinking water quality management

2.7.1 Introduction

There is increasing recognition that monitoring for numerical limits is not sufficient to guarantee the safety and quality of drinking water supplies (WHO, 2004). Some countries have developed frameworks for managing drinking water quality as a whole. While the EU came up with water framework directive of 2000 for the member countries, the Australian National Health and Medical Research Council (NHMRC) developed a framework for management of drinking water quality for incorporation in the Australian Drinking Water Guidelines (Rizak et al., 2003). Similarly, South Africa developed the framework for management of drinking water in 2005 (DWAF, 2005a). The framework enables effective management of drinking water quality to protect public health based on an integrated system of approaches and procedures. These procedures address the key factors that govern drinking water quality and safety (Rizak et al., 2003; DWAF, 2005a). The framework emphasizes prevention, the importance of risk assessment, maintenance of the integrity of the water supply systems and application of multiple barriers to ensure protection of public health (WHO, 2008). Furthermore, in South Africa DWAF made a commitment to introduce a regulation on incentives and sanctions in the framework in order to emphasize the importance of proper drinking water management.

2.7.2 The Blue Drop incentive based regulation

DWAF unveiled its drinking water quality management regulation on incentives and sanctions in 2008 to show commitment in water quality management (DWAF, 2009a). The regulation facilitates a more transparent way of reporting as well as a method of awarding towns within Water Services Authorities' (WSAs) with Blue and/or Green Drop status if they are compliant with Drinking Water and Waste Water legislative. Furthermore, this incentive-based regulation acknowledges excellence in drinking and wastewater quality management. Consequently the Blue and Green Drop status provides citizens with credible information on water quality. The WSAs are expected to meet all the required drinking water criteria which include water quality compliance,

development of drinking water safety plans and submission of drinking water quality results. Under this regulation all WSAs drinking water services system scoring 80% and above will be assessed by an independent Advisory Committee to validate the score. A WSA with drinking water or waste water services systems qualifying for Blue or Green Drop Certification status, receives a formal acknowledgement from the Minister of Water Affairs and Forestry and the town is issued a flag/plaque and trophy to display the Blue or Green Drop Certification status. This is accompanied by official permission to use the Blue or Green Drop Certification status in the marketing of a town or city for tourism and economic purposes (DWAF, 2009a).

Analysis of Blue Drop assessment in South Africa

Nationally a total of 107 municipalities and 402 water supply systems in 2009 were assessed while in 2010 the number increased to 153 municipalities and 787 systems. In 2011 162 municipalities and 914 water supply systems were assessed. The 2009 Blue Drop score was 51.4% while the 2010 improved status was 67.2%, and the score has even improved more in 2011 with an average national score of 72.9%. Similarly, the number of blue drop awards has increased from 25 in 2009 to 38 in 2010 which has shown an increase to 66 in 2011 with the Western Cape receiving the highest number of awards at 36, although on the national performance position log Gauteng province got first position while Free State province was at number five. Based on the statistics the incentive-based regulatory approach seems to have succeeded to raise the overall awareness and to act as positive stimulus for gradual and sustainable improvement across South Africa (DWA, 2011).

Analysis of Blue Drop assessments for the Free State

In the Free State, analysis of the Blue Drop assessments and site inspection results indicate that performance vary from excellent to very poor. A positive finding is the increased number of systems assessed, based on a 100% assessment coverage of municipalities during the 2010/11 Blue Drop Certification. In 2009 there were a total of 17 municipalities out of which 14 were assessed while in 2010 all 17 municipalities were assessed. The number of municipalities increased to 20 in 2011 and these were all assessed. The water systems that were assessed were 26 in 2009, 58 in 2010 and 76 in 2011. The provincial blue drop score was 7 in 2009 which increased to 13 in 2010 and subsequently increased to 29 in 2011. The number of blue drop awards also increased from one in 2009 to 2 and 3 in 2010 and 2011 respectively. These data show that the Free State is succeeding to continue along an upward improvement trend which started in 2009. The provincial percentage scores increased from 40.0% (2009) to 48.5% (2010) to 64.1% in 2011 (DWA, 2011).

Analysis of Blue Drop assessment for Mangaung Metropolitan Municipality (MMM)

Though the Free State province is doing well, regrettable, MMM did not maintain the upward movement. The MMM Blue Drop score in 2011 dropped to 84.69% as opposed to the 95.05% which was scored in 2010. The reason for the poor performance is that the MMM and its water service provider Bloem Water failed to provide sufficient information to maintain Blue Drop certification status (DWA, 2011).

Chapter 3

Materials and Methods

3.1 Introduction

Two areas around Bloemfontein were selected for this study, namely, the Bainsvlei area and Woodland Hills Estate. These areas use treated water supplied by the MMM and also untreated water obtained from boreholes. The Bainsvlei area was selected because it is beyond the urban edge of Bloemfontein and the area is known for farming and small holdings which are used for a range of different small businesses such as a pig farm, oil extraction plant, chicken abattoirs, rusk factory and shops. The Woodland Hills Estate, a secure living estate, was selected because it receives treated water from the municipality; however the management has constructed four boreholes which they wish to connect to the existing municipal supply.

3.2. Study area

The study area comprising of Bainsvlei and the Woodland Hills Estate of Bloemfontein is in the Motheo District Municipality, Free State (Figure 3.1). Bainsvlei is located on the western side of Bloemfontein surrounding the Dealesville road, while the Woodland Hills Estate lies in the northwestern quadrant of Bloemfontein between the Bloemfontein-Dealesville road in the south and Bloemfontein-Johannesburg railway line in the east.

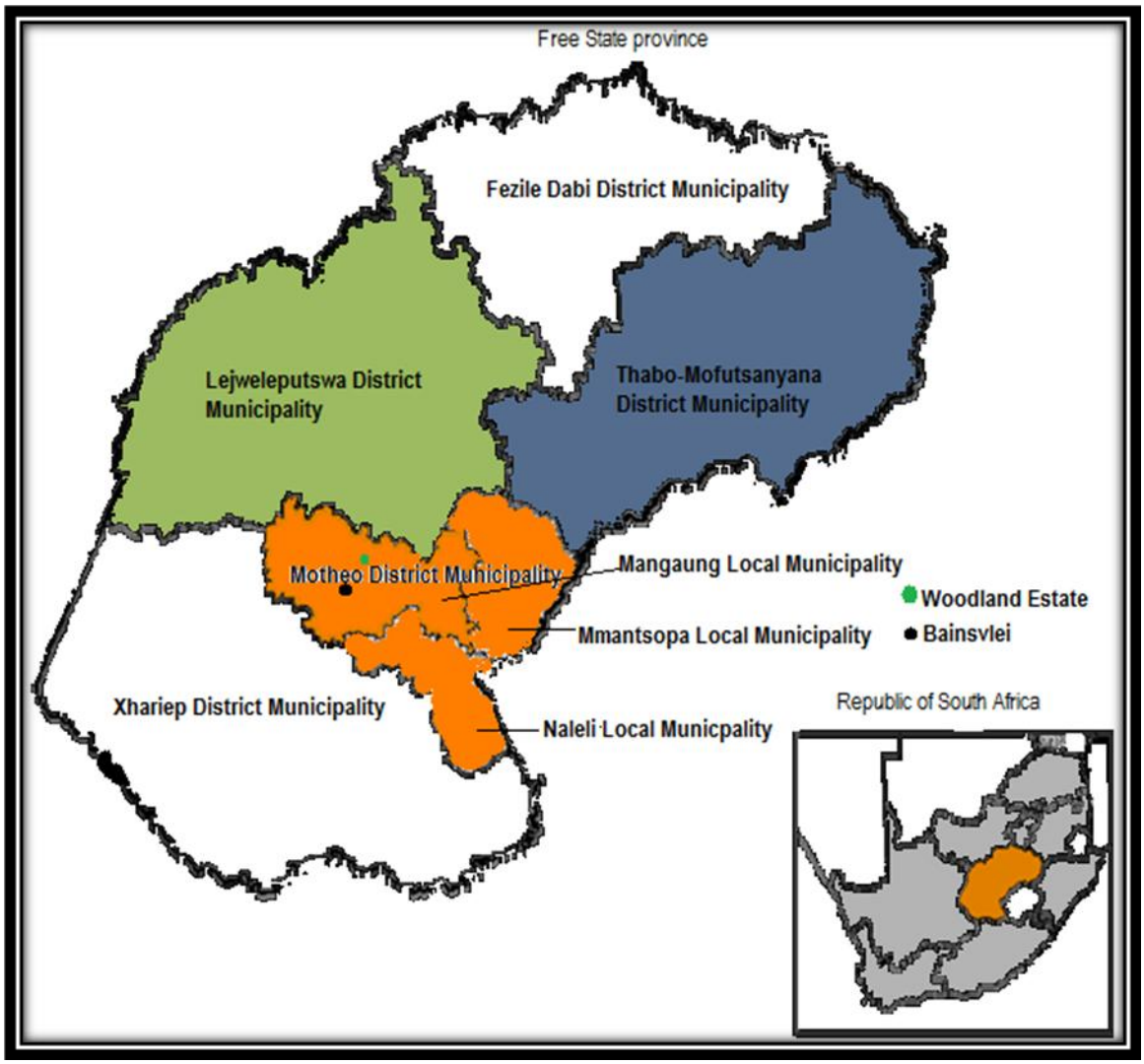


Figure 3.1 Map of Free State showing the Motheo District municipality and local municipalities

3.3 Study design

The study was planned using an experimental design. In this design specified objectives were met through the collection and analyses of data whereby the results of the experiments were not known in advance. The study design comprised of three distinct stages (Figure 3.2). The first stage involved the scouting of the Bainsvlei area and the Woodland Hills Estate. The second stage involved the collecting of the water samples from the sampling

points and recording some measurements at the sampling points. Off-site analyses were made in the laboratory. Lastly, the third stage comprised of the capturing of measurements and analyses of data, which were then compared to the SANS 241 (2011) specifications. Three water sampling visits were undertaken so that possible seasonal effects could be identified. These visits were approximately ten weeks apart.

