Drinking water quality in towns of Alfred Nzo District Municipality in the Eastern Cape Province

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By

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Declaration

I, Magareth Thulisile Ngcongo, declare that the subject matter of experimental work entitled '**Drinking water quality in towns of Alfred Nzo District Municipality in the Eastern Cape Province**' was conducted at the Central University of Technology, Free State, under the supervision of Dr Leana Esterhuizen and Professor Annabel Fossey.

I have used only the literature and other information sources that are cited in the work and listed in the bibliography at the end of this work. No part of this dissertation has been submitted for any research degree or diploma to any other University/Institute.

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Magareth Thulisile Ngcongo

March 2019

I certify that the above statement is correct

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Dr Leana Esterhuizen

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Abstract

Background: Access to safe potable drinking water continues to be one of the most pressing challenges for rural communities in South Africa. It is estimated that 3.5 million of people in South Africa do not have access to safe drinking water. The Eastern Cape Province has been participating in Blue Drop assessments since 2009. The Blue Drop score for the Eastern Cape Province declined in 2014 with 10% from the previous assessment, from 82 to 72%. The Blue Drop results identified that municipal drinking water quality management in the Eastern Cape Province varied from excellent to unsatisfactory. Since 2009, the Alfred Nzo District Municipality was unsuccessful in obtaining Blue Drop certification. The aim of the study was thus to assess the quality of drinking water from six water distribution networks in the Alfred Nzo District Municipality over a period of three years.

Methodology: Drinking water samples were collected on a monthly basis from 32 drinking water sampling points. Six drinking water samples were collected from the clean drinking water outlet of each drinking water distribution network and 26 drinking water samples from the end-user water sampling points. The drinking water samples were analysed for eight drinking water quality parameters. The parameters included turbidity, pH, temperature, electrical conductivity, total dissolved solids, free residual chlorine, *Escherichia coli* and coliform bacteria. The measurements were statistically analysed and also compared to the drinking water quality standards specified by SANS 241 (SABS, 2015). To ascertain the overall quality of a particular sampling site, a water quality index (WQI) was also calculated for each of the drinking water sampling points. The Canadian Council of Ministers of the Environment Water Quality Index (CCME–WQI) was selected and used, taking into account of the WQI that allowed for multiple rounds of measurements.

Results: The drinking water quality measurement for pH, temperature, electrical conductivity, total dissolved solids and free residual chlorine were within acceptable limits in all three years according to SANS 241 (SABS, 2015). Although free residual chlorine was within prescribed limits, the measured values were at very low levels. The turbidity measurements of drinking water quality measured in all water distribution networks indicated that results were variable; from acceptable to unacceptable levels. The measurements of the two microbiological parameters, total number of *Escherichia coli* and total number of coliform bacteria exceeded the limits specified by SANS 241 (SABS, 2015). For the total number of coliform bacteria, 90% were non-compliant, while 94% of the measurements of total number of *Escherichia coli* were non-compliant. The CCME–WQI calculations supported statistically outcome. The CCME–WQI values of all water sampling points ranged from 68 to 80. These findings revealed that the drinking water quality of all water sampling points were of poor quality.

Conclusions: The high turbidity may lead mostly to ineffective or poor disinfection. The presence of *Escherichia coli* indicates faecal pollution, possible presence of pathogens and ineffectiveness of the disinfection processes. Polluted drinking water may cause waterborne illnesses such as diarrhoea, which is one of the major causes of child mortality globally. The high levels of coliform bacteria in the drinking water are indicative that the treatment on the drinking water was incomplete.

Keywords: Drinking water quality, *Escherichia coli*, coliform bacteria

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Abbreviations and Acronyms

α	Alpha
ANDM	Alfred Nzo District Municipality
ANOVA	Analysis of Variance
°C	Degrees Celsius
CCME-WQI	Canadian Council of Ministers of the Environment Water Quality Index
CSIR	Council for Scientific and Industrial Research
DoH	Department of Health
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	Electrical Conductivity
EHPs	Environmental Health Practitioners
EPA	Environmental Protection Agency
IRIS	Integrated Regulatory Information System
IWA	International Water Association
µS	Micro Siemens
MPN	Most Probable Number
NFSWQI	National Sanitation Foundation Water Quality Index
NTU	Nephelometric Turbidity Units
SABS	South African Bureau of Standards
SANS	South African National Standards
TDS	Total Dissolved Solids

THMs	Trihalomethanes
TOC	Total Organic Carbon
USGS	United States Geological Survey
WAWQI	Weight Arithmetic Water Quality Index
WDN	Water Distribution Network
WHO	World Health Organization
WQI	Water Quality Index
WSA	Water Services Authority
WSP	Water Sampling Point
WTP	Water Treatment Plant
W-WQI	Weighted Water Quality Index

Chapter 1

Introduction

1.1. Introduction

Water is one of the most precious gifts provided by nature to all living creatures. It plays a vital role in the survival of all forms of life on earth (Ali et al., 2013). Water is a fundamental human need and plays an essential role in people's health, food production and the environment (Jafari et al., 2018). Every person on the planet needs water every day for drinking, cooking and for keeping themselves clean (Ali et al., 2013). Clean, safe and adequate fresh water is essential for domestic, industrial, agricultural, recreational and environmental activities (DWAF, 1996; DWAF, 2004; Shihab and Chalabi, 2014).

The quality of surface water is affected by a wide range of natural and anthropogenic activities. The most natural processes that affect the quality of water are rainfall and geology influences. Rainfall generates runoff which carries waste such as plastics, papers, faeces and sewage, and channels them into nearby streams (Chigor et al., 2012). Runoff may also carry plant debris, silt, and clay to rivers and streams, making the water appear muddy or turbid (Summerscales and Mcbean, 2011). Anthropogenic activities that affect the quality of water include agriculture, industry and mining activities (Zaidi et al., 2016). Agricultural contaminants include fertiliser, pesticide, animal waste and microorganisms. Microorganism contaminants originate mostly from human and animal faecal matter, such as *Escherichia coli (E. coli)* and coliform bacteria. Industry and mining activities contribute mostly to the chemical deterioration of surface water. Chemical contaminants include arsenic, uranium, nitrates, and phosphates (Zaidi et al., 2016).

The quality of water is described in terms of its physical, chemical and microbiological parameters. These parameters determine the fitness of use (Abera et al., 2017). In South Africa, the South African Bureau of Standards (SABS) (2015), which is prescribed by the Department of Water Affairs and Forestry (DWAF, 1997), dictates acceptable levels of these parameters. For drinking water to be of acceptable quality, SABS (2015) specifies the acceptable levels of these drinking water parameters for the points of delivery. Whether or not drinking water is safe will depend on which substances are present and in what concentrations (Mhlongo et al*.,* 2018). Physical parameters of particular interest in assessing drinking water quality are turbidity, pH and electrical conductivity, while chemical parameters include the concentrations of, for example, free residual chlorine, nitrate, phosphate, sulphate and several minerals (SABS, 2015). The biological parameters are usually assessed in terms of the presence of the indicator microorganisms, *E. coli,* and coliform bacteria. Aesthetic parameters that are used to describe water quality include colour, smell, and taste (SABS, 2015).

Drinking water of poor quality is a major cause of disease. It is estimated that worldwide 1.7 million people die annually from waterborne diseases (Oparaocha, 2010). Chemical contamination of drinking water may cause serious health problems (Gaurav, 2015). For example, high levels of nitrate in drinking water may result in blue baby syndrome (Ward et al., 2005). Blue baby syndrome decreases the ability of blood to carry oxygen and can be fatal in infants (Gaurav, 2015). Ingestion of contaminated drinking water containing high levels of microorganisms may cause various diseases, such as diarrhoea, dysentery, typhoid fever, hepatitis and cholera, that could result in death (Zamxaka et al., 2004; Ward et al., 2005; Nel et al., 2009; Bacha et al., 2010).

In South Africa, access to safe drinking water is a challenge, particularly in rural communities. It is estimated that 3.5 million people in South Africa do not have access to safe drinking water (Heleba, 2012).

In the Eastern Cape, drinking water remains of poor quality and is typically considered to be unsafe (Momba et al., 2004). The Department of Water Affairs introduced the Blue Drop incentive-based water quality regulation strategy in 2008 (DWA, 2011a). This regulatory strategy requires that municipal service providers obtain Blue Drop certification, which describes the overall drinking water quality management within a particular municipality (DWA, 2011b). During the Blue Drop assessment cycle of 2012, only a few of the municipalities in the Eastern Cape received Blue Drop certification (Blue Drop Report, 2012). The Blue Drop results demonstrated that municipal drinking water quality management in the Eastern Cape varied from excellent to unsatisfactory.