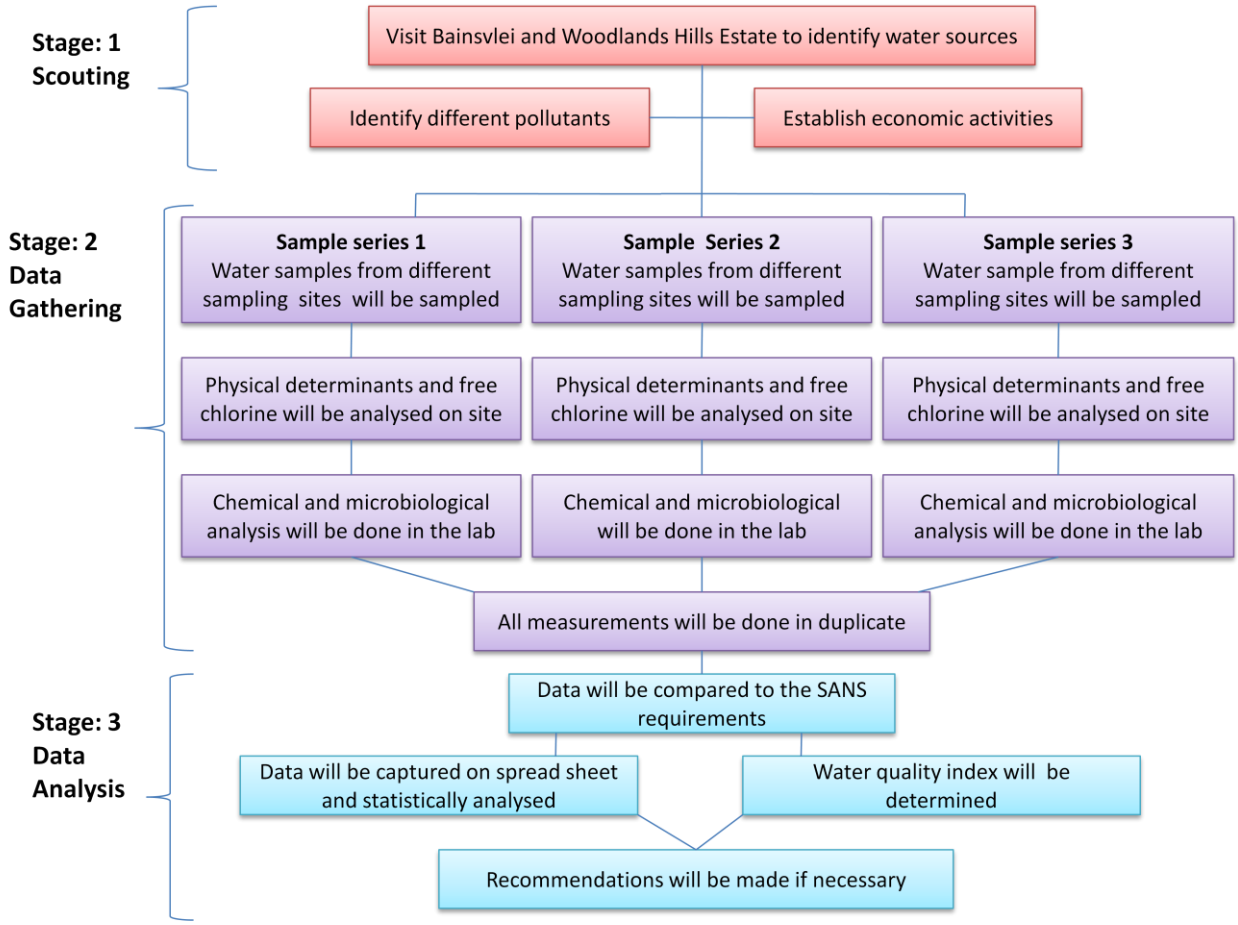


Figure 3.2 Different stages of the study

3.3.1 Stage 1: Scouting

The scouting stage comprised of a visit to the Bainsvlei area and the Woodland Hills Estate on the 21st of June 2011 to identify a total of 20 sampling points for the study. The selection of the different sampling points was made upon the recommendation of a Mangaung Environmental Health Practitioner (EHP) to ensure that both borehole and municipal sampling points would be included in the study. During this visit the different sampling points were identified as being either boreholes or municipal water supply points and their coordinates recorded. Economic activities in this area, as well as pollution events were also recorded.

3.3.2 Stage 2: Data gathering

The data gathering stage involved the collection and analysis of water samples from the identified sampling points. Measurements of water quality determinants were made on-site as well as in the laboratory.

On-site measurements included the measurement of the physical determinants turbidity, electrical conductivity, temperature and pH and the chemical determinant free chlorine. In the laboratory other chemical determinants were measured, together with microbiological determinants as specified by Level 4 of SANS 241 (2006) as shown in Table 3.1. Although analysis of Level 1 determinants are deemed the minimum requirements for the purpose of indicating ongoing levels of operation and efficiency in a water treatment plant and acceptable water quality within the distribution network, Level 4 determinants were chosen as a good representation of determinants that would cover a wide range of determinants as opposed to routine water monitoring (SANS 241, 2006). However, not all those determinants that fall within Level 4 were assessed. The determinants that were not assessed were excluded because of financial constraints (Table 3.1).

Table 3.1 SANS 241 (2006) Level 4 determinants analysed and determinants excluded

Physical determinants		Chemical determinants		Microbiological determinants	
Assessed	Not assessed	Assessed	Not Assessed	Assessed	Not Assessed
Turbidity E. conductivity pH Temperature	Colour Dissolved solids Odour Taste	Free Chlorine Ammonia (N) Calcium (C) Chloride (Cl) Fluoride (F) Magnesium (Mg) Manganese (Mn) Nitrate (N) Sodium (Na) Sulfate (SO_4) Aluminium (Al) Arsenic (As) Cyanide (CN-) Iron (Fe) Lead (Pb) Mercury (Hg)	Potassium (K) Antimony (Sb) Cadmium (Cd) T.Chromium (Cr) Cobalt (Co) Copper (Cu) Nickel (Ni) Selenium (Se) Vanadium (V) Dissolved Organic Carbon (C) Total Trihalomethanes (THM) Phenols	E. coli Total coliforms	Heterotrophic plate count Somatic coliphages Cytopathogenic parasites Protozoan parasites Faecal coliforms

3.3.3 Stage 3: Data analysis

The measurements of all the assessed water quality determinants were captured on Excel spreadsheets, after which data were statistically analysed and compared to the SANS 241 (2011) specifications. A drinking water quality index (WQI) was determined to get the overall water quality of different sources.

3.4 Methodology

When water was collected at a particular water sampling point, a number of activities were performed. These included the collection of water for the laboratory analyses and the collection of water for the on-site measurements. Besides water collection, site data were also recorded, particularly on the first visit. Site data included, GPS coordinates of a sampling point, date and time of water sampling and sampling point number. Any other information that may be required at some time during the study was also recorded.

At a water sampling point, sufficient water was collected for chemical analyses of the chemical determinants, besides free chlorine. The analyses of the chemical determinants were performed by the Institute of Groundwater Studies (IGS) laboratory at the University of the Free State in Bloemfontein. Microbiological analyses of *E. coli* and total coliforms were performed at the Environmental Health laboratory at the Central University of Technology, Free State, Bloemfontein.

3.4.1 At the water source

Water samples were analysed for physical determinants (turbidity, electrical conductivity, temperature and pH) and for free chlorine at the water source. The taps that were used were sterilised by flaming them with a portable gas

burner for approximately one minute. After sterilisation, a tap was opened and the first draw-off of water was allowed to run for a minute and then water was collected from the tap. Water samples were first collected for laboratory analyses. For laboratory chemical analyses sterile 500 ml bottles were used and for microbiological analyses sterile 100 ml bottles were used. For the chemical analyses, the 20 sampling points were divided into two groups; sampling points one to 10 and sampling points 11 to 20. The first set of samples, one to 10, were taken in duplicate to provide a control group without the testing laboratory being aware of a duplicate set of samples, while only a single sample was taken for the second sample group. Similarly, only a single sample was taken at each sampling point for the microbiological analyses. Duplicate samples were only taken for 10 of the chemical samples, because of financial constraints. All sample bottles were labeled with sample number and date. All samples destined for the laboratory were placed on ice.

The duplicate chemical sample sets were numbered: B1 and B11; B2 and B12; B3 and B13; B4 and B14; B5 and B15; B6 and B16; B7 and B17; B8 and B18; B9 and B19; B10 and B20.
The single chemical sample sets were numbered: WB1; WB2; WB3; WB3; WB4; WB5; WB6; WB7; WB8; WB9 and WB10. The microbiological sample set was numbered with sample number and date.

For the on-site measurements a HACH DR/820 colorimeter was used to assess both turbidity and free chlorine and a MARTINI MI 806 pH/EC/Temperature Portable meter was used for the measurements of temperature, pH and electrical conductivity (EC). The HACH DR/820 colorimeter is battery operated instrument and uses a spectrum of rays that are reflected by the sample and captured as a measurement as shown in Figure 3.3.

Figure 3.3 DR820 Colorimeter

Measurement of turbidity and free chlorine

1. Water was collected at the source using a 250 ml beaker, after which the water was poured into a cuvette and filled up to the 10 ml line.

2. The HACH DR/820 colorimeter instrument was then switched on and a blank cuvette containing <0.1 nephelometric turbidity units (NTU) calibration solution, was wiped clean with a clean cloth and placed in the receptacle of the instrument.

3. The blank cuvette was covered and the zero key pressed.

4. After a reading of zero displayed on the screen, the blank cuvette was removed.

5. Immediately after removing the blank cuvette from the instrument, the cuvette containing the water sample was wiped clean with a clean cloth and placed in the receptacle and covered.

6. For the turbidity measurement, the appropriate unique code 95 was entered into the instrument. The read key was then pressed and the turbidity reading on the screen recorded as NTUs.

7. The cuvette containing the water sample was then taken out after the turbidity reading was recorded.

8. The diethyl-p-phenylenediamine (DPD) indicator for free chlorine was added to the same sample that was used for the measurement of turbidity and shaken vigorously.

9. The blank cuvette was again placed in the receptacle, covered and the zero key pressed.

10. After a reading of zero displayed on the screen, the blank cuvette was removed.

11. Once the DPD indicator for free chlorine had dissolved the cuvette was wiped clean with a clean cloth and placed in the receptacle of the instrument.

12. For the free chlorine measurement, the appropriate unique code 9 was entered into the instrument. The read key was then pressed and the free chlorine reading on the screen recorded as mg/L. This process of exchanging the water sample cuvette and the blank cuvette was repeated for all the sampling points and measurements recorded in a workbook.

The MARTINI MI 806 pH/EC/Temperature portable meter was used for measurements of temperature, pH and electrical Conductivity (EC). The MARTINI MI 806 pH/EC/Temperature portable meter is a battery operated instrument that has a sensor probe that is immersed in a water sample and reading obtained through a screen on the instrument as shown in Figure 3.4. Prior to taking the readings of the three physical determinants, the instrument was first calibrated.

Figure 3.4 MARTINI MI 806

Calibration procedure for pH

1. The Instrument was switched on and the pH mode entered by pressing the range key.

2. The calibration buffer set was selected by pressing and holding the “ON/OFF” key until “TEMP” was displayed on the screen. Then the “ON/OFF” key was pressed again and the “BUFF” message appeared on the screen.

3. Thereafter, the “7.01 pH BUFF” was selected by pressing the “SET” key and the “ON/OFF” key was then pressed again to exit.

4. After removing the protection cap of the probe, the probe was immersed in a 250 ml beaker containing a buffer solution pH7.01 (MA 9007).

5. The “ON/OFF” was pressed and held until “CAL” was displayed on the screen.

6. The “ON/OFF” was released and the “7.01 pH USE” message was displayed and the “ON/OFF” was pressed to return to normal mode.

7. Finally the instrument was switched off.

Calibration procedure for electrical conductivity

1. The protection cap of the probe was removed and the probe cleaned in a beaker containing M10000 cleaning solution.

2. The probe was removed from the M10000 solution and immersed in a 250 ml beaker containing a MA9030 calibration solution.

3. The Instrument was switched on and the EC mode entered by pressing the range key.

4. The “ON/OFF” key was pressed and held “CAL” was displayed on the screen.

5. The “ON/OFF” key was then released and the message reading “12.88 mS” appeared on the screen.

6. After the completion of the steps 1 to 5, the instrument performed an automatic calibration and this was confirmed by displaying “OK” for a second before returning to normal mode.

7. Thereafter, the “CAL” message was displayed on the screen to indicate that the calibration was complete.

Measurement of pH, temperature and electrical conductivity

1. The instrument was turned on by pressing the “ON/OFF” key.

2. The protective cap was removed from the sensor probe and rinsed in a 250 ml beaker containing distilled water.

3. The instrument was then switched on and the pH range selected by pressing the “RANGE” key.

4. The sensor probe was removed from the rinsing solution and immersed in a 250 ml beaker containing a water sample and then the water sample was stirred gently with the sensor probe.

5. When the flashing clock icon on the screen stopped flashing, the two readings on the screen, pH and temperature were recorded.

6. Immediately after recording the pH and temperature, the instrument was switched to EC mode.

7. When the flashing clock icon on the screen stopped flashing, the EC reading was recorded.

8. The pH, temperature and EC readings of the next water sample were obtained by repeating steps 2 to 7

9. Once all measurements had been taken, the instrument was switched off and the sensor probe’s protective cap replaced.

3.4.2 In the laboratory

Microbiological analyses for *E. coli* and total coliforms were performed by using the IDEXX (Colilert18) Quanti-Tray™ method. The IDEXX (Colilert18) Quanti-Tray™ method is a biotechnological detection approach, which uses the multi-well most probable number (MPN) method. It incorporates a defined substrate medium which contains *0*-nitrophenyl-β-D-galactopyranoside (ONPG) and 4-methylumbelliferyl-β-D-glucuronide (MUG). After incubation at 37^{0}C for 18 to 22 hours coliform bacteria produce a yellow colour because of the production of β-

galactosidase and *E. coli* produces blue fluorescence as a result of the action of β-glucuronidase under UV light (Health Protection Agency, 2004). The MPN is calculated from the number of positive wells.

Measurement of *E. coli* and coliforms using the IDEXX (Colilert18) Quanti-Tray™ method

1. Water of over filled water sample bottles were first decanted so that the water in the 100 ml sample bottles reached the 100 ml mark on the bottle.

2. An indicator Colilert 18 medium snap pack was carefully separated from the other Colilert 18 medium snap packs in the group.

3. A Colilert 18 medium snap pack was then gently tapped to ensure that all the powder collected at the bottom of the pack.

4. The Colilert 18 medium snap pack was then opened by snapping back the top, and the powder added to the 100 ml sample bottle containing the water sample.

5. The sample bottle was gently shaken to dissolve Colilert 18 medium and then left the stand for a few minutes.

6. The water sample bottle was again gently shaken to ensure that the entire Colilert 18 medium had dissolved.

7. The 51-well Colilert18 Quanti-Tray™ was used for municipal water (treated water), while the 97-well Colilert18 Quanti-Tray™ 2000 was used for borehole water (untreated water).

8. The appropriate Colilert18 Quanti-Tray™ was selected, depending on the water sample, labeled with the sample number and date, and then opened by squeezing the tray and pulling away the tab at the top of the tray.

9. The 100 mL water sample solution was poured into the Colilert18 Quanti-Tray™, which was then sealed in the pre-warmed sealer. Thereafter the Colilert18 Quanti-Tray™ was removed from the sealer and incubated for 18 to 22 hours at 37º Celsius.

10. The Colilert18 Quanti-Tray™ was finally removed from the incubator after no longer than 22 hours incubation and the *E. coli* and coliforms quantified.

Quantification of *E. coli* and coliforms

After the incubation of the Colilert18 Quanti-Tray™ had been completed, the number of yellow wells was used to quantify coliforms while the number of UV illuminated fluorescent blue wells was used to quantify *E. coli.* An example of the 51-well tray was used to quantify coliforms in the form of yellow wells as shown in Figure 3.5 while the number of *E. coli* was determined by counting the number of blue fluorescent wells after placing the Colilert18 Quanti-Tray™ under UV light.

Figure 3.5 IDEXX 51-well Quanti-Tray

Having recorded the number of wells for both coliforms and *E. coli* the IDEXX 51-Well Quanti–Tray® MPN table was then used to obtain the number of colony forming units (CFUs) for *E. coli* and for coliforms in the following manner:

1. For coliforms there were 3 wells on the left side of the table and the corresponding MPN reading from the right side of table was 3.1 CFU per 100 mL of water as shown in Figure 3.6.

2. Similarly, If there were 3 wells of *E. coli* by counting the fluorescent blue wells the adjacent reading on the table would be recorded as the MPN result as CFUs for *E. coli* per 100 mL of water as in Figure 3.6

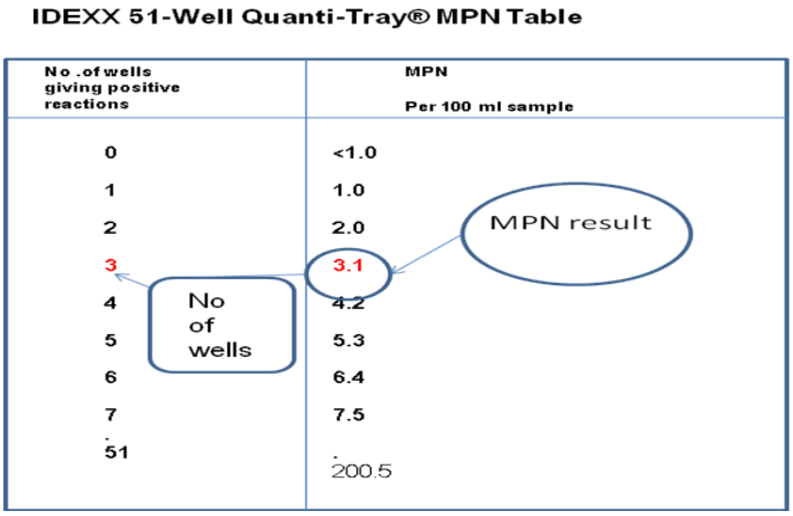


Figure 3.6 Quantification of a 51-well Quanti-tray results

For a 97-well tray the IDEXX Quanti–Tray®/2000 MPN table was then used to obtain the number of colony forming units (CFUs) for *E. coli* and for coliforms. The result of yellow wells was counted as 17 large and 3 small wells as shown in Figure 3.7a. As the same tray was placed under UV light the number of all large yellow wells and small wells fluoresced as seen in Figure 3.7b.

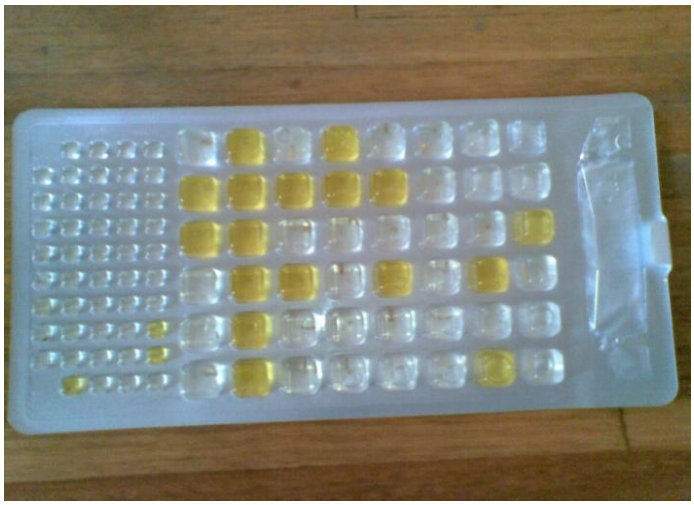


Figure 3.7a IDEXX 97- well Quanti tray with yellow wells

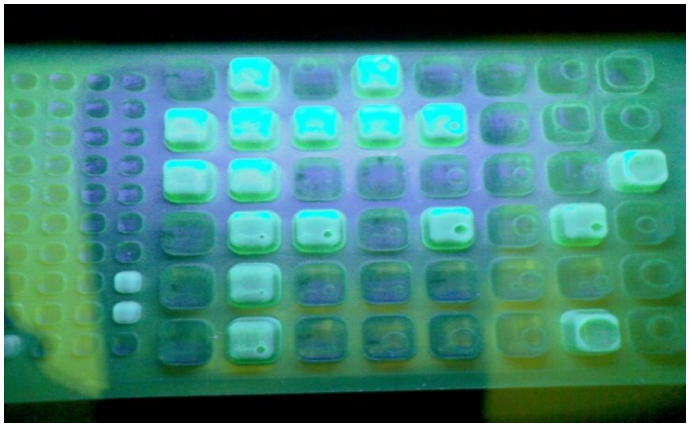


Figure 3.7b IDEXX 97 well Quanti tray 2000 with fluoresced wells

The number of wells was interpreted into a result using the IDEXX quanti-Tray 2000 Most Probable Number (MPN) table readings. In this example the result from the MPN Table was 24.0 for both coliforms and *E. coli* as shown in figure 3.8. This number was rounded up to give the result of 24 per 100 ml.

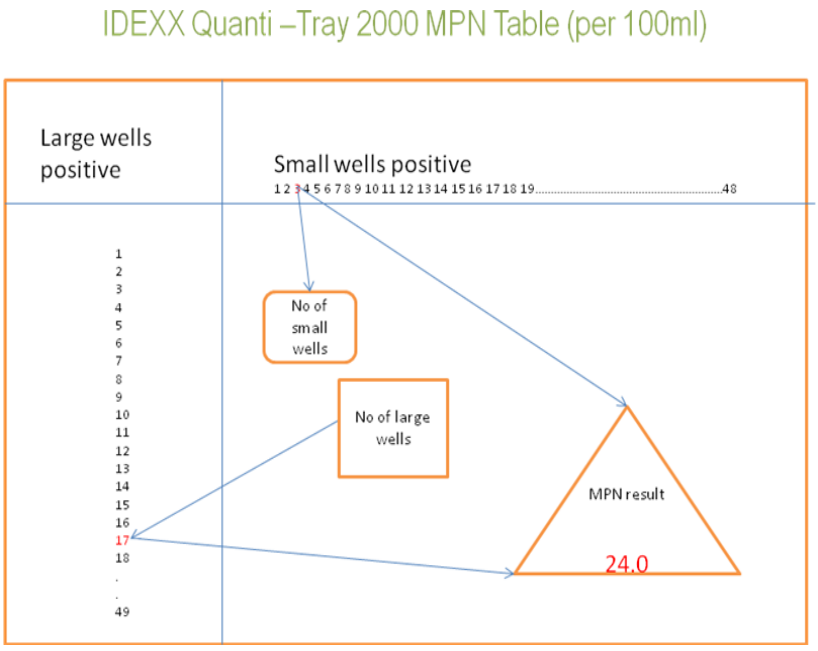
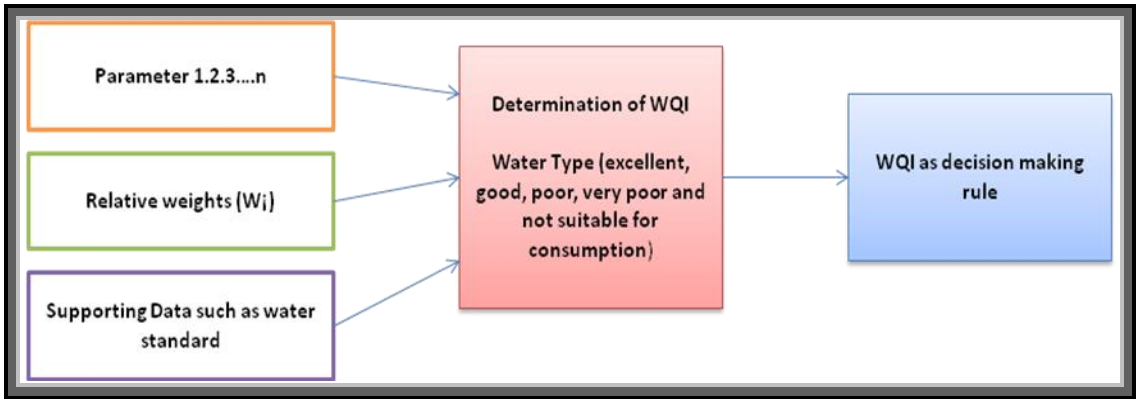


Figure 3.8 Quantification of a 97-well Quanti-tray results

3.4.3 Water quality Index (WQI)

After analysis of all the determinants, a WQI was calculated. In this technique the computation of weightage factor of water quality determinants, the supporting data which is water quality standard (SANS 241) and analysed concentration of respective determinants were used to calculate water quality index. The calculated WQIs of the different water sampling points were then used to assess if the water of a particular sampling point was suitable for human consumption as illustrated in Figure 3.7.



(Source: modified Sharma & Patel, 2010)

Figure 3.9 Water Quality Index technique approach

Calculation of WQI

For the calculation of the WQIs for the 20 water sampling points, the widely used formulations devised by Ramakrishnaiah et al., (2009) were used. The SANS 241 (2011) standard was used as the standard measurement in the calculation of the WQIs. For computing the WQI, three steps were followed. In the first step, the 23 determinants were assigned with a weight (wi) according to their relative importance in the overall quality of water for drinking purposes in South Africa. The maximum weight of five was given to nitrate, free chlorine and *E. coli* because of their importance in water assessment while weights of between two and four were assigned to the determinants such as chloride, fluoride, sulfate, magnesium, sodium, calcium, aluminium, arsenic, cyanide, iron, lead, mercury, and manganese, pH, temperature and electrical conductivity.

In the second step, the relative weight (Wi) was computed from the following equation:

$$W_i = w_i / \Sigma^{n}_{i=1} w_i \quad (1)$$

Where, Wi is the relative weight, wi is the weight of each determinant and n is the number of determinants.

In the third step, a quality rating scale (qi**)** for each determinant was assigned by dividing its concentration in each water sample by its respective standard according to the SANS 241 (2011) and the result multiplied by 100:

$$qi = (Ci / Si) \times 100 \quad (2)$$

Where qi is the quality rating, Ci is the concentration of each chemical determinant in each water sample in mg/L, and SI is SANS 241 (2011) for each determinant.

For computing the WQI, the SI was determined for each determinant, which was then used to determine the WQI as per the following equation;

$$SI = Wi.qi \quad (3)$$

$$WQI = \Sigma SI \quad (4)$$

Where SI is the sub index of ith determinant; qi is the rating based on concentration of ith determinant and n is the number of determinants.