The Blue Drop incentives based regulation programme was designed for drinking water quality management. The Blue Drop programme endeavours to facilitate and drive this continuous improvement process, seeking sustainable improvement in service delivery, progressive improvement in drinking water quality and steadfast coverage of un-serviced areas. This form of incentive and risk based regulation holds the intent to synergise with the current goodwill exhibited by municipalities and existing government support programmes to give the focus, commitment and planning needed (Mashele, 2016). It was designed and implemented with the core objective of managing and safeguarding the quality of tap water in the country (DWA, 2012). This study assessed the drinking water quality of ANDM following the introduction of Blue Drop incentive based regulatory programme.

1.2. Aim and objectives

The Alfred Nzo District Municipality (ANDM) in the Eastern Cape has been participating in Blue Drop assessments since its inception but has never obtained Blue Drop Certification (Blue Drop Report, 2012).

Therefore, the aim of this study was to assess drinking water quality in five rural towns of ANDM. To achieve this aim, the following objectives were devised:

- to identify drinking water sampling points in the five rural towns;
- to sample drinking water monthly for a period of three years;
- to assess the drinking water quality in terms of physical, chemical and microbiological parameters;
- to determine the drinking water quality compliance when compared to SANS 241 (SABS, 2015) standard;
- to calculate the water quality index for all the drinking water sampling points in the study; and
- to identify towns where drinking water supply requires an intervention.

1.3. Dissertation layout

This dissertation has been partitioned into six chapters.

Chapter 1: Introduction

In this chapter, the research project is introduced, the problem, aim and the objectives are presented.

Chapter 2: Literature review

In this chapter, a comprehensive review of the literature pertaining to water quality and potential dangers of contaminated water is presented. The key factors that influence the quality of drinking water are also described. Furthermore, the legislation used in South Africa to measure the quality of drinking water is described.

Chapter 3: Materials and methods

Descriptions of the study area, study design and drinking water sampling points are prescribed in this chapter. The materials and methods that were used in this study are also described.

Chapter 4: Drinking water quality results

This chapter describes the drinking water quality of all the sampling points of the five rural towns of ANDM.

Chapter 5: Water quality index

In this chapter, the drinking water quality of all the sampling points of the five rural towns in ANDM is described in terms of water quality indices.

Chapter 6: Discussion and conclusion

The final chapter provides a discussion of the key findings of the study and makes suggestions for future research.

Chapter 2

Literature Review

2.1. Introduction

All organisms, including humans, require water for their survival. Water is required for growth and the maintenance of many biological activities (Kayembe et al., 2018). In 2010, the United Nations General Assembly formally recognised the right to safe and clean drinking water and sanitation as a human right that is essential for the full enjoyment of life and all human rights (Resolution A/RES/64/292). In accordance with this resolution, everybody has the right to sufficient, continuous, safe, clean, physically accessible, and affordable water for personal and domestic use (UN General Assembly, 2010; WHO, 2017).

Only a small amount of the earth's water is useful freshwater. About 70 % of the earth's surface is covered by water, of which approximately 2.5 % of the water is fresh water; or about 34.5 million cubic kilometers. A large quantity of this fresh water is inaccessible, being trapped in the ice caps. Thus, the total amount of usable fresh water on the earth is estimated to be approximately 200,000 cubic kilometers (Gleick et al., 2009).

Water sources include wells, lakes, springs or rivers. Many rural communities in developing countries often rely exclusively on groundwater for domestic use (Agudosi et al., 2018). However, one of the major challenges of the 21st century remains access to safe drinking water (WWAP, 2009). Approximately 2.1 billion people lack access to safe drinking water (Guilfoos et al, 2019). Access to the quality of drinking water has become an important public health issue at local to national levels. The majority of the populations that are deprived of safe water reside in Sub-Saharan Africa and Asia (Lewis et al., 2018).

The World Health Organization (WHO) defined 'drinking water' as water that 'does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages' (WHO, 2011). It is therefore imperative to ensure a safe and adequate water supply for human well-being because water plays an essential role in health, economy, food production and the environment (Singh and Saharan, 2010). Water scarcity already affects every continent and hinders the sustainability of natural resources, as well as economic and social development. The Millennium Development Goals Report of 2015 recorded that water scarcity affects more than 40% of people around the world, and is expected to increase (UN, 2015).

Worldwide, the proportion of urban communities that have access to safe drinking water is much greater than rural communities. In 2015, 96 % of urban communities had access to safe drinking water, compared with 84 % of rural populations. The proportion of global rural populations without access to safe drinking water has declined by more than half since 1990, from 38 to 16 % in 2015 (UN, 2015). Similarly, when comparing water supply, four out of five people living in urban areas have access to piped drinking water, while only one in three people living in rural areas have access to piped drinking water (UN, 2015).

2.2. Water resources in South Africa

Overall, South Africa is a water scarce country. South Africa is ranked as the 30th driest country in the world (GreenCape, 2017). Water availability in South Africa varies greatly in space and time. While the West is dry with rainfall only during the summer and as low as 100 mm, the East and Southeast receive rainfall throughout the year with an average of up to 1,000 mm. Total annual surface runoff is estimated at 43 to 48 km^3, depending on the source (Aquastat, 2016).

In South Africa, two main types of rivers occur, which include mountain rivers and lowland rivers. The water of mountain rivers flows rapidly along narrow valleys, while the water of lowland rivers, flow slower in wider channels, often with terraced valleys (Khan et al., 2013). The main rivers in South Africa are the Orange River draining to the Atlantic Ocean, while the Limpopo River, Incomati River, Maputo River, Tugela River, Olifants River (Limpopo), and Breede River all drain to the Indian Ocean.

Surface waters include all inland waters that occur permanently or intermittently on earth. Surface water is found in lakes, rivers, and reservoirs (Amouei et al., 2012). Lakes form through the natural flow of water that moves under the force of gravity along channels and accumulate in depressions in the earth (Khan et al., 2017). Lakes are fed by surface water runoff and rivers (Viljoen, 2006). Where water is not trapped in a lake, the lake is only temporary. This may occur when the water flow is fast allowing the water to flow into a river, or seep into the ground or evaporate (Dev and Bali, 2018). The size of a lake is determined by factors such as the origin of the depression where water accumulates, the water regime, river channel stability, water exchange characters, water balance structure, temperature and dissolved load (Lazarova et al., 2011). In contrast to a naturally formed lake, is a human-made inland lake that is referred to as a reservoir. A reservoir is a natural or artificial place where water is collected and stored for use (Ponsadailakshmi et al., 2018).

Groundwater resources are limited, because of geology. Groundwater is fresh water found in the subsurface pore space of soil and rocks where it travels and fills openings in the rocks. The spaces in the rocks that store and transmit groundwater are referred to as aquifers. Large porous aquifers occur only in a few areas in South Africa (Ponsadailakshmi et al., 2018). Groundwater is, however, often the primary water source in the rural and more arid areas of the country (DWS, 2015). It is expected that groundwater use for human consumption will further increase, especially in the western part of the country, where perennial rivers do not occur (GreenCape, 2017).

2.3. Water supply

South Africa's complex water supply system relies mostly on surface water, which is dominated by a matrix of rivers, dams, pipelines, tunnels and reticulation networks. Over 70% of the water used in both rural and urban areas in South Africa is surface water (Ochieng et al., 2010). Water supply is ensured by different state institutions and private businesses that are active along the water value chain (GreenCape, 2017). In recent times, South Africa has made considerable progress in providing piped drinking water. Although most rural households now have access to piped drinking water, the drinking water quality may not be safe for human consumption (Health Systems Trust, 2016).

Central to the supply of water is the water services development plan of the relevant water services authority, which is required by legislation. The water services development plan describes the arrangements for water service provision in an area, both present, and future (Momba et al., 2009). The water services development plan defines the minimum and the desired level of water service for a particular community. Thus, a water services provider of a community is required to adhere to the water services development plan (Momba et al., 2006), and act in accordance with by-laws of the Water Services Act (Ponsadailakshmi et al., 2018).

Drinking water is supplied to urban towns and rural areas through water distribution networks (WDNs). These WDN include both surface and groundwater sources (Zamxaka et al., 2004). Drinking water requirements of communities and towns vary substantially, depending upon factors such as climatic conditions, level of service, socio-economic situation, institutional capacity and consumer behaviour (Algotsson et al., 2009). Approximately 68% of communities are supplied year-round by water WDNs that use surface water (Mhlongo et al., 2018). In almost all South African metropolitan areas, the consumer is provided with high-quality drinking water. However, in many rural communities, the situation is very different. Many rural WDNs in South Africa do not produce drinking water of acceptable quality for domestic consumption (Momba et al., 2004). For example, the microbiological water quality of drinking water in the Eastern Cape is substandard (Mackintosh and Colvin, 2003).