The computed WQI values are classified into five types as shown in Table 3.2. If the water index value is less than 50 the water is deemed as excellent for drinking. The score of between 50 and 100 makes the water of good quality. However if the score rises to between 100 and 200 the water is qualified as poor. A value of 200 to 300 represents very poor water while a score of above 300 represents drinking water that is unsuitable for drinking (Ramakrishnaiah et al., 2009).

Table 3.2 Water quality classification based on WQI

WQI Value	Water Quality
<50	Excellent
>50 - <100	Good
>100 - <200	Poor
>200 - <300	Very Poor
>300	Unsuitable Drinking Water

Chapter 4

Experimental Measurements

4.1 Introduction

Physical, chemical and microbiological determinants were analysed for water sampled in the Bainsvlei area near Bloemfontein and the Woodlands Hills Estate in Bloemfontein. Water was collected at 20 sampling sites in three series approximately ten weeks apart, although only 19 sampling sites were sampled and analysed in Series 3. One sampling point was not accessible during the third series of sampling. The measurements of the different determinants were compared to the SANS 241 (2011) standard to determine compliance.

Seasonal variations of the various determinants were determined by comparing the measurements of the three sampling series. For both the physical and chemical determinants duplicate samples were taken during the first sampling series. Having found that no significant differences ($p < 0.05$) existed between the two measurements, only single measurements were taken in Series 2 and 3.

4.2 Sampling sites

In this study fifteen sites were sampled in the Bainsvlei area and five in the Woodlands Hills Estate in the outer region of western Bloemfontein as shown in Figure 4.1. Each of the sampling sites was provided with a unique number, classified and GPS coordinates recorded.

Figure 4.1 Map of sampling sites in Bainsvlei and Woodlands

The water sampled in this study was either from boreholes (12 sites) or from municipal taps (8 sites) as listed in Table 4.1. The groundwater sampled from the boreholes was not exposed to any form of treatment, while municipal water was treated.

Table 4.1 Water sampling sites in Bainsvlei and Woodlands

Area code	Area	Coordinates	Sample Type	Activity
B1m	Bainsvlei	S29.044390: E26.094634: E1420	MW	School
B2m	Bainsvlei	S29.035298: E26.074597: E1372	MW	Clinic
B3b	Bainsvlei	S29.020304: E26 575818: E1299	BH	Oil factory
B4b	Bainsvlei	S29.041105: E26.014767: E1343	BH	School
B5b	Bainsvlei	S29.041224: E26.013086: E1352	BH	Mixed farm

B6b	Bainsvlei	S29.024618: E26.021822: E1334	BH	Crop farm
B7b	Bainsvlei	S29.030825: E26.042479: E1338	BH	Pig farm
B8m	Bainsvlei	S29.030330: E26.044891: E1340	MW	General dealer store
B9m	Bainsvlei	S29.021647: E26.040459: E1330	MW	Rusk factory
B10b	Bainsvlei	S29.022299: E26.034204: E1328	BH	Chicken abattoir
B11m	Bainsvlei	S29.001508: E26.045321: E1326	MW	General dealer store
B12b	Bainsvlei	S29.005959: E26.032146: E1317	BH	Chicken farm
B13b	Bainsvlei	S29.022399: E26.034276: E1328	BH	Chicken abattoir
B14m	Bainsvlei	S29.022387: E26.034250: E1328	MW	Chicken abattoir
B15m	Bainsvlei	S29.034867: E26.101554: E1422	MW	Cultural village
W16b	Woodlands	S29.025573: E26.110107: E1412	BH	Residential area
W17b	Woodlands	S29.021819: E26.115850: E1373	BH	Residential area
W18b	Woodlands	S29.025046: E26.113739: E1389	BH	Residential area
W19b	Woodlands	S29.024975: E26.114046: E1386	BH	Residential area
W20m	Woodlands	S29.025207: E26.105411: E1411	MW	Residential area

BH = borehole; MW = municipal water, B = Bainsvlei; W = Woodlands, m = municipal; b = borehole

A variety of activities were recorded at the various sampling sites. These included factories that produced cold pressed oil and rusks, chicken abattoirs, general dealers and farms such as pig and crop farms. Potential pollution sources were recorded, for example manure and excessive ploughing that could pollute water with microorganisms and chemicals such as nitrates. Photos of examples of the different water sources were taken and are presented in Figure 4.2.

B7b

B9m

B14m

W18b

B11m

B8m

Figure 4.2 Pictures of some of the sampling sites (B = Bainsvlei and W = Woodlands Hill Estate)

4.3 Physical determinants

In this study the four physical determinants turbidity (measured in nephelometric turbidity units, NTUs) electrical conductivity (EC) (measured in mg/L), pH (measured in pH units) and temperature (measured in degrees Celsius) were measured over the three seasons to ascertain to what extent the measurements varied over the study period. The measurements of pH, EC and temperature fell within the SANS 241 (2011) specifications (Table 4.2). In contrast, turbidity revealed measurements that were outside the SANS 241 (2011) specifications in all three sampling series (marked in red in Table 4.2).

In Series 1, 65% of the sampling sites had turbidity measurements exceeding the SANS 241 (2011) standard of 1 NTU, 50% in Series 2 and 58.9% in Series 3. All mean values were greater than the SANS 241 (2011) specifications (Table 4.2). The dispersion around the mean for all three series' was relatively high. The ranges of the turbidity measurements for the three seasons were also high. The highest maximum value of the three series was found in the first series.

Table 4.2 Measurements and summary statistics of pH, turbidity, EC and temperature and SANS (2011) specifications of Series 1, 2 and 3

Sample code	pH (standard = 5 -9.5)			Turbidity (standard = 1 NTU)			EC (standard = <150mg/L)			Temp. (standard = 25°C)		
	pH S1	pH S2	pH S3	NTU S1	NTU S2	NTU S3	E.C S1	E.C S2	E.C S3	Temp S1	Temp S2	Temp S3
B1m	9.4	8.3	8.0	1.0	1.0	4.0	26.0	38.0	40.0	8.2	20.1	21.6
B2m	8.4	8.2	8.0	7.0	0.0	1.0	26.0	40.0	40.0	6.4	16.4	21.4
B3b	7.2	7.3	7.3	1.0	2.0	1.0	87.0	93.0	90.0	8.5	20.8	23.9
B4b	7.1	7.5	7.4	12.0	2.0	1.0	97.0	103	80.0	10.1	20.0	24.6
B5b	7.2	7.5	7.3	2.0	0.0	1.0	102	106	80.0	13.8	22.6	23.8
B6b	7.4	7.6	7.6	0.0	0.0	0.0	77.0	79.0	80.0	13.3	20.4	24.4
B7b	7.3	7.7	7.5	0.0	0.0	1.0	70.0	74.0	0.8	12.4	12.4	24.7

B8m	8.4	8.2	8.0	**6.0**	**5.0**	1.0	24.0	40.0	40.0	11.0	20.0	23.1
B9m	8.6	8.3	NA	**2.0**	0.0	NA	24.0	39.0	NA	12.5	19.0	NA
B10b	7.2	7.5	7.2	**20.0**	**29.0**	**16.0**	83.0	93.0	90.0	11.3	18.9	21.1
B11m	8.5	8.3	8.0	**2.0**	1.0	1.0	24.0	41.0	40.0	14.2	18.3	23.7
B12b	7.5	7.6	7.5	**5.0**	1.0	**3.0**	98.0	99.0	120.0	13.3	18.2	25.2
B13b	7.3	8.4	8.1	1.0	**3.0**	**2.0**	81.0	52.0	40.0	17.6	15.8	23.1
B14m	8.4	8.2	8.0	**7.0**	**6.0**	**5.0**	24.0	39.0	40.0	19.9	16.5	21.7
B15m	8.6	8.3	8.0	**3.0**	**2.0**	**3.0**	24.0	38.0	40.0	12.5	19.8	24.6
W16b	7.2	7.2	7.2	**39.0**	**5.0**	**32.0**	89.0	100.0	90.0	19.6	21.8	22.2
W17b	7.3	7.3	7.3	**126.0**	**34.0**	**63.0**	122.0	123.0	120.0	21.0	21.4	20.7
W18b	7.7	7.9	7.6	1.0	1.0	**10.0**	62.0	66.0	60.0	20.1	21.5	21.4
W19b	7.8	7.8	7.8	1.0	1.0	**4.0**	63.0	70.0	60.0	20.5	20.5	22.3
W20m	8.7	8.2	8.0	**3.0**	**5.0**	**5.0**	24.0	49.0	50.0	15.8	20.9	22.2
Median	7.6	7.8	7.6	2.5	1.5	3.0	66.5	68.0	64.0	13.3	20.0	23.1
Mean	7.9	7.9	7.7	11.9	4.9	8.1	61.4	69.1	69.2	14.1	19.3	22.9
Maximum	9.4	8.4	8.1	126.0	34.0	63.0	122.0	123.0	122.0	21.0	22.6	25.2
Minimum	7.1	7.2	7.2	0.0	0.0	0.0	24.0	38.0	39.0	6.36	12.4	20.7
SD	0.6	0.4	0.3	27.6	9.1	14.9	32.7	27.8	26.1	4.32	9.4	1.4
%	100	100	100	35	50	42	100	100	100	100	100	100
Compliance												

Red colour = exceed standard, B = Bainsvlei; W = Woodlands, m = municipal; b = borehole, NA = site not sampled, Temp. = Temperature; = EC = Electrical conductivity.

Many of the sampling sites had turbid water, a few with very turbid water, some of which were in all three series such as W17b (Figure 4.3). On the other hand only two sampling sites, B6b and B7b maintained a clean record of meeting the SANS 241 (2011) requirement throughout the three series.

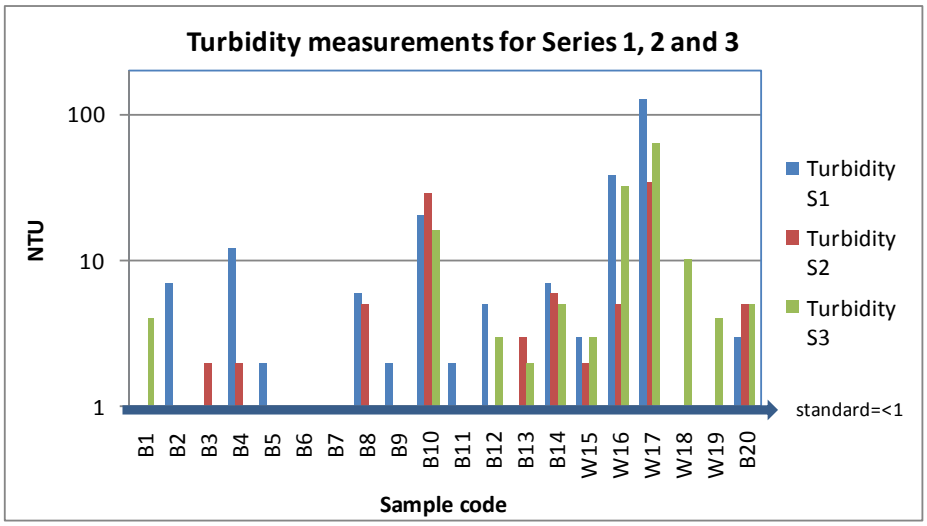


Figure 4.3 Turbidity measurements of sampling sites for Series 1, 2 and 3

4.4 Chemical determinants

In this study 10 macro-determinants (measured in mg/L) and seven micro-determinants (measured in µg/L) belonging to level 4 of the SANS 241 (2011) standard were measured over three visits with ten weeks apart. These measurements of the respective visits were compared with the SANS 241 (2011) specifications to determine compliance.

4.4.1 Chemical macro-determinants

The measurements of nine out of the 10 sampled macro-chemicals fell within the requirements of the SANS 241 (2011) specifications (Table 4.3). One of the sampling sites (W17b) showed relatively high magnesium levels, marginally below the maximum required by SANS 241 (2011). Nitrates, on the other hand, did not meet the SANS 241 (2011) specifications.