South Africa faces several problems with ensuring that its water resources are clean and plentiful enough for use. Many water resources have a growing toxicity problem, because of increased bacterial growth, including *Escherichia coli*, Aeromonas, Pseudomonas, Salmonella, Shigella and Vibrio spp (Gibellini et al., 2017). Acid mine drainage is also a major contributor to South Africa's growing levels of toxic water. The effect of the contaminated water from the mines can persist for more than 10 km beyond the source (Naicker et al., 2003). Mine polluted water will have to be managed on a continuous basis for decades to come (Ochieng et al., 2010). A further problem in the drinking water supply comes from institutional municipal problems. Common across municipalities is a lack of operation and maintenance of the existing schemes, deterioration of water infrastructure and poor drinking water quality (Mackintosh and Colvin, 2003).

2.4. Water use

Water is used extensively in society for various purposes. Water is used for domestic, commercial, industrial, agricultural, mining, recreational, and environmental activities (Cohen et al., 2012). Each community, household, and individual uses water for various domestic purposes. Domestic use includes water that is used in the home every day for household purposes, such as drinking, food preparation, bathing and washing clothes and dishes (Cohen et al., 2012).

Water is essential to most industries. Steel, food, paper, chemical and petroleum refining industries are major users of water (Daud et al., 2017; Dev and Bali, 2018). Industrial water is used for a variety of purposes, such as processing, cleaning, transportation, dilution, and cooling in manufacturing and other industries (Dev and Bali, 2018). The amount of industrial water use varies from area to area, but is usually low in rural areas. Most of the water used by industry is not consumed and can be returned to the water supply. This wastewater can contain hazardous material such as heavy metals or acids. However, industrial returned wastewater is usually regulated by environmental legislation, which provides guidelines for its treatment so it can be safely re-used by the population (Gibellini et al., 2017).

Water is used extensively in the South African mining sector. Mining water is used for the extraction of minerals such as coal, iron, sand, and gravel. Water is also used for mineral processing, dust suppression, and slurry transport. In quarrying operations, water is used in crushing, screening washing, and flotation of mined materials (Khan et al., 2017).

Agriculture is one of the main water users. Globally, agriculture accounts for 70% of all water withdrawals (Bester and Vermeulen, 2010). Agricultural water is used to grow fresh produce and sustain livestock, which is the central dietary requirement. Farming activities such as orchards, pasture, horticultural crops, stock animals, feedlots and fish farms require vast amounts of water. The most important use of agriculture water is for irrigation (Kourgialas et al., 2017). Approximately two-thirds of South Africa's water is used for agricultural irrigation (GreenCape, 2017).

2.5. Water pollution

Water pollution occurs when harmful substances, such as chemicals or microorganisms, contaminate water bodies. Owa (2014) defined water pollution as the presence of excessive amounts of a hazard (pollutants) in water in such a way that it is no longer suitable for drinking, bathing, cooking or other uses. Water supplies continue to dwindle because of resource depletion and water pollution. This is particularly severe in the more arid countries, such as South Africa, where water scarcity, water pollution, limited social and economic development are linked closely to the prevalence of poverty, hunger, and disease (Ochieng et al., 2010). Water bodies become polluted through natural processes or through mechanisms of displacement and dispersal related to anthropogenic activities, although water degradation is mostly the result of human activities (Daud et al., 2017).

Pollutants enter water sources from two main types of sources. These sources include point sources and non-point sources (Varol and Şen, 2009). A point source is a single, identifiable source of pollution, such as a pipe or a drain. Contaminants from point sources discharge either into surface water or groundwater through an area that is small relative to the area or volume of the receiving water body (Daud et al., 2017). For example, industrial wastes are commonly discharged into rivers and the sea in this way. In contrast, non-point sources, which are often termed 'diffuse' pollution, refer to pollution that occurs over a wide area and not easily attributed to a single source (Khan et al., 2004). Non-point sources are often associated with particular land uses deposition from the atmosphere, both by precipitation (wet deposition) or by dry fallout (dry deposition). Fertilisers and pesticides from agricultural fields also release contaminants into water bodies (Jerome and Pius, 2010).

2.5.1. Water pollution through natural processes

Natural pollution of water bodies occurs mainly through geological influences and rainfall. The geology of the surrounding river drainage basin has been considered as one of the leading natural factors that affect the quality of water in streams. Rocks present in the bed of water channels can slowly dissolve by carbonic and sulphuric acids that are absorbed by rain from the atmosphere (DWAF, 2004). The dissolved rocks increase the sediment load and alter the acidity of the water in streams (DWAF, 2004). Heavy metals from the geological surroundings, such as lead, mercury, zinc, cadmium, and arsenic, are dangerous pollutants that are often deposited with natural sediment in the bottoms of stream channels (Khattak et al., 2012). Mercury contamination of aquatic ecosystems has been known for decades. Mercury may enter water-ways through erosion of natural mercury deposits. One of the best-known examples of mercury toxicity was recorded in the coastal town of Minamata on Kyushu island of Japan. People became seriously ill in the middle of the twentieth century, because of high toxic levels of mercury in the water (Khattak et al., 2012).

Rainfall contributes to the pollution of water bodies through depositing contents of runoff. Rainfall carries waste, such as plastics, papers, faeces, sewage along channels into water bodies in the vicinity (Chigor et al., 2012). In addition, runoff may also carry plant debris and sand, silt and clay into rivers and streams resulting in muddy, turbid water. Severe rainfall events lead to excessive erosion and landslides, which may dramatically increase the content of the suspended material in affected rivers and lakes (Palmer et al., 2004). Arsenic may enter our water supplies through rainfall. The occurrence of arsenic in drinking water is now recognised as a global problem. For example, arsenic in groundwater in Bangladesh has affected many millions, of some of the poorest people in the world (Khattak et al., 2012).

2.5.2. Water pollution through anthropogenic activities

A wide range of anthropogenic activities pollutes water bodies. Anthropogenic activities are widespread and vary in the degree in which they disrupt ecosystems and restrict water use (Lajçi et al., 2017). Some of these activities include indiscriminate waste disposal, farming, and mining (Varol and Şen, 2009; Gyamfia et al., 2019).

The waste disposal from various industrial, household and agricultural activities is a major contributor to the contamination of water. With the ever-increasing world population, disposing of wastewater have become a substantial problem (Sharma and Kumari, 2019). The treatment capabilities for wastewater are lacking in many areas of the world, especially in the poorer and developing countries (Minolfi et al., 2018). As a result, large amounts of sewage-polluted untreated water are discharged into water bodies every day, contaminating the water intended for drinking and other uses (Zamxaka et al., 2004; Bodrud-Doza et al., 2016). Furthermore, in the poorer areas, many townships and municipalities do not have means of disposing of household waste (Chigor et al., 2012).

Factories, manufacturing industries, and mining are major contributors to water pollution. These industries are often responsible for point source pollution by discharging industrial waste into streams, rivers or sea. Chemical production by metal processing and smelting has been proven to be primary sources of heavy metal pollution (Yang et al., 2018). Tie and dye industries produce chemicals such as zinc sulphate and copper salts, which have devastating effects on aquatic environments when they are discharged into rivers (Owa, 2014).

Agriculture is one of the major contributors to the pollution of water bodies. The application of pesticides, fertilisers and also insufficient sewage disposal enter water bodies, mainly through runoff (Ambani and

Annegarn, 2015). The nutrient enrichment through runoff, mainly nitrogen and phosphorus, causes excessive algae growth. This enrichment process is also known as eutrophication (Owa, 2014; Zhang et al., 2017). Excessive amounts of nutrients can lead to low levels of dissolved oxygen in the water, which together with algal growth, blocks much needed light penetration for aquatic plant growth, leading to the death of plants, fish and other aquatic animals (Yang et al., 2018).

Despite its social and economic importance, mining degrades water quality in various ways. The impact of mining pollution depends on the type of minerals, chemicals used in metal extraction processes, climate, life stage of the mine and environmental management practices in place (Musvoto and de Lange, 2019). Only a small proportion of the large quantities of excavated mining ore contain the desired substance. In mining, large amounts of water is used to process ores, which generate large amounts of chemicals, heavy metals, soil, and other waste rock materials. Metals, such as, arsenic, cadmium and lead, leach from mining sites into the surroundings and contaminate water bodies in the vicinity of the mines (Minolfi et al., 2018). Apart from heavy metals, sulphide minerals that may be present in the mining rocks, also leach from the mining sites when exposed to water and oxygen, through a process known as acid mine drainage (AMD), also referred to as acid rock drainage (Boyacioglu and Boyacioglu, 2007). AMD contamination has also gradually increased around multiple dams, such as the Middelburg, Witbank, and Boesmanspruit dam in South Africa. The effect of AMD on the Boesmanspruit dam that supplies potable water to Carolina was studied in 2012 (Masindi et al., 2018). This study revealed that AMD emanating from active or abandoned mines and from mine wastes are often net acidic. These effluents pose an additional risk to the environment since they often contain elevated concentrations of metals (iron, aluminium and manganese, and possibly other heavy metals) and metalloids (Masindi et al., 2018). The resulting sulphuric acid creates acidic conditions that speed up the leaching of heavy metals from the rocks. Thus, chemicals from the processing of ores, for example, cyanide, may also leach from mining sites (Ambani and Annegarn, 2015). In a study conducted by Naicker et al. in 2003 revealed that the groundwater in the mining district of Johannesburg, was heavily contaminated and acidified as a result of oxidation of pyrite contained in the mine tailings dumps and has elevated concentrations of heavy metals (Ochieng, 2010). Chemical analyses showed that during an unusually heavy storm, tailings ponds, containing coalmine runoff, overflowed and water contaminants (iron, manganese, and aluminium) flowed into the reservoir behind the dam lowering the water's pH, causing serious biological side effects (Ochieng, 2010).

2.6. Drinking water quality assessment

2.6.1. Introduction

One of the unique characteristics of water is its excellent dissolving capability. During the hydrological cycle of water, it comes into contact with a wide range of substances, which may be dissolved by the water to a greater or lesser extent (DWAF, 2001). The type of substances, as well as the amount of the substances, determines the parameters (quality) of the water. Oxygen and carbon dioxide are important gasses that dissolve in water (Minolfi et al., 2018). Inorganic compounds that dissolve in water include sodium chloride and calcium sulphate, while organic substances include humic acids and carbohydrates. Besides the dissolved substances found in water, substances that do not dissolve, but remain in suspension as very small suspended or colloidal particles, are also found in water (Kasperczyk et al., 2017). Such suspended substances, in particular microorganisms, also affect the quality of water. Thus, to evaluate the quality of water, the concentration of dissolved substances is determined, together with physical and microbiological parameters of the water (Owa, 2014).

A wide range of different substances is found in water. However, in water quality assessment only a few of the commonly occurring substances occur at concentrations to be of concern for domestic water users (Kasperczyk et al., 2017). These substances can be grouped into four groups (DWAF, 2001); substances that give an indication of general water quality; substances that are normally present in most waters at concentrations, which may affect the health of consumers; substances which do not occur frequently at concentrations of concern to health, but are typically present in soft corrosive waters, which cause them to be leached from pipes and appliances; and substances that could be commonly found in water at concentrations, which may affect aesthetics, for example the staining of clothes, or may have economic effects, such as corrosion (Table 2.1).

Table 2.1 Commonly occurring substances used in water quality assessment (modified from DWAF, 2001).

Substance	**Type of indicator**
Substances that give an indication of general water quality (Indicates potential problems and should be frequently tested at all points in the water supply system).	
Total dissolved solids (TDS)	Indicator of total dissolved salts (TDS), and also establishes if the water is drinkable and capable of slaking thirst.
Escherichia coli	Indicator of the possible presence of disease-causing organisms. It establishes if water is polluted with faecal matter.
Potential Hydrogen (pH) value	Has a marked effect on the taste of the water and also indicates possible corrosion problems resulting from dissolution of metals such as copper, zinc, and cadmium that can be toxic.
Turbidity	Affects the appearance, and thus the aesthetic acceptability, of the water.
Free residual chlorine (FRC)	A measure of the effectiveness of the disinfection of the water. Free residual chlorine (FRC) is the chlorine concentration remaining at least 30 minutes after disinfection. There should be FRC in the water, but if concentrations are too high it may impart an unpleasant taste and smell to the water. (Measured only if the water has been treated with chlorine-based disinfectants).
Substances that are normally present in most waters at concentrations, which may affect the health of consumers	
Nitrate & nitrite (NO_3^-/NO_2)	Common in groundwater (borehole) samples, particularly in areas of intensive agricultural activity,

Substance	Type of indicator
	or where pit latrines are used. Severe toxic effects are possible in infants.
Fluoride	This is often elevated in groundwater in hot, arid areas. Can cause damage to the skeleton and the staining of teeth.
Sulphate (SO_4^{2})	Common in mining areas. Causes diarrhoea, particularly in users not accustomed to drinking water with high sulphate concentrations.
Chloride (Cl^-)	Often elevated in hot, arid areas, and on the western and southern Cape coasts (particularly in groundwater). May cause nausea and vomiting at very high concentrations.
Arsenic (As)	May be present in groundwater, particularly in mining areas. Can lead to arsenic poisoning.
Coliform bacteria	Provides an additional indicator of disease-causing organisms and the effectiveness of disinfection.
Substances which do not occur frequently at concentrations of concern to health, but are typically present in soft corrosive waters	
Cadmium (Cd)	Occurs along with zinc in acidic waters where it may have been dissolved from appliances.
Copper (Cu)	Affects the colour of the water and can cause upset stomachs. Normally occurs only when copper piping is used to carry water with low pH value.
Substances commonly found in water at concentrations, which may affect aesthetics or have economic effects	
Manganese (Mn)	Common reason for brown or black discolouration of fixtures and for stains in laundry. Can be common in bottom waters of dams, or in mining areas.
Zinc (Zn)	Affects the taste of water. The usual cause is acidic water dissolving zinc from galvanised pipes or from appliances.
Iron (Fe)	Affects the taste of the water and may also cause a reddish brown discolouration. Can be common in bottom waters of dams, or in mining areas. Can cause growth of slimes of iron-reducing bacteria that ultimately appear as black flecks in the water.
Potassium (K^+)	Affects the taste of the water and is bitter at elevated concentrations.
Sodium (Na^+)	Affects the taste of the water. Often elevated in hot, arid areas and on the western and southern Cape coasts (particularly in groundwater).
Calcium (Ca^{2+})	Can cause scaling and can reduce the lathering of soap.
Magnesium (Mg^{2+})	Affects the taste of the water. It is bitter at high concentrations. Common in some areas and it

Substance	Type of indicator
	adds to the effect of calcium.
Hardness, total	A combination of calcium and magnesium. It is associated with scaling and inhibition of soap lathering.

In water quality assessments, the parameters of water are measured in terms of the physical, chemical and microbial parameters of water. The measurement of the parameters provides information about the fitness of the water for the intended use (Heleba, 2012). These water measurements are then compared to a set of standards to determine whether the quality is compliant. In South Africa, the South African National Standard Drinking water Part 1: Microbiological, physical, aesthetic and chemical parameters (SABS, 2015), which is prescribed by DWAF (1997), dictates the acceptable levels of physical, chemical and microbiological parameters. Water that complies with Part 1 of SANS 241 is deemed to present an acceptable health risk (SABS, 2015) for lifetime consumption. This implies an average consumption of 2 L of water per day for 70 years by a person that weighs 60 kg. Drinking water quality should be free from physical, chemical and microbiological concentration that exceeds prescribe standards (Khan et al., 2004; Eggers et al., 2018; Setty et al., 2018).

2.6.2. Physical parameters of drinking water

The physical parameters of drinking water include parameters such as turbidity, pH, electrical conductivity (EC), colour, odour, and taste. The physical parameters of drinking water largely determine the aesthetic parameters of drinking water and include appearance, taste and general drinkability of the water (DWAF, 2001). Physical characteristics of drinking water are mostly determined by senses of touch, sight, smell and taste (Jotwani et al., 2014). Turbidity is a measure of the clarity of drinking water. Suspended and colloidal material in the drinking water determines the light-transmitting parameters of the drinking water and ultimately influences the clarity of the drinking water (Mohsin et al., 2013). The passage of light through drinking water decreases, as the presence of suspended and colloidal material in drinking water increases. Thus, drinking water that exceeds the SABS (2015) standards will contain relatively high levels of suspended and colloidal material and will be regarded as being turbid. Turbidity also influences the temperature of drinking water. As turbidity increases, so does the temperature also increase, because suspended particles tend to absorb more heat (WHO, 2004). Warmer drinking water that is a result of higher turbidity levels causes the concentration of dissolved oxygen (DO) to decline because warm drinking water holds less DO than cold drinking water. Because of the reduced light penetration of turbid drinking water, photosynthesis and the production of DO is also reduced, which affect the growth rate of aquatic algae and other aquatic plants (Mohsin et al., 2013).