Table 4.3 Measurements and summary statistics of chemical macro-determinants and SANS 241 (2011) specifications for Series 1, 2, and 3

Sample code	Calcium (Ca)			Magnesium (Mg)			Sodium (Na)			Fluoride (F)			Chloride (Cl)			Nitrite (N)			Nitrate (N)			Sulfate $(SO)_4$			Ammonia (N)			Free chlorine		
SANS std mg/L	≤150			≤70			≤200			≤1.5			≤300			≤0.9			≤11			≤500			≤1.5			≤5		
Series	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
B1m	20.9	27.0	37.0	7.18	13.5	17.5	12.3	20.0	26.0	0.16	0.08	0.14	16.3	16.2	22.0	<0.01	<0.01	<0.01	0.20	0.01	<0.05	8.32	17.0	18.8	0.14	0.10	0.21	0.07	0.48	0.10
B2m	22.0	25.0	36.7	8.38	12.7	17.5	12.5	20.4	24.8	0.12	0.12	0.03	14.2	19.4	21.8	<0.01	<0.01	<0.01	0.53	0.02	<0.05	11.7	17.5	18.8	0.10	0.13	0.17	0.66	0.75	0.13
B3b	65.8	58.9	71.3	30.1	30.2	32.6	62.3	63.8	67.2	0.46	0.50	0.49	48.5	47.3	48.0	<0.01	<0.01	<0.01	23.5	18.3	19.6	51.1	52.3	55.4	0.09	0.09	0.14			
B4b	77.9	70.6	68.2	35.3	38.7	32.6	48.8	50.4	53.7	0.36	0.37	0.23	64.5	73.0	43.4	<0.01	<0.01	<0.01	29.6	34.3	21.8	55.4	58.4	55.5	0.09	0.08	0.14			
B5b	80.3	72.4	67.4	36.5	39.4	32.2	49.9	52.5	51.8	0.43	0.45	0.27	71.1	76.8	42.7	<0.01	<0.01	<0.01	32.5	35.1	21.9	57.1	59.6	55.1	0.10	0.09	0.15			
B6b	59.3	52.9	71.2	33.6	34.9	40.9	37.6	36.9	41.0	0.14	0.15	0.05	42.1	42.9	49.5	<0.01	<0.01	<0.01	9.29	10.2	10.4	16.7	15.5	17.1	0.18	0.07	0.10			
B7b	54.1	49.2	62.9	31.1	32.4	36.7	33.5	33.0	38.0	0.19	0.21	0.08	35.6	39.6	44.4	<0.01	<0.01	<0.01	12.9	12.4	15.4	12.6	11.7	12.1	0.10	0.08	0.11			
B8m	21.1	24.2	42.5	7.88	12.4	19.3	12.0	19.5	26.4	0.08	0.13	0.12	13.0	20.0	22.3	<0.01	<0.01	<0.01	0.42	0.01	0.00	11.4	17.1	19.0	0.12	0.08	0.12	0.23	0.76	0.14
B9m	20.7	26.3	NA	7.71	13.5	NA	12.2	20.3	NA	0.10	0.11	NA	13.0	19.7	NA	<0.01	<0.01	NA	0.43	0.02	NA	11.2	17.3	NA	0.10	0.07	NA	0.05	0.99	NA
B10b	61.9	64.9	79.2	34.2	42.2	49.8	43.4	42.3	38.3	0.32	0.12	0.08	48.7	58.4	65.8	<0.01	<0.01	<0.01	9.59	12.5	15.3	21.7	10.7	12.2	0.11	0.18	0.11			
B11m	21.0	25.0	37.2	7.85	12.7	17.3	12.1	20.1	24.3	0.09	0.10	0.05	13.0	20.1	21.4	<0.01	<0.01	<0.01	0.43	0.01	0.09	11.2	17.7	18.1	0.13	0.09	0.27	0.04	0.04	0.09
B12b	64.9	67.6	93.6	32.8	40.0	48.6	67.9	79.7	84.2	0.22	0.20	0.14	82.4	95.0	129	<0.01	<0.01	<0.10	8.43	9.13	9.04	14.8	14.2	14.0	0.11	0.08	0.12			
B13b	20.9	28.6	37.1	7.77	14.5	17.2	12.1	28.0	21.8	0.09	0.09	0.01	13.1	18.9	20.7	<0.01	<0.01	<0.01	0.37	<0.05	0.17	11.1	18.0	18.0	0.17	0.17	0.15			
B14m	65.8	26.0	40.2	41.1	13.4	18.5	29.0	21.1	24.1	0.15	0.15	0.04	33.3	19.4	22.3	<0.01	<0.01	<0.01	10.3	0.01	0.05	8.54	17.3	18.3	0.12	0.09	0.14	0.10	0.31	0.11
B15m	19.4	27.7	40.7	7.27	14.0	18.7	12.5	20.8	24.7	0.13	0.11	0.04	16.6	16.9	23.2	<0.01	<0.01	<0.01	0.28	0.01	0.08	8.26	17.5	19.3	0.17	0.13	0.16	0.30	0.50	0.10
W16b	70.1	72.3	84.4	35.2	38.4	42.8	49.2	57.3	56.0	0.25	0.17	0.10	67.3	81.5	74.7	<0.01	<0.01	<0.01	1.11	1.59	1.28	70.6	73.4	70.6	0.16	0.14	0.11			
W17b	98.6	89.6	104	56.4	56.4	65.5	48.1	50.2	55.4	0.01	<0.10	0.04	117	107	131	<0.01	<0.01	<0.10	3.42	2.88	2.60	93.0	100	131	0.11	0.25	0.10			
W18b	33.8	30.4	40.0	17.0	16.4	18.6	62.5	67.8	70.5	0.55	0.63	0.63	29.3	30.2	35.8	<0.01	<0.01	<0.01	<0.05	<0.05	0.00	30.0	30.6	32.0	0.20	0.27	0.16			

W19b	36.7	34.8	40.0	18.2	18.4	19.1	63.5	70.7	73.8	0.54	0.58	0.58	31.8	34.8	33.7	<0.01	<0.01	<0.01	<0.05	<0.05	0.00	35.3	37.0	34.4	0.23	0.27	0.20			
W20m	18.9	28.9	40.5	6.95	16.7	19.8	11.4	33.1	29.3	0.10	0.13	0.12	14.5	29.2	33.7	<0.01	<0.01	<0.01	0.30	<0.05	0.11	9.51	20.4	18.5	0.12	0.16	0.15	0.03	0.16	0.18
Median	45.4	32.7	42.5	24.2	17.6	19.9	35.6	35.0	38.3	0.16	0.14	0.10	32.6	32.6	35.8	0.00	-0.01	0.00	0.82	0.02	0.17	13.7	17.7	18.8	0.12	0.10	0.14	0.08	0.49	0.13
Mean	46.7	45.2	57.6	23.2	25.6	29.8	12.4	40.4	43.8	0.23	0.22	0.17	39.3	43.4	46.7	0.00	<0.01	0.00	7.18	6.84	6.21	27.5	31.2	33.7	0.13	0.13	0.15	0.18	0.50	0.20
Maximum	98.6	89.6	104	56.5	56.4	65.6	67.9	79.7	84.3	0.55	0.63	0.63	118	108	132	0.00	<0.01	0.00	32.5	35.2	21.9	93.1	100	132	0.23	0.27	0.27	0.66	0.99	0.61
Minimum	18.9	24.3	36.7	6.95	12.4	17.2	11.5	19.6	21.9	0.01	<0.10	0.01	13.0	16.3	20.7	0.00	<0.01	0.00	<0.1	<0.1	<0.1	8.26	10.7	12.1	0.09	0.07	0.10	0.03	0.04	0.09
SD	25.1	20.9	21.4	14.7	13.3	13.9	20.6	19.6	19.6	0.16	0.18	0.18	28.2	28.1	32.5	0.00	0.00	0.00	9.99	10.8	8.23	24.2	24.1	28.1	0.04	0.06	0.04	0.20	0.30	0.52
Range	79.6	65.4	67.5	49.5	44.0	48.6	56.4	60.2	62.4	0.54	0.73	0.63	105	91.4	110	0.00	0.00	0.00	32.6	35.2	21.9	84.8	90.2	120	0.14	0.20	0.17	0.63	0.90	0.17
% Compliance	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	**80**	**75**	**74**	100	100	100	100	100	100	100	100	100

NA = site not sampled; b = borehole; m = municipal; red colour = exceed standard; B = Bainsvlei; W = Woodlands

Of all the macro-determinants analysed, nitrates displayed measurements that were non compliant to the SANS 241 (2011) from the same sampling sites throughout the whole sampling period. In Series 1, 20% of the sampling sites did not comply with the SANS 241 (2011), in Series 2, 25% and 24% in Series 3. Sampling sites such as B3b, B4b, and B5b were non compliant in all the three series' and had maximum values that were double that of the standard limit of 11 mg/L. Two sites (B6b and B10b) were non compliant in the second and third series respectively (Figure 4.2).

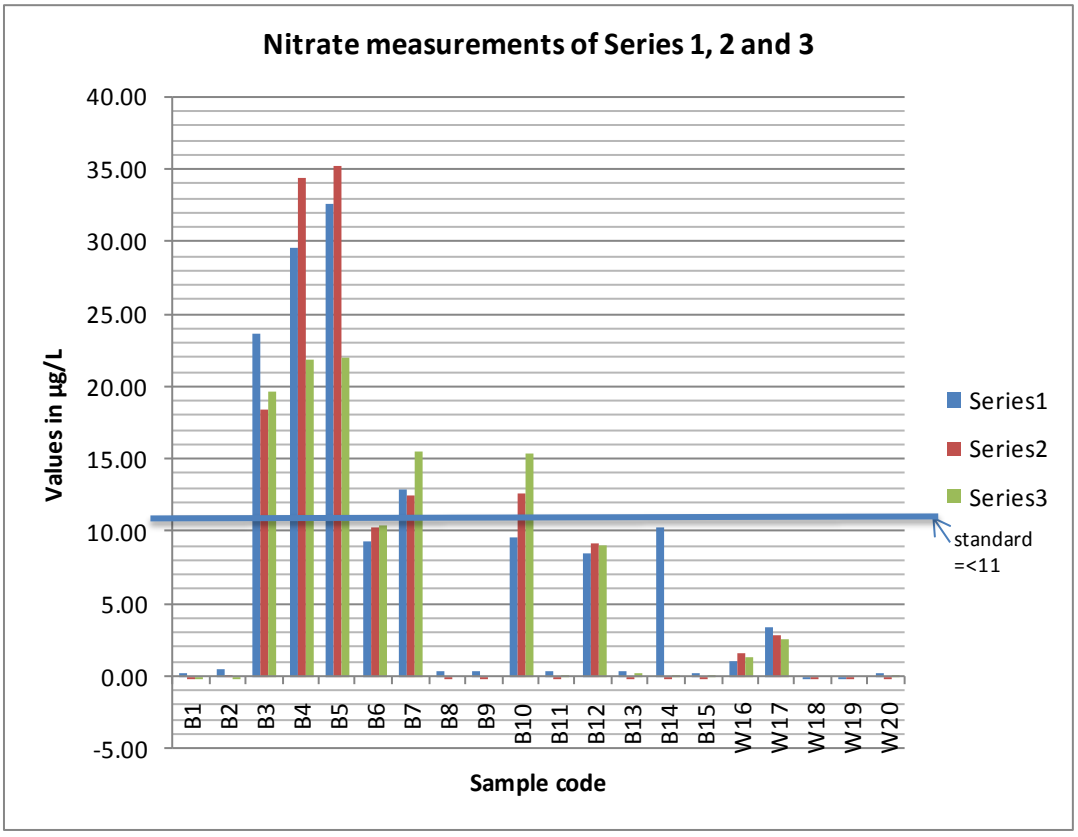


Figure 4.4 Nitrates measurements for Series 1, 2 and 3

4.4.2 Chemical micro-determinants

The measurements of almost all the micro-chemicals were within the SANS 241 (2011) requirement. Determinants such as arsenic, lead and mercury were not detected in all of the series' (Figure 4.7).

Table 4.4 Measurements and statistical summary of micro-chemical determinants in Series 1, 2 and 3 and SANS 241 (2011) specifications

Sample code	Aluminium (Al)			Arsenic (As)			Cynide (CN)			Iron (Fe)			Manganese (Mn)			Lead (Pb)			Mercury (Hg)		
SANS std µg/L	≤300			≤10			≤70			≤2000			≤500			≤10			≤6		
Series	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
B1m	46.5	17.6	0.02	<0.01	<0.01	<0.01	15.1	<2.00	0.01	32.8	15.9	0.01	8.03	5.98	0.01	<0.01	<0.01	<0.01	0.00	0.00	0.00
B2m	45.0	13.6	0.02	<0.01	<0.01	<0.01	11.3	2.14	0.00	42.4	14.2	0.01	10.4	9.43	0.01	<0.01	<0.01	<0.01	0.00	0.00	0.00
B3b	7.88	2.67	0.01	<0.01	<0.01	<0.01	3.16	<2.00	0.00	12.9	15.0	0.01	8.53	9.14	0.01	<0.01	<0.01	<0.01	0.00	0.00	0.00
B4b	0.00	4.76	0.01	<0.01	<0.01	<0.01	3.60	2.66	0.00	13.3	13.6	0.01	8.77	10.7	0.01	<0.01	<0.01	<0.01	0.00	0.00	0.00
B5b	5.85	4.17	0.00	<0.01	<0.01	<0.01	0.00	<2.00	0.00	10.0	14.5	0.01	9.66	11.8	0.01	<0.01	<0.01	<0.01	0.00	0.00	0.00
B6b	4.38	3.56	0.00	<0.01	<0.01	<0.01	2.39	<2.00	0.00	8.92	13.2	0.01	8.13	7.77	0.00	<0.01	<0.01	<0.01	0.00	0.00	0.00
B7b	0.00	4.56	0.00	<0.01	<0.01	<0.01	5.24	<2.00	0.00	8.6	13.4	0.01	7.30	8.37	0.01	<0.01	<0.01	<0.01	0.00	0.00	0.00
B8m	28.4	23.8	0.01	<0.01	<0.01	<0.01	5.83	<2.00	0.01	18.5	17.3	0.02	7.29	8.96	0.00	<0.01	<0.01	<0.01	0.00	0.00	0.00
B9m	21.7	23.2	NA	<0.01	<0.01	NA	5.31	<2.00	NA	15.0	18.0	NA	6.24	8.43	NA	<0.01	<0.01	NA	0.00	0.00	NA
B10b	105	102	0.01	<0.01	<0.01	<0.01	0.00	2.00	0.01	61.5	94.6	0.02	10.9	7.14	0.00	<0.01	<0.01	<0.01	0.00	0.00	0.00
B11m	20.3	20.5	0.02	<0.01	<0.01	<0.01	3.48	2.40	0.00	12.9	16.8	0.01	6.42	9.79	0.01	<0.01	<0.01	<0.01	0.00	0.00	0.00
B12b	14.0	3.02	0.00	<0.01	<0.01	<0.01	3.09	2.13	0.00	14.2	13.1	0.01	8.82	5.90	0.00	<0.01	<0.01	<0.01	0.00	0.00	0.00
B13b	30.4	39.6	0.01	<0.01	<0.01	<0.01	2.15	0.00	0.01	33.0	17.4	0.01	7.36	8.50	0.00	<0.01	<0.01	<0.01	0.00	0.00	0.00
B14m	8.63	24.2	0.01	<0.01	<0.01	<0.01	3.39	2.86	0.01	19.4	19.4	0.01	7.55	8.03	0.00	<0.01	<0.01	<0.01	0.00	0.00	0.00
B15m	18.12	20.2	0.01	<0.01	<0.01	<0.01	21.32	5.26	0.00	12.6	14.8	0.01	9.17	7.46	0.00	<0.01	<0.01	<0.01	0.00	0.00	0.00
W16b	15.0	4.97	0.00	<0.01	<0.01	<0.01	4.18	0.00	0.01	292	53.3	0.02	11.4	9.12	0.00	<0.01	<0.01	<0.01	0.00	0.00	0.00
W17b	10.2	0.89	0.00	<0.01	<0.01	<0.01	3.50	0.00	0.00	240	37.5	0.01	148	29.1	0.03	<0.01	<0.01	<0.01	0.00	0.00	0.00
W18b	8.85	5.64	0.00	<0.01	<0.01	<0.01	11.1	2.00	0.00	204	135	0.04	55.2	40.2	0.04	<0.01	<0.01	<0.01	0.00	0.00	0.00

W19b	14.1	5.39	0.00	<0.01	<0.01	<0.01	5.65	3.00	0.01	270	134	0.02	71.1	45.9	0.03	<0.01	<0.01	<0.01	0.00	0.00	0.00
W20m	19.3	28.1	0.01	<0.01	<0.01	<0.01	5.77	0.00	0.01	15.8	18.4	0.01	8.33	11.7	0.00	<0.01	<0.01	<0.01	0.00	0.00	0.00
Median	14.6	9.64	0.01	0.01	0.00	0.00	3.89	0.00	0.00	17.2	17.1	0.01	8.65	9.04	0.01	0.01	0.00	0.00	0.01	0.00	0.00
Mean	21.2	17.7	0.01	0.00	0.00	0.00	5.78	0.52	0.00	66.9	34.6	0.01	20.9	13.2	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	105	103	0.02	0.00	0.00	0.00	21.3	5.26	0.01	292	135	0.04	148	45.9	0.04	0.00	0.00	0.00	0.00	0.00	0.00
Minimum	0.00	0.89	0.01	0.00	0.00	0.00	0.00	-2.0	0.00	8.62	13.2	0.01	6.24	5.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SD	23.0	22.3	0.01	0.00	0.00	0.00	5.09	2.21	0.00	94 4	38.5	0.01	33.6	11.1	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Range	105	102	0.02	0.01	0.00	0.00	21.3	7.26	0.02	284	122	0.04	142	40.0	0.04	0.01	0.00	0.00	0.01	0.00	0.00
%																					
compliance	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

NA = site not sampled; b = borehole; m = municipal; B = Bainsvlei; W = Woodlands

4.5 Microbiological determinants

In this study the two microbiological determinants which were studied were *E. coli* and total coliforms. The measurements of the two determinants were compared to the SANS 241 (2011) for compliance.

Table 4.5 Measurements and statistical summary of microbiological determinants and SANS 241 (2011) of Series 1, 2 and 3

Sample code	Series 1		Series 2		Series 3	
	E.coli	Total coliforms	*E.coli*	Total coliforms	*E.coli*	Total coliforms
Standard/100ml	**0**	**≤10**	**0**	**≤10**	**0**	**≤10**
B1m	0	0	0	0	0	1
B2m	0	0	0	0	0	**21**
B3b	**3**	**119**	0	2	0	3
B4b	**1**	**17**	0	2	0	**18**
B5b	0	8	0	**2420**	0	9
B6b	0	**10**	0	**52**	0	3
B7b	0	**20**	0	**59**	0	4

B8m	0	0	0	0	0	**16**
B9m	0	0	0	2	0	NA
B10b	**9**	**196**	0	0	**2**	2
B11m	0	0	0	1	0	3
B12b	0	**201**	0	8	0	**2420**
B13b	0	**11**	0	5	0	**30**
B14m	0	0	0	2	0	**19**
B15m	0	0	0	0	0	0
W16b	0	2	0	**649**	0	1
W17b	0	**13**	0	0	**24**	**24**
W18b	0	0	0	0	0	1
W19b	0	**11**	0	1	0	2
W20 m	0	0	0	0	0	9
Median	0	5	0	2	0	4
Mean	1	30	0	160	1	136
Maximum	9	201	0	2420	24	2420
Minimum	0	0	0	0	0	0
SD	2	62	0	537	5	538
Range	9	201	0	2420	24	2420
% compliance	**85**	**55**	100	**80**	**90**	**65**

Red colour = exceed standard; NA = site not sampled; b = borehole; m = municipal

For coliforms, in Series 1, 45% of the sampling sites were not compliant with SANS 241 (2011), in series 2, 20% and in Series 3, 35%. *E. coli,* on the other hand, complied 100% with SANS 241 (2011) in Series 2, whereas in Series 1 and in Series 3 compliance was 85% and 90% respectively. Only one sampling point (B15m) maintained a clean record throughout the sampling period. In all three visits the same maximum value was displayed in both Series 2 and Series 3 for coliforms, while for *E. coli* the highest maximum value was in Series 3. The dispersion around the means of the three series was very high in the three visits demonstrating the wide range of measurements (Figure 4.5*)*.

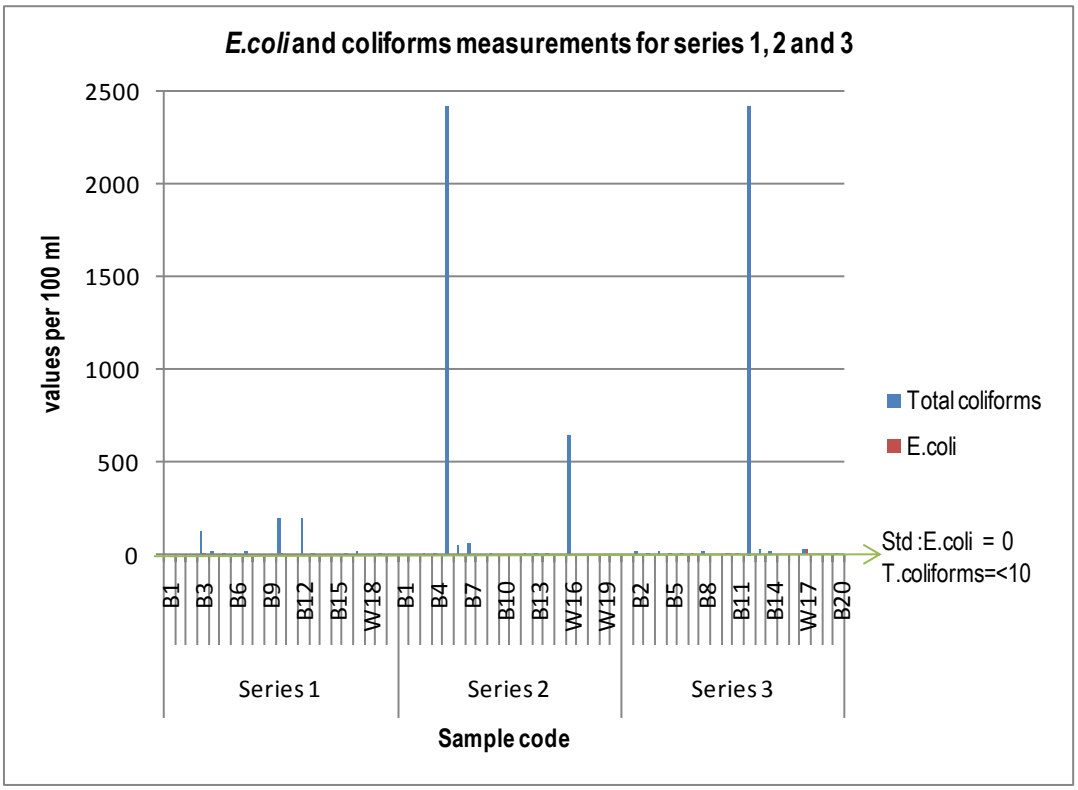


Figure 4.5 *E.coli* and coliforms measurements for Series 1, 2 and 3

Chapter 5

Comparative Analysis of Water Samples

5.1 Introduction

Statistical analyses were performed to firstly, compare the levels of all physical, chemical and microbiological determinants found in borehole water as opposed to municipal drinking water. Secondly, statistical analyses were performed on the data to explore whether seasonal variation in water quality existed. Significance of variation or differences in the determinants' concentrations was tested by applying analysis of variance (ANOVA) at 95% level of significance. Lastly, water quality indexes (WQIs) were calculated to obtain a notion of the overall drinking water quality of the different water sampling points.

5.2 Seasonal effects

5.2.1 Seasonal variation of physical determinants

For the respective physical determinants, analysis of variance tests revealed significant differences between the three sampling series for pH, EC and temperature ($p < 0.05$), while no significant differences could be established between the different sampling series' for turbidity ($p > 0.05$) (Table 5.1).

Table 5.1 ANOVA tests for seasonal variation of pH, EC, turbidity and temperature

Physical determinant	df	SS	MS	F value	*p* value
pH	2	1.34	0.67	5.91	0.01
Turbidity	2	1695.40	847.70	1.76	0.19
EC	2	66217.70	33108.90	122.54	0.00
Temperature	2	770.17	385.08	41.24	0.00

d = degrees of freedom; SS = sum of squares; MS = mean square; F= F value; *p* = probability; red colour = $p < 0.05$.

The post-hoc Scheffe tests revealed for pH significant differences ($p < 0.05$) between Series 1 and 2, as well as between Series1 and 3 (Table 5.2a). For temperature, significant differences were found between all season pairs ($p < 0.05$) (Table 5.2b). For EC only Series1 differed significantly from Series 3 ($p < 0.05$) (Table 5.2c).