The pH of drinking water is a measure of the relative amount of free hydrogen and hydroxyl ions in water. The pH scale (1 to 14) is a logarithmic scale used to specify the acidity or basicity of drinking water. A neutral pH of 7 is neither an acid nor a base, while a pH value >7 is alkaline, and a pH value <7 will cause the drinking water to be acidic (Mohsin et al., 2013). The pH of drinking water determines the solubility and biological availability of chemical constituents such as nutrients in the water, which are important to sustain aquatic life in nature or may render the water harmful for human consumption (Bester and Vermeulen, 2010).

EC is a measure of the capacity of drinking water to conduct electrical current. EC is also directly related to the concentration of salts dissolved in drinking water, and therefore to the TDS. Thus, salts and inorganic materials, such as alkalis, chlorides, sulphides, and carbon compounds, dissolved in drinking water into positively charged ions and negatively charged ions, which conduct electricity (Kasperczyk et al., 2017).

These dissolved salts and inorganic materials are known as electrolytes. When the concentration of charged ions in drinking water is increased, the EC of the drinking water will also increase (Bester and Vermeulen, 2010). Thus, EC of distilled or deionised water is low because of the absence of charged ions, while the EC of seawater is high, because of a much higher concentration of charged ions present in the seawater (Mohsin et al., 2013).

The colour, odour and taste are all aesthetic qualities of the drinking water. Changes in the colour, odour and taste of drinking water may be the first evidence of a problem with the quality of the water. The colour of drinking water may be because of the presence of coloured organic matter, such as humic substances, metals such as iron and manganese, or highly coloured industrial wastes (WHO, 2008). Coloured drinking water creates the perception that the water is unfit to drink, even though the water may be perfectly safe for human consumption (Nel et al., 2009). Recently, colour has been used as a quantitative assessment of the presence of potentially hazardous or toxic organic materials in drinking water (Eggers et al., 2018). If the qualities odour and taste of drinking water are aesthetically unacceptable, it could undermine the confidence of consumers and lead to complaints. Odours in drinking water are caused mainly by the presence of organic substances. Some odours are indicative of increased biological activity; others may result from industrial pollution (WHO, 2008). Unpleasant odours include that of strong chlorine, rotten egg, musty or unnatural smells. Taste qualities include sour, salty, sweet and bitter (Palmer et al., 2004).

2.6.3. Chemical parameters of drinking water

The health concerns associated with chemical constituents of drinking water arise mainly from the ability of chemical substances to cause adverse health effects after extended exposure time. There are few chemical constituents of drinking water that can lead to health problems resulting from even a single exposure (Arora et al., 2017).

The chemical parameters of drinking water are determined by four main groups of dissolved substances (Wang et al., 2018). The group of metallic substances includes arsenic, cadmium, calcium, copper, iron, magnesium, manganese, potassium, sodium and zinc, while examples of inorganic non-metallic substances are chloride, fluoride, nitrate, and sulphate (DWAF, 2001). The final two groups are the aggregate group of organic substances and the aggregate inorganic substances.

Several metallic substances occur in trace amounts in drinking water. A trace element or substance occurs at very low concentrations in drinking water (Wang et al., 2018). Cyanide, although it is not a metallic substance, is often listed amongst the trace elements, because it also occurs in trace amounts in drinking water (DWAF, 2001). Table 2.2 provides a list of the most important trace substances that are found in drinking water, together with some facts and effects.

Table 2.2 Main trace substances that occur in drinking water.

Trace element/substance	Facts and effects
Aluminium (Al)	Al is one of the trace metals present in drinking water. Al salts are used extensively as coagulants in drinking water treatment to enhance the removal of particulate, colloidal and dissolved substances (Wang et al., 2018).
Antimony (Sb)	Sb is a metal found in natural deposits such as ores containing other elements. Sb is a metal that is present naturally in small quantities of drinking water, rocks, and soils metal element found naturally in the earth's crust (Stang et al., 2018).
Arsenic (As)	As is odourless and tasteless and enters drinking water supplies from natural deposits in the earth or agricultural and industrial practices. As may be found in some drinking water supplies, including wells. Exposure to high levels of As can cause health effects (Mhlongo, et al., 2018).

Trace element/substance	Facts and effects
Cadmium (Cd)	Cd is a metal found in natural deposits as ores containing different elements (Mhlongo et al., 2018).
Chromium (Cr)	Cr is an odourless and tasteless metallic element and is found naturally in rocks, plants, soil and volcanic dust, humans, and animals (WHO, 2011).
Cobalt (Co)	Co is a naturally-occurring element that has parameters similar to those of iron and nickel. Small amounts of Co are naturally found in most rocks, soil, and drinking water (Mhlongo et al., 2018).
Copper (Cu)	Cu is a metal found in natural deposits such as ores containing other elements. The substantial sources of Cu in drinking water are corrosion of household plumbing systems and erosion of natural deposits. When Cu leaches into water through corrosion, dissolving of the metal is caused by a chemical reaction between water and plumbing (Mhlongo et al., 2018).
Iron (Fe)	Fe is common in groundwater supplies used by many forest service water systems. Fe deposits can cause build-up in pressure tanks, storage tanks, water heaters and pipelines (Mhlongo et al., 2018). Moreover, Fe deposit build-up can decrease capacity, reduce pressure and increase maintenance (Gordon et al., 2008).
Lead (Pb)	The primary sources of Pb in drinking water are corrosion of household plumbing systems and erosion of natural deposits (Boakye-Ansah et al., 2016). Pb can leach into drinking water from pipes, solder, fixtures, and faucets (brass) and fittings (Chabukdhara et al., 2017). The amount of Pb in drinking water also depends on the types and amounts of minerals in the drinking water, how long the drinking water stays in the pipes, the amount of wear in the pipes, and the drinking water's acidity and temperature (Gordon et al., 2008).
Manganese (Mn)	Mn is a naturally occurring element found ubiquitously in the air, soil, and water. Mn is also an essential nutrient for humans and animals. Mn naturally occurs in many surface and groundwater sources and in soils that may erode into these waters (Mhlongo et al., 2018).
Mercury (Hg)	Hg is typically released from industrial processes, agricultural processes, household, commercial and medical products containing mercury, sewage discharge and sediment (Lajçi et al., 2017). Hg vapour may cause nervous system damage when exposed to high concentrations (Gordon et al., 2008). Inorganic mercury is produced from elemental mercury through the process of oxidation. Hg is the most common form present in drinking water but is not considered to be very harmful to humans (WHO, 2011).
Nickel (Ni)	Ni is a lustrous white, hard, ferromagnetic metal. The primary source of Ni in drinking water is the leaching of metals in contact with drinking water, such as pipes and fittings (Gordon et al., 2008). Ni

Trace element/substance	Facts and effects
	may also be present in some groundwater as a consequence of dissolution from nickel ore-bearing rocks (Mhlongo et al., 2018).
Selenium (Se)	Se is a metal found in natural deposits such as ores containing other elements. Substantial sources of Se in drinking water are discharge from petroleum and metal refineries, erosion of natural deposits and discharge from mines (Lajçi et al., 2017).
Uranium (U)	U is a naturally occurring element commonly found in soil and rocks. The concentration of U in water is typically minimal, but varies from region to region, depending on the type of minerals in the soil and bedrock, for example, in granite bedrock the average concentration of U have been found to be higher (Jobbágy et al., 2017).
Vanadium (V)	V occurs naturally in soil, water, and air. Natural sources of atmospheric V include continental dust, marine aerosol and volcanic emissions (Bereskie et al., 2017). The release of V to the environment is mainly associated with industrial sources, especially oil refineries and power plants using V rich fuel oil and coal (Gordon et al., 2008).
Cyanide	Cyanides are occasionally found in drinking water, primarily as a consequence of industrial contamination (WHO, 2003a) Cyanide is produced naturally in the environment by various bacteria, algae, fungi and numerous species of plants. Incomplete combustion during forest fires is believed to be a substantial environmental source of cyanide, and also incomplete combustion of articles containing nylon produces cyanide through depolymerisation (Daud et al., 2017).

Inorganic chemical substances are commonly present in surface and groundwater. Most of the dissolved, inorganic substances in drinking water occur as ions. These ions enter a water body from the atmospheric, rock weathering and runoff (Daud et al., 2017). In a drinking water quality assessment, the concentration of the ions is determined and reported rather than the concentration of the compounds (DWAF, 2001). The main ionic species in drinking water are listed in Table 2.3.

Table 2.3 Main ionic species in that occur in drinking water.

Major cations	**Facts and effects**
Sodium (Na^{+})	Is essential for humans (Mhlongo et al., 2018). Sodium may be of health significance to individuals. Sodium salts are generally highly soluble in drinking water and are leached from the terrestrial environment to groundwater and surface water (Arora, 2017). Na is not considered to be toxic (WHO, 2004).
Potassium (K^{+})	Potassium is an essential nutritional element in drinking water supplies, but in excessive quantities, it acts as a laxative (Arora, 2017).
Calcium (Ca^{2+})	Calcium is essential to human nutrition and a key element in the formation of teeth and bones. It is also known as limestone and is a cause of drinking water hardness (Arora, 2017).
Magnesium (Mg^{2+})	Magnesium is one of the most common elements in the earth's crust. Magnesium Sulfate at very high concentrations may have a laxative effect on some people. It also gives an unpleasant taste at high concentration (Arora, 2017).
Major anions	**Facts and effects**
Chloride (Cl^{-})	Chloride in drinking water is generally not harmful to human health except when present in high concentrations, although at high concentrations it may be injurious to heart and kidney (Arora, 2017). Chlorine is commonly added to drinking water as a disinfectant. When chlorine is added to drinking water, some of the chlorine reacts first with organic materials and metals in the drinking water and is not available for disinfection (known as the chlorine demand of the water). The remaining chlorine concentration is referred to as total chlorine (Stang et al., 2018). Total chlorine is divided into combined chlorine, which is the amount of chlorine that has reacted with nitrates and is unavailable for disinfection, and FRC, which is the chlorine available to inactivate disease-causing organisms. Therefore, FRC is measured to determine the potability of drinking water (Abdel-Satar et al., 2017).
Sulphate (SO_4^{2-})	Sulphates may result in a bitter taste. It also contributes to the odour of drinking water (Arora, 2017).
Carbonates/Bicarbonates (CO_3^{2-}/HCO_3^{-})	Excessive bicarbonate adds to the salinity and total solid content of drinking water, while carbonate content of drinking water can cause hardness, which can be removed through boiling (Arora, 2017).
Nitrates (NO_3^{-})	Nitrates, even at low concentrations, can cause health problems to infants of six months of age or less, and in pregnant women by affecting the oxygen carrying capacity of blood (Arora, 2017).

Drinking water can contain a large number of organic compounds. The main element of organic compounds is carbon. Organic compounds behave differently in a liquid. They usually do not dissolve as ions, but rather go into solution as molecules of the compound (Abdel-Satar et al., 2017). Organic compounds in drinking water include algae and bacterial by-products; carbohydrates and proteins; synthetic organic compounds such as pesticides and herbicides; and products formed during water treatment such as chloroform and other chlorinated products (DWAF, 2001). These compounds are usually present in very low concentrations, but they may be harmful even at low concentrations. Because it is not always possible to determine the concentration of each organic compound in drinking water, an indication of the general organic quality of the drinking water can be obtained by determining aggregate substances such as total organic carbon (TOC) and chemical oxygen demand (COD) and trihalomethanes (THM) (DWAF, 2001). TOC is defined as a measure of the total amount of organic matter present in the drinking water, mostly because of biological decomposition. THMs are halogen-substituted single-carbon compounds (Mhlongo et al., 2018). The general formula of THMs is CHX3, where X represents a halogen, which may be fluorine, chlorine, bromine, or iodine, or combinations thereof. The most commonly found THMs in drinking water are chloroform, bromodichloromethane or dichlorobromomethane, dibromochloromethane or chloro-dibromomethane and bromoform (CHBr3) (Bereskie et al., 2017). THMs are formed in drinking water primarily as a result of chlorination of organic matter present in raw water supplies. The rate and degree of THM formation increase is a function of the chlorine and acid concentration, temperature, pH and bromide ion concentration. In addition to being the most common THM, chloroform is also the primary disinfection by-product in chlorinated drinking water (Gordon et al., 2008).

Microcystins are compounds that are toxins that are produced by cyanobacteria. Cyanobacteria are also known as blue-green algae and are ubiquitous in surface water when conditions are favourable for growth and formation of algal blooms (Wang et al., 2018). Cyanobacteria release these toxins on cell death and these toxins, when released, may persist for weeks to months (Gordon et al., 2008).

Phenol is an aromatic organic compound which can be found in the industrial wastewater. Phenol in soil tends to enter groundwater. Phenol has been detected in surface waters, rainwater, sediments, drinking water, groundwater, industrial and urban runoff, and at a hazardous waste site (Wang et al., 2018).

Aggregate inorganic substances are measured by TDS and hardness. TDS is the term used to describe the inorganic salts and small amounts of organic matter present in solution in drinking water (DWAF, 2001). The principal constituents are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen carbonate, chloride, sulfate, and nitrate anions (Mhlongo et al., 2018). The total solids content of drinking water is defined as the residue remaining after evaporation of the water and drying the residue to a constant weight at 103°C to 105°C (Arora, 2017). Hardness is a natural characteristic of drinking water, which can enhance its palatability and consumer acceptability for drinking purposes (DWAF, 2001). The hardness of water is due to the presence of calcium and magnesium minerals that are naturally present in the water (DWAF, 2001). The common signs of hard water supply are poor lathering of soaps and scum. The hardness is made up of two parts: temporary (carbonate) and permanent (non-carbonate) hardness. The temporary hardness of drinking water can easily be removed by boiling the water (Arora, 2017).

2.6.4. Microbiological parameters of drinking water

Many types of microorganisms live in water and could cause fish, land animals and humans to become ill. Serious diseases such as cholera, shigellosis, and Campylobacteriosis come from microorganisms that live in drinking water (Burgess and Pletschke, 2008). Untreated water sources such as streams, rivers, lakes, or unprotected open wells are mechanisms for the transmission of waterborne diseases (Daud et al., 2017).

Waterborne diseases are usually caused by enteric pathogens. Enteric pathogens are transmitted by the faecal-oral route. These pathogens are generally excreted in faeces by infected people, carried in faecally contaminated food or drinking water and ingested by other individuals. However, drinking water also plays a role in the transmission of pathogens, which are not faecally excreted, such as opportunistic pathogens that are normal external body flora (Burgess and Pletschke, 2008).

To ensure safe drinking water, there must be no pathogens in the drinking water at the point of use. The microbiological quality of the raw water is directly linked to the quality of the treated drinking water. The assessment of the microbiological quality of drinking water is usually based on the test of indicator microorganisms (McOmber, 2017). An ideal indicator organism should always be present when the pathogen is present and should be absent in uncontaminated drinking water; should be present in numbers greater than the pathogen it indicates; should have a survival in the environment and resistance to the treatment processes that is comparable to that of pathogens; should not be harmful to human health; should be easy to identify and to isolate; and should be suitable for all types of water (Burgess and Pletschke, 2008).

One of the categories of indicator microorganisms is coliform bacteria. Certain coliform groups are members of the normal microbial flora of the human gastrointestinal tract and are relatively easy to detect (Nkwe et al., 2015). Coliform bacteria comprise of aerobic and/or facultative anaerobic Gram-negative, non-spore forming, rod-shaped bacteria that ferment lactose to gas (Daud et al., 2017). If coliform bacteria are present in treated drinking water, it is an indication that the drinking water has not been adequately disinfected (McOmber, 2017). The absence of coliform bacteria in the distribution system minimises the likelihood for faecal pathogens to be present in drinking water (WHO, 2013).

The indicator organism *Escherichia coli (E. coli)* is used as an indicator organism for the presence of faeces of humans and other warm-blooded animals in drinking water. *E. coli* is a species within the thermotolerant coliform group, generally regarded as the most specific indicator of faecal contamination, and therefore an essential indicator for public health (Ikonen et al., 2017; Lam et al., 2017). The presence of *E. coli* in drinking water samples, thus also indicates the possible presence of pathogenic organisms of human origin (Nkwe et al., 2015).

Besides *E. coli* and coliform bacteria, the presence of several other organisms is also determined when assessing drinking water quality. These organisms are protozoan parasites, heterotrophs, and bacteriophages. Cryptosporidium and Giardia species are typical protozoan parasites. Although Cryptosporidium species are commonly transmitted by water; other sources of infection include food-borne and person-to-person transmissions (Ikonen et al., 2017). Giardia is a genus of anaerobic flagellated protozoan parasites of the phylum Sarcomastigophora that colonises and reproduces in the small intestines of several vertebrates and causes giardiasis (Zhang et al., 2017). Heterotrophs are broadly defined as microorganisms that require organic carbon for growth and include bacteria, yeasts, and moulds (Ikonen et al., 2017). A variety of simple culture-based tests that are intended to recover a wide range of microorganisms from drinking water are collectively referred to as heterotrophic plate count (HPC) test procedures (WHO, 2013). Bacteriophages are regarded as enteric viral indicators in faecally contaminated drinking water and may indicate the presence of human viral pollution. Somatic coliphages, F-specific bacteriophages, and bacteriophages infecting Bacteroides fragilis are currently used as suitable indicators of faecal pollution of drinking water. These organisms also provide possible indications of the presence of human enteric viruses in drinking water (Nkwe et al., 2015).