Table 5.2 Post hoc Scheffe tests for (a) pH, (b) temperature and (c) electrical conductivity (EC)

a.

Series	Series 1	Series 2	Series 3
Series 1		0.008208	0.039078
Series 2			0.627040
Series 3			

b.

Series	Series 1	Series 2	Series 3
Series 1		0.000010	0.000000
Series 2			0.001912
Series 3			

c.

Series	Series 1	Series 2	Series 3
Series 1		0.252635	0.029058
Series 2			0.556218
Series 3			

Red colour = $p < 0.05$.

5.2.2 Seasonal variation of chemical determinants

Out of the 17 chemicals determinants measured, only 13 were analysed because no traces of arsenic, lead or mercury were found in any of the samples; hence these values (0) were not used. Similarly free chlorine was not analysed because it was only measured in municipal sampling sites. Of the 13 determinants analysed, ANOVA tests revealed seasonal variation for only the micro-determinants cyanide and iron ($p < 0.05$) (Table 5.3).

Table 5.3 ANOVA tests for seasonal variation of chemical determinants

Chemical determinant	df	SS	MS	F value	*p* value
Calcium	2	1783.76	891.88	1.66	0.20
Magnesium	2	438.98	219.49	1.06	0.35
Sodium	2	832.47	416.24	1.01	0.37
Fluoride	2	0.04	0.02	0.54	0.59
Chloride	2	532.71	266.36	0.29	0.75
Nitrite	2	0.00	0.00	0.29	0.75
Nitrate	2	9.34	4.67	0.05	0.95
Sulfate	2	375.23	187.62	0.27	0.77
Ammonia	2	0.00	0.00	0.60	0.55
Aluminium	2	1986.63	993.31	2.60	0.08
Cyanide	2	306.78	153.39	8.33	0.00
Iron	2	28637.25	14318.63	3.84	0.03
Manganese	2	1392.97	696.48	1.43	0.25

d = degrees of freedom; SS = sum of squares; MS = mean square; F= F value; *p* = probability; red colour = $p < 0.05$.

The post-hoc Scheffe tests revealed for cyanide significant seasonal differences between Series 2 and 3 and between Series 1 and 2 ($p < 0.05$) (Table 5.4a). Similarly, significant seasonal differences were also established between Series 1 and 3 for iron ($p < 0.05$) (Table 5.4b).

Table 5.4 Post hoc Scheffe tests for (a) cyanide and (b) for iron

a.

Series	Series1	Series2	Series3
Series 1		0.001298	0.730295
Series 2			0.014308
Series 3			

b.

Series	Series1	Series2	Series3
Series 1		0.252635	0.029058
Series 2			0.556218
Series 3			

Red colour = $p < 0.05$.

5.2.3 Seasonal variation of microbiological determinants

Although the two microbiological determinants were analysed, an ANOVA test was performed only on coliforms. This test established no significant differences between the different sampling series' for coliforms ($p > 0.05$) (Table 5.5).

Table 5.5 ANOVA test for seasonal variation of coliforms

Microbiological determinant	df	SS	MS	F value	*p* value
Coliforms	2	262008	131004.10	0.45	0.64

d = degrees of freedom; SS = sum of squares; MS = mean square; F= F value; *p* = probability

5.3 Municipal versus borehole effects

5.3.1 Municipal versus borehole variation of physical determinants

The measurements of the physical determinants of municipal sampling points were compared to that of the boreholes. Analysis of variance tests for the individual physical determinants revealed significant differences between municipal and borehole sampling points for pH and EC ($p < 0.05$), while no significant differences could be established between municipal and borehole sampling points for turbidity and temperature ($p > 0.05$) (Table 5.6).

Table 5.6 ANOVA tests for municipal versus borehole measurements of physical determinants

Physical determinant	df	SS	MS	F value	*p* value
pH	1	2.814	2.81	38.77	0.00
Turbidity	1	498.84	498.84	0.99	0.32
EC	1	11999.89	11999.89	7.26	0.01
Temperature	1	21.03	21.03	1.10	0.30

d = degrees of freedom; SS = sum of squares; MS = mean square; F= F value; *p* = probability; red colour = $p< 0.05$.

5.3.2 Municipal versus borehole variation of chemical determinants

The measurements of the chemical determinants of municipal sampling points were compared to that of the boreholes. Only the 13 chemical determinants for which measurements were obtained were analysed. Arsenic, lead and mercury were thus not included in the ANOVAs. Similarly, free chlorine was also excluded, because it was only measured in eight municipal sites. The ANOVA tests revealed that out of the 13 chemical determinants only seven determinants demonstrated significant differences between municipal and borehole measurements ($p < 0.05$) (Table 5.7).

Table 5.7 ANOVA tests for municipal versus borehole measurements of chemical determinants

Chemical Determinant	df	SS	MS	F value	*p* value
Calcium	1	5681.90	5681.90	17.58	0.00
Magnesium	1	2022.72	2022.72	17.09	0.00
Sodium	1	5194.91	5194.91	23.05	0.00
Fluoride	1	0.20	0.20	6.89	0.01
Chloride	1	8782.07	8782.07	12.39	0.00
Nitrite	1	0.00	0.00	0.09	0.77
Nitrate	1	935.20	935.20	9.68	0.00
Sulfate	1	3405.24	3405.24	5.22	0.03
Ammonia	1	0.00	0.00	0.85	0.36
Aluminium	1	360.94	360.94	1.17	0.29
Cyanide	1	58.07	58.07	3.85	0.06
Iron	1	6712.70	6712.72	1.42	0.24
Manganese	1	937.86	937.86	1.50	0.23

d = degrees of freedom; SS = sum of squares; MS = mean square; F= F value; *p* = probability; red colour = $p < 0.05$.

5.3.3 Municipal versus borehole variation of microbiological determinants

Although the two microbiological determinants were analysed, an ANOVA test was performed only on coliforms. This test established no significant differences between the different sampling series' for coliforms ($p > 0.05$) (Table 5).

Table 5.8 ANOVA tests for municipal versus borehole measurements of coliforms

Microbiological determinant	df	SS	MS	F value	*p* value
Coliforms	1	251839.00	251839.20	0.89	0.35

d = degrees of freedom; SS = sum of squares; MS = mean square; F= F value; *p* = probability;

5.4 Water quality index

5.4.1 Introduction

WQIs were computed to rate the composite influence of all 23 individual water quality determinants (physical, chemical and microbiological) on the overall quality of each water sampling source in the three seasons. For the computation of WQIs, the SANS 241 (2011) compliance limits for individual determinants were used as the basis of supporting data to assign weights and to calculate quality ratings.

WQI calculation

For computing WQIs, three steps were followed. In the first step, each of the 23 determinants was assigned a weight (wi) according to its importance in the overall quality of water for drinking purposes and its effect on the health of the consumers (Ramakrishnaiah et al., 2009; Ishaku, 2011). The weights were assigned according to Ramakrishnaiah et al., (2009). For the determinants that were not previously rated, the prescribed risk (health, operational and aesthetic) associated with consumption of such determinants were used as the basis for assigning the weights (SANS 241, 2011). Similarly, for determinants EC, temperature turbidity and pH, the effect posed by these determinants on chlorination and bacterial persistence in drinking water contributed in assigning weights to such determinants (LeChevallier et al., 1991). Consequently, the maximum weight of five was assigned to the

parameters nitrate, free chlorine and *E. coli*, because these determinants are important in water assessment and impact on public health (Vasanthavigar, 2010).The value of four was assigned mostly to those determinants with a chronic health risk such as cyanide, sulfate, mercury and arsenic. The lowest value of two was assigned to determinants that mostly have an aesthetic risk such as ammonia and calcium.

In the second step, the relative weight (Wi) was determined for each determinant, which was computed from the following equation:$Wi = wi / \Sigma^{n}w^{i=1}$ where, Wi is the relative weight, wi the weight of each determinant and n the number of determinants(Table 5.9).

Table 5.9 Weight and relative weight of determinants

Parameters	SANS 241	Weight(wi)	Relative weight (Wi)
Turbidity	≤ 1	4	0.048780
E. conductivity	≤170	4	0.048780
pH	5.0 - 9.5	4	0.048780
Temperature	25°C	4	0.048780
Free Chlorine	≤ 5 mg/L	5	0.060976
Ammonia(N)	≤1.5 mg/L	2	0.024390
Calcium (Ca)	≤150 mg/L	2	0.024390
Chloride (Cl)	≤300 mg/L	2	0.024390
Fluoride (F)	≤1.5 mg/L	4	0.048780
Magnesium (Mg)	≤ 200 mg/L	3	0.036585
Nitrate (N)	≤11 mg/L	5	0.060976

Nitrite (N)	≤0.9 mg/L	5	0.060976
Sodium (Na)	≤ 200 mg/L	3	0.036585
Sulfate (So4)	≤ 500 mg/L	4	0.048780
Aluminium (Al)	≤ 300 µg/L	4	0.048780
Arsenic (As)	≤ 10 µg/L	4	0.048780
Cyanide (CN-)	≤ 70 µg/L	4	0.048780
Iron (Fe)	≤ 2000 µg/L	2	0.024390
Lead (Pb)	≤ 10 µg/L	4	0.048780
Manganese (Mn)	≤ 500 µg/L	2	0.024390
Mercury (Hg)	≤ 6 µg/L	4	0.048780
E. coli	0/100 mL	5	0.060976
T.coliforms	10/100 mL	2	0.024390
n =23		Σwi = 82	ΣWi=1

SANS 241 = SANS 241 (2011); EC = electrical conductivity

In the third step, a quality rating scale (qi) for each determinant was determined by dividing its concentration in each water sample by its respective standard according to the SANS 241 (2011) and the result multiplied by 100. The formula for the calculation of the quality index rating, qi = (Ci / Si) x 100 was used, where qi is the quality rating, Ci the concentration of each determinant in each water sample in mg/L or µg/L, and Si the SANS 241 (2011) compliance limit for each determinant.

In the last step, the WQIs were computed for all the sampling sources providing a single value describing the water quality of a particular water source (Table 5.10). Firstly the SIi were computed using the formula SIi=Wi.qi, where Wi is the relative weight and qi quality rating after which the WQIs were calculated using the formula WQI = ΣSIi, where SIi is the sub index of ith determinant; qi is the rating based on concentration of ith determinant and n is the number of determinants.

Table 5.10 Water quality indexes and Water quality ranges of Series 1, 2 and 3

Sample code	Sample type (BH/MW)	Series 1		Series 2		Series 3	
		WQI	WQR	WQI	WQR	WQI	WQR
B1m	MW	0	Excellent	53	Good	68	Good
B2m	MW	0	Excellent	48	Excellent	57	Good
B3b	BH	112	Poor	69	Good	66	Good
B4b	BH	131	Poor	79	Good	70	Good
B5b	BH	75	Good	661	Very Poor	68	Good
B6b	BH	53	Good	66	Good	56	Good
B7b	BH	57	Good	67	Good	63	Good
B8m	MW	76	Good	73	Good	57	Good
B9m	MW	57	Good	49	Excellent	NA	NA
B10b	BH	252	Very Poor	199	Poor	147	Poor
B11m	MW	57	Good	53	Good	54	Good
B12b	BH	126	Poor	62	Good	662	Unsuitable
B13b	BH	52	Good	65	Good	65	Good
B14m	MW	91	Good	78	Good	76	Good

B15m	MW	64	Good	59	Good	63	Good
W16b	BH	240	Very Poor	231	Very Poor	205	Very Poor
W17b	BH	672	Unsuitable	218	Very Poor	513	Unsuitable
W18b	BH	55	Good	55	Good	98	Good
W19b	BH	58	Good	56	Good	70	Good
W20m	MW	63	Good	74	Good	75	Good

WQI = Water Quality Index; WQR = Water quality Range; BH = Borehole; MW = Municipal water; b = borehole; m = municipal

A comparison of the two source types (borehole and municipal) was made using the computed WQIs per series. The WQI values in Series 1 ranged from 0 (B1m, B2m) to 672 (W17b). In Series 2 the WQI values ranged from 48 (B2m) to 661 (B5b) while in Series 3 the range was from 54 (B11m) to 662 (B12b). For all three series', the sampling sites with the lowest WQI values were municipal sources while borehole sources had the highest WQI values. The high WQI value at sampling site W17b in Series 1 can be attributed to the high values of turbidity. Similarly, in B5b Series 2 and B12b in Series 3 the WQI values were elevated because of high coliform count. Throughout the sampling periods only borehole sampling sites were found to be poor, very poor or unsuitable as compared to municipal sampling sites which were either excellent or good (Table 5.11).