2.6.5. Water Quality Index

A water quality index (WQI) is a method of providing an overall description of water quality. A WQI is a composite indicator of water quality that pools together complex water quality data into an aggregate value. A WQI thus reduces a large amount of information about water quality into a single value (Shiji et al., 2016; Singh and Hussian, 2016; Galal Uddin et al., 2017).

Water quality, expressed in the form of a WQI, was first reported in 1965. This first attempt to develop a WQI was undertaken by Horton (1965). Later, a WQI similar to Horton's index was developed by Brown et al. in 1970 (Brown et al., 1970). Thereafter, countries such as the United States of America and Canada developed indices that were designed to be more suited to water conditions of their countries (Bereskie et al., 2017). Subsequently, indices were formulated by several national and international organisations. These WQIs were developed to be more flexible so that they incorporated a variable composition of water quality measurements that were more location-specific and took into account changing water conditions (Brown, et al., 1972; Bereskie et al., 2017; Yousefi et al., 2018). These WQIs include the National Sanitation Foundation Water Quality Index (NFSWQI) (Brown et al., 1970); Weight Arithmetic Water Quality Index (WAWQI) (Brown, et al., 1972), Weighted Water Quality Index (W-WQI) (Tiwari and Mishra, 1985); British Columbia Water Quality Index (CCME, 1999) and Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) (CCME, 2001).

In recent times, the utilisation of a WQI has gained popularity because of its single value description of water quality. A WQI is often used to classify water quality data into simple terms, such as excellent, good, poor, very poor, and unsuitable for drinking (Sorlini et al., 2013; Shiji et al., 2016; Yousefi et al., 2018). These classifications provide important information about the general water quality status, which facilitates choices of water-treatments (Yousefi et al., 2018). The use of a WQI on a continuous basis provides long-term data that is helpful in decision-making when communicating information about water quality (Akter et al., 2016; Galal Uddin et al., 2017). These data can then be used to predict potentially harmful conditions of water, such as for aquatic habitats, aquatic life, quality of irrigation water for agriculture and livestock, recreation, aesthetics, and drinking water supplies (Scheili et al., 2015). Using a WQI to describe the overall quality of water is also a convenient method of communicating the overall potential impact of water when planning water quality interventions (Singh and Hussian, 2016).

2.7. Health effects of polluted drinking water

When chemicals or microbial organisms occur in drinking water at limits beyond the SANS 241 standards, consumers may be at risk of becoming ill. Today, water pollution has become a major problem and is among the leading causes of disease and death in the world (SABS, 2015; Daud et al., 2017). The health effects that poor quality of drinking water may have on a consumer can be divided into two categories; those health effects that are acute or those that are chronic in nature. Acute health effects appear soon after consumption of water of poor quality, while the chronic health effects show only after water of poor quality has been consumed for a long time (DWAF, 1996). Chronic health effects could be serious and long-lasting, or they may be insignificant and only temporary.

Most chemicals arising in drinking water are of health concern only after extended exposure of years, rather than months. The major exception is nitrate (WHO, 2017). However, this is only a very small proportion of the chemicals that may reach drinking water from various sources. Typically, changes in chemical water quality occur progressively, except for those substances that are discharged or leach intermittently to flowing surface waters or groundwater from, for example, wastewater treatment plants or contaminated landfill sites (Daud et al., 2017). Several chemicals, when they occur at unacceptable levels in drinking water, may be of concern for human health (Table 2.4).

Table 2.4 Drinking water chemicals that are of concern to human health.

Chemical	Health effects
Arsenic (As)	Populations ingesting arsenic-contaminated drinking-water show signs of chronic arsenicism, including dermal lesions such as hyperpigmentation and hypopigmentation, peripheral neuropathy, skin cancer, bladder and lung cancers and peripheral vascular diseases (Daud et al., 2017). Dermal lesions were the most commonly observed symptom, occurring after minimum exposure periods of approximately 5 years. Effects on the cardiovascular system were observed in children consuming arsenic-contaminated drinking water (mean concentration of 0.6 mg/l) for an average of 7 years (WHO, 2011).
Chloride (Cl^-)	This is often elevated in hot, arid areas, and on the western and southern Cape coasts (particularly in groundwater). May cause nausea and vomiting at very high concentrations (DWAF, 2001).
Fluoride	Fluoride is beneficial to human health in trace amounts but can be toxic when ingested in excessive amounts (Varol and Davraz, 2016). At high concentrations, fluoride is a dominant calcium absorbing element and can interfere with the calcified structure of bones and teeth in the human body to cause dental or skeletal fluorosis (Mhlongo et al., 2018).
Magnesium (Mg)	Excessive amounts make water bitter and may cause diarrhoea (DWAF, 1998).
Nitrate/Nitrite (NO_3^-/NO_2^-)	Bottle-fed infants less than 6 months old are at risk of contracting methaemoglobinaemia (blue-baby syndrome) through nitrite exposure after consumption of formula reconstituted with drinking water that contains nitrite (WHO, 2017). Nitrates in the drinking water form compounds in the body that change haemoglobin to methaemoglobin, thereby decreasing the ability of blood to carry oxygen. (Varol and Davraz, 2016).
Sulphate (SO_4^{2})	This is particularly common in mining areas. Causes diarrhoea, particularly in users not accustomed to drinking water with high sulphate concentrations (DWAF, 2001; Daud et al., 2017).

Waterborne related diseases are becoming a serious problem worldwide. Increasing populations are exerting more and more pressure on available water sources (Onyango et al., 2018). Consequently, more than 1.2 billion people worldwide do not have access to safe drinking water (Hartmann et al., 2018; Onyango et al., 2018). It is estimated that over 1.5 million children die from waterborne related diseases each year (Hartmann et al., 2018). Besides causing death, waterborne diseases also prevent people from working and living active lives (Onyango et al., 2018). Waterborne diseases, related to the consumption of contaminated or inadequately treated drinking water, are a global public health concern (Murphy et al., 2016).

Drinking water is susceptible to contamination with microorganisms and organic matter among other pollutants, regardless of the source. Drinking water acts as a passive carrier for numerous organisms that can cause human diseases. Infectious diseases caused by pathogenic bacteria, viruses, and parasites, for example, protozoa and helminthes, are the most common and widespread health risk associated with drinking water (WHO, 2017; Daly et al., 2018). Microbial contaminants such as coliforms, *E. coli*, *Cryptosporidium parvum*, and *Giardia lamblia* compromise the safety of the drinking water. The presence of *E. coli,* Klebsiella, and *Enterobacter species* in drinking water are likely indicators of the presence of pathogenic organisms such as *Clostridium pafringens*, Salmonella, and Protozoa. These pathogens cause diarrhoea, giardiasis, dysentery, and gastroenteritis, which are common among the rural dwellers of developing nations (Onyango et al., 2018). Among the waterborne protozoan pathogens, *Giardia* and *Cryptosporidium* are the most common causes of major diarrhoeal outbreaks globally (Moreno et al., 2017).

In 1993 an epidemic of cryptosporidiosis struck Miluwaukee, Wisconsin. Hundreds of thousands of people became ill and 50 died (Choffnes and Mack, 2009). In May 2000, 4,800 people in the rural town of Walkerton in Ontario, Canada, experienced an outbreak of waterborne disease caused by *E. coli* O157: H7 and *Campylobacter* in the drinking water system (Khan et al., 2017). Seven people died and many people became seriously ill. The contamination was ultimately traced to a source that had been identified 22 years earlier as a threat to the drinking water, but no remedial action was taken to manage the public health risk. These events demonstrate that even “modern” drinking water treatment and distribution facilities are vulnerable to contamination by infectious pathogens (Choffnes and Mack, 2009).

In Africa, on the 6th of September 2018, a cholera outbreak in Harare, Zimbabwe, was declared by the Ministry of Health and Child Care. Twenty-five patients were admitted to a hospital in Harare presenting with acute watery diarrhoea and vomiting caused by Vibrio cholerae serotype O1 Ogawa. One woman died. By the 15th of September, a further 3,621 cumulative suspected cases were reported (WHO, 2018). Contaminated drinking water from boreholes and wells in Harare was suspected to be the source of the outbreak. In developing counties, the microbial contamination of drinking water is a serious problem; where the situation of freshwater availability is impacted by the lack of proper management and financial constraints (Khan et al., 2017).