Table 5.11 Water quality by source type

	Series 1			**Series 2**			**Series 3**		
Water quality range	**MW**	**BH**	**Total**	**MW**	**BH**	**Total**	**MW**	**BH**	**Total**
Excellent	2	0	2	2	0	2	0	0	0
Good	6	6	12	6	8	14	7	8	15
Poor	0	3	3	0	1	1	0	1	1
Very Poor	0	2	2	0	2	2	0	1	1

Unsuitable	0	1	1	0	1	1	0	2	2
Total	**8**	**12**	**20**	**8**	**12**	**20**	**7**	**12**	**19**

MW = municipal water; BH = borehole water.

The computed WQIs were categorized into five types to show percentages of water samples that fell within the different water quality categories. These types ranged from “excellent water” to “water that is unsuitable for drinking purposes”. This classification provided an idea of the overall water quality in the study area over the different series. In all the three series the water quality category with the highest percentage was “good” water. When combining the excellent and good quality category, Series 2 had the highest percentage of 80% followed by Series 3 with 79% and Series 1 with 70%. On the other hand when combining the poor, very poor and unsuitable water quality categories Series 1 had the highest percentage of sampling sites of 30% followed by Series 3 with 21% and Series 2 at 20% (Table 5.11).

Table 5.12 Water quality ranges by percentages

Water quality value	**Water quality**	**Percentage (%)per series**		
		1	**2**	**3**
< 50	Excellent water	10	10	0
<50–>100	Good water	60	70	79
<100–>200	Poor water	15	5	5
<200–>300	Very poor water	10	10	5
> 300	Water unsuitable for drinking purposes	5	5	11

Chapter 6

Discussion and Conclusions

6.1 Discussion

This study was undertaken to investigate the drinking water quality of different water sources (municipal and borehole) in the peri-urban area of Bainsvlei and Woodlands Hills Estate in Bloemfontein. These areas use treated water supplied by the MMM and also untreated water obtained from boreholes. The Bainsvlei area was selected because it is beyond the urban edge of Bloemfontein and is known for farming and small holding businesses. These businesses include small businesses such as pig farming, an oil extraction plant, chicken abattoirs, a rusk factory and a number of small shops. This consideration was important as urban fringe areas, such as Bainsvlei, are particularly susceptible to the dangers of polluted water, particularly because these communities often do not have access to treated water (municipal water) and have to rely solely on groundwater (Adams et al., 2001).

Water quality indexes (WQIs) were computed to provide a better understanding of the overall water quality of the respective municipal and boreholes water sources. This mathematical calculation was used to transform all the measurements of a particular water source into a single descriptive value (Sanchez et al., 2007; Ramakrishnaiah et al., 2009; Kilgour et al., 2013). The percentage of water sources with WQIs that placed them into the categories of *excellent* and *good* was 70% in the first series, 80% and 79% for Series 2 and 3 respectively. It could therefore be concluded that the overall water quality was relatively good in all three series. The study also revealed four determinants which demonstrated levels higher than the SANS 241 (2011) requirement that could be of public health concern (SANS 241, 2011). These determinants were turbidity, high nitrate concentrations, and high numbers of coliforms including *E. coli.*

The revelations of this study concur with the Blue Drop score, which is a comprehensive measure of the water quality status. The Blue Drop assessment goes beyond quality of drinking water alone but also looks into other fields such as risk assessment, operations and asset management. In 2010 MMM scored the required 95% target of excellence which all water service authorities (WSA) and water service providers (WSP) should aspire to achieve (DWAF, 2009a; Prince & Williams, 2012). Unfortunately, in 2011 the municipality scored 84.69% and did not obtain the Blue Drop status. A number of defects were found which led to the poor score. These defects included fluoride failures in water as well as the deterioration of water in the distribution network from Welbedacht dam which supplies the western part of Bloemfontein (DWA, 2011). Similarly in 2012 the municipality scored 84.45% which is still below the required score of 95%. The factors which affected the score include among others lack of chemical compliance monitoring programme in the Mangaung west, poor approach to incident management, and lack of full participation of all staff in the improvement of water safety planning process. This planning, is a fundamental component of the Blue Drop Certificate Programme, which is considered the safety net to ensure that people's lives are not placed at risk when issues of contamination occur (DWA, 2012).

The physical determinants mostly revealed compliant measurements. Compliance for pH, EC and temperature was 100% in all the three series'. Turbidity, on the other hand, demonstrated relatively high non compliant values of 65% for Series 1, 50% for Series 2 and 58% for Series 3. When looking at the seasonal variation, pH, EC and temperature demonstrated significantly different values ($p < 0.05$), while for turbidity there were no significant differences between series ($p > 0.05$). When municipal water sources were compared to that of borehole water, pH and EC differed significantly ($p < 0.05$), while turbidity and temperature were not significantly different ($p > 0.05$).

Turbidity in water is generally caused by suspended matter such as clay, silt, organic and inorganic matter and microscopic organisms (LeChevallier et al., 1991). Series 1 sampling was preceded by the summer and autumn rains while the spring rains preceded Series 3 (World Weather, 2013). These rains probably contributed to the relatively high turbidity values by eroding surface soils, conveying agricultural and urban runoff, as well as other pollutants into surface water sources in the vicinity of the sampling sites (Adekunle et al., 2007).

The Welbedacht dam and Caledon River are surface water sources of sampling points in this study area (DWAF, 2009b) before purification. When these sources are affected by the rain, they could in turn pollute groundwater sources through leaching (Luchini, 2013). Similarly, groundwater turbidity could also be caused by inorganic particulate matter resulting from weathering of rocks (Cobbinna et al., 2013). High turbidity levels in groundwater indicate potential contamination of the water by a number of pollutants such as algae and high chemical content (USEPA, 1999a; Salih et al., 2012). These high levels of turbidity are a public health concern as the water may contain toxins, harbour microorganisms and produce unwanted smells and tastes (Shah et al., 2013).

High levels of turbidity in surface water generally increase chlorine demand for those surface water sources that are treated for drinking purposes (Galal-Gorchev, 1996; Negoitescu & Tokar, 2012). The disinfection efficiency demand model predicts that an increase in turbidity from 1 NTU to 10 NTU would result in an eightfold decrease in efficiency of disinfection (Xu & Braune, 2010). Thus, high turbidity measurements are usually an indication of inadequate treatment in municipal drinking water (Salih et al., 2012). If water is not adequately disinfected, turbidity also promotes regrowth of pathogens in the distribution system leading to waterborne outbreaks such as gastroenteritis (Huben, 1991 in USEPA, 1999b). In developing countries such as India and East Africa, where municipal water is chlorinated without being coagulated and filtered, disinfection has been ineffective resulting in large outbreaks of acute hepatitis (Kumar, 2013).

Organic material in drinking water such as humic and fulvic acids from the decay of vegetable and animal matter react with chlorine to produce disinfection by-products (DBPs) (USEPA, 1999c). Of these DBPs, trihalomethanes (THMs) are produced in high concentrations and are persistent in water. Studies have shown an association between THMs and several cancers such as rectum and bladder in humans (ADWG, 2011).

The other chemical determinants studied complied with the SANS requirement except nitrates. Nitrates demonstrated non compliance of 20%, 25% and 26% in Series' 1, 2 and 3 respectively. Four boreholes (B3b, B4b, B5b, and B7b) did not comply in all three series, while borehole B10b did not comply in the second and third series only. When the measurements of the three series were compared, no significant differences could be demonstrated for all the chemicals ($p > 0.05$), except for cyanide and iron ($p < 0.05$). Furthermore, when the municipal water sources were compared to boreholes significant differences ($p < 0.05$) were indicated for seven chemicals (Ca, Mg, Na, F, Cl, N and SO_4).

All the boreholes that demonstrated non compliant levels of nitrates were in the vicinity of the agricultural area. Nitrates in this area were probably produced from the oxidation of vegetable and animal debris, agricultural fertilization, manure and animal feeds (Elhatip et al., 2003) which then infiltrated into the water by means of rainfall and runoff (Self & Waskom, 2008). Additionally, the presence of nitrates in water may also be accompanied by pesticides and bacterial contaminants (Rao Prakasa & Putanna, 2000). Shallow boreholes and those with less than 12 m of lining and not properly sealed are particularly at a risk of being contaminated (Landon et al., 2012).High levels of nitrates in drinking water may contribute to a number of human health effects. For example, ingesting nitrate contaminated drinking water during early pregnancy may increase the risk of certain birth defects such as neural tube and cleft palate (Fan & Steinberg, 1996). Exposure to high levels of nitrates may also cause methemoglobinaemia in young children, especially infants younger than five months (Bundy et al., 2011). Infants

suffering from gastrointestinal disturbances are particularly vulnerable and could suffer brain damage and even die if severe (Fewtrell, 2004). Additionally, studies such as the one conducted in Slovakia, Spain and Hungary in 2001 and 2002 found a correlation between nitrates and stomach cancer in adults. In animals, especially those that are underfed, nitrate contaminated water results in poor appetite, poor animal growth and abortions (Bundy et al., 2011). *N*-nitroso compounds (NOC) have also been found to cause cancerous tumors in animals (Ward et al., 2005; Adekunle et al., 2007).

Coliforms are naturally found in the soil. In water, coliforms may be caused by agricultural runoff, effluent from septic systems or sewage discharges as well as infiltration of domestic or wild animal faecal matter (Adekunle et al., 2007). Thus, the presence of coliforms in water indicates the potential for the presence of disease causing organisms (Shah et al., 2013). Water source compliance for the presence of coliforms in this study revealed non compliant values of 45%, 20% and 35% in Series 1, 2 and 3 respectively. The improved compliance in the second series can be attributed to the cold winter temperatures which could have inhibited the growth of microorganisms (Low, 2001). In Series 3, at the onset of spring September to November, rains and increased temperatures contributed again to the dropping of compliance (Zamxaka et al., 2004). In Series 1 and 2 all the non-compliant sources were boreholes while in the third series 57% of the non compliant sources were boreholes. A seasonal comparison of the presence of coliforms revealed no significant differences between the three series ($p > 0.05$). Similarly, no differences for the presence of coliforms could be established when the municipal and borehole water sources were compared ($p > 0.05$).

The presence of *E. coli* in water indicates contamination of water with faecal matter from warm blooded animals including humans (AGWT, 2012). Compliance of *E. coli* was 100% for Series 2, while for Series 1 compliance was 85% and 90% for Series 3. All non compliant water sources were boreholes with a maximum value of nine in

Series 1 and 24 in Series 3. Once again the presence of *E. coli* in Series 1 and 3 could be attributed to the rains which caused leaching of pathogens from manure into the water sources (Zamxaka et al., 2004). Consumers of *E. coli* contaminated water are at risk of contracting diarrhoeal diseases (Makoni, 2001). For example, a child living on a cattle farm in Ontario was hospitalised with bloody diarrhoea. After several tests were conducted it was found that the cause of the illness was *E. coli* 0157:H7 found in the well water. The source of contamination was manure contaminated surface water which had seeped into the well during heavy rains (Jackson et al., 1998).

6.2 Conclusions

This study revealed that the water quality of some water sources in the fringe urban areas of Bloemfontein are of concern. These data strongly support the below standard Blue Drop scores attained by the water service provider (Bloem Water) which supplies Mangaung West including the study area (DWA, 2012). The Blue Drop reports highlighted the aging distribution network, drinking water quality compliance and poor water safety planning process as major contributors to the deterioration of water quality (DWAF, 2009a; DWA, 2011; 2012).

It has thus become clear from the Blue Drop assessment and the revelations of this limited study that the areas of concern identified needs to be investigated and addressed to ensure that water quality in the greater Mangaung region is improved, thereby facilitating the attainment of goal seven of the eight United Nations General Assembly Millennium Goals which is to "Ensure Environmental sustainability*"*. This broad goal has a number of explicit targets such as target 10 which states that all nations are to "*half by 2015 the proportion of people without sustainable access to safe drinking water and sanitation"* (MDGs, 2000).

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