Poor drinking water quality poses a risk of health effects mainly to a sensitive group. The sensitive group includes people who may have particular medical conditions, babies, children and the elderly. A sensitive group is more susceptible to poor drinking water quality (DWA, 2001). The CCME–WQI values revealed that the drinking water quality of the six WTPs water sampling points and 26 end-user water sampling points may be used without health effects by the majority of individuals of all ages, but may cause effects in some individuals in the sensitive group (DWA, 2001).

Safe drinking water is essential for life. Safe drinking water quality must comply with the recommended water quality limits as prescribed by the South African National Standards for Drinking Water (SANS) 241 (2015). The drinking water quality must comply in terms of physical, chemical and microbiological parameters. Non-compliant drinking water quality may cause health effects at specified limits (Table 2.5). In a study conducted by Momba et al. in 2009 revealed the correlations between free residual chlorine (FRC) and microbiological regrowth in the WDN. The low levels of FRC measurements in the WDN may indicate the possibility of post-treatment microbiological contamination.

Table 2.5 Drinking water quality limits and effects for specified health parameters.

Water quality parameter	SANS 241(2015)	Health limit (Esterhuizen, 2014)	Drinking water (DWAF, 2001)	Food preparation (DWAF, 2001)
Turbidity	≤1 NTU	1–20 (NTU)	Possibility of secondary health effects	Possibility of secondary health effects
pH	≥5 to ≤ 9.7	≤4 and ≥10	Irritation of mucous membranes	Irritation of mucous membranes
EC	≤170 mS/m	150–370 mS/m	Slight possibility of salt overload in sensitive group	Slight possibility of salt overload in sensitive group
TDS	≤1200 mg/L	1000–2400 mg/L	Slight possibility of salt overload in sensitive group	Slight possibility of salt overload in sensitive group
FRC	≤5 mg/L	≤0.05 mg/L	Serious risk of infection if raw water source microbiologically contaminated	Serious risk of infection if raw water source microbiologically contaminated
E. coli	Not detected	10–100 counts/100 mL	Clinical infections common even with once-off consumption	Clinical infections common even with once-off consumption
Coliform bacteria	≤ 10 mg/L	10–100 counts/100 mL	Clinical infection unlikely in healthy adults, but may occur in some sensitive groups	Clinical infection unlikely in healthy adults, but may occur in some sensitive groups

NTU = Nephelometric Turbidity Units; EC = electrical conductivity; *E. coli* = *Escherichia. coli*; TDS = total dissolved solids; FRC = free residual chlorine; pH = potential hydrogen

2.8. Legislation and monitoring of drinking water

In South Africa, a commitment to providing safe drinking water is regulated by legislation. The Constitution of the Republic of South Africa, Section 24 (Act 108 of 1996), states that everyone has a right to an environment that is not harmful to their health or well-being, which includes a constant supply of safe drinking water (South Africa, 1996). Section 27(1) (b), of the constitution, states that everyone has the right to have access to safe drinking water. The Department of Water and Sanitation (DWS), formerly known as the Department of Water Affairs, is the custodian of South Africa's water resources (DWAF, 2005). Part of the mission of the DWS is to ensure that the quality of water resources remain fit for use and that the viability of aquatic ecosystems is maintained and protected (Heleba, 2012). The DWS operates at national, provincial and local levels across all elements of the water cycle, such as water resource management, water abstraction, water processing and distribution of potable drinking water (Momba et al., 2004). The DWS oversees and regulates the water sector business through appropriate policies and regulations, which are implemented through its nine provincial offices in South Africa (DWS, 2015). Also, the DWS monitors the performance of the sector and regulates the drinking water quality against the legislation, and recommends changes to the business environment within which the various role players have to perform.

In 2008 the DWS responded by publishing the Blue Drop certification programme. The Blue Drop certification programme regulated compliance of drinking water provided by the water services authorities (WSAs) (DWA, 2011a). The Department of Water Affairs (DWA) followed a process of conducting consultative audits to all WSA to assess drinking water quality operations and management performance in line with the set of Blue Drop requirements (Mashele, 2016).

Blue Drop certification programme has been transformed into a central data basis, the Integrated Regulatory Information system (IRIS). The IRIS assesses the drinking water supply of water services authorities and provides checklists for improving performance (DWA, 2012; DWS, 2015; DWS, 2017). An IRIS assessment report provides details about the drinking water quality supply services to a particular town and surrounding water supply areas by the water treatment plants (WTPs) for that particular area (DWS, 2017). This approach of the IRIS promotes an understanding of entire WDNs, the events that can compromise drinking water quality and the operational control necessary for optimising drinking water quality and protecting public health (DWS, 2017).

Several legislative role players ensure the regulation of drinking water quality. The water services act, 1997 (Act 108 of 1997), prescribes the legislative duty of municipalities as water service authorities (WSAs) to provide drinking water supply according to national standards and norms (DWAF, 1997). The water services act, 1997 (Act 108 of 1997), also regulates water boards as water service providers (WSPs) and gives the executive authority and responsibility to the minister of water and sanitation to support and strengthen the capacity of municipalities to manage their affairs, exercises their powers and perform their functions (DWAF, 1997; Momba et al., 2004; Momba et al., 2006). Thus, regional bulk WDNs are managed by the DWS, municipalities and water boards (DWS, 2015). Water services provision treat drinking water to potable standards, which are specified by the South African National Standards (SANS) 241 for drinking water, sets acceptable limits for drinking water quality for water specific quality parameters (SABS, 2015).

Several guidelines and standards have been developed to provide guidance when classifying drinking water quality. In 1983 to1984 and 1993 to1997, the World Health Organization (WHO) published the first and second editions of the guidelines for drinking water quality (WHO, 2003b; WHO, 2006). These guidelines were devised particularly for health regulators, policymakers and their advisors, to assist a country to develop their own national standards (WHO, 2008). In South Africa, the DWS developed standards, which specify drinking water quality limits of an acceptable levels for domestic use (DWAF, 1996). The South African standards is the South African National Standards (SANS) 241 for drinking water (SABS, 2015).

At a municipal level, municipalities are responsible for safeguarding drinking water quality and for implementing a Water Safety Plan (WSP) (WHO, 2005; SANS, 2015). A WSP ensures the safety of a drinking water supply through the use of the risk assessment and risk management approaches from catchment to consumer (WHO and IWA, 2009). The WSP ensures regular monitoring of drinking water treatment plant performance so that any complications can be addressed promptly. Thus, scheduled (quarterly, annual or bi-annual) compliance monitoring is undertaken by WTPs to ensure that the treatment plant is in a proper working order (DWAF, 2006; Dev et al., 2018).

Environmental health is the first line of human defense against environmental hazards, which are the direct cause of diseases. The scope of practice of environmental health profession is under the regulation of the Regulation 698 of 2009 (26 June 2009), which determines the role of environmental health in drinking water quality monitoring, specifically the physical, chemical and microbiological quality of drinking water (DoH, 2009). Thus, the Department of Health (DoH) monitors whether drinking water is fit for human consumption and suitable for domestic use (DWAF, 2005). This is accomplished through the National Health Act, 2003 (Act 61 of 2003), which provides the outlines required for municipal health services to monitor drinking water quality (DoH, 2003). The environmental health norms and standards are addressed by the National Health Act (Act no 61 of 2003), which states that drinking water quality monitoring strategies should be developed and implemented (DoH, 2013). Through such strategies of the evaluating and monitoring of drinking water quality risk to human health can be identified and mitigated (DWAF, 2005). Despite the monitoring of drinking water quality, conducted by Environmental Health Practitioners (EHPs) and other water service providers, drinking water quality remains a challenge in South African rural municipalities (Momba et al., 2004). A major concern has been that rural municipalities are failing to report the required information and are not complying with some of the regulator's requirements that address the overall management of drinking water quality monitoring rather than the actual drinking water quality itself (Rivett et al., 2013).

2.9. Conclusion

Water is needed to sustain life on the planet. However, the quality of water on the planet is dwindling, mostly because of anthropogenic factors. To ensure the health of all people, it is imperative to protect all water resources to ensure sustainable life and to continue to monitor the quality of water. Monitoring of drinking water is the key to determine the constituents of drinking water and to reveal drinking water quality variations that might have a health effect on human health. This study reveals, in particular, details about the quality of drinking water in rural municipalities of South Africa. And, the aim is to demonstrate the importance of sampling as well as the implementation of corrective measures. The role of the EHPs is highlighted throughout this study.

Chapter 3

Materials and Methods

3.1. Introduction

The quality of drinking water in the Alfred Nzo District Municipality (ANDM) in the Eastern Cape was analysed on a monthly basis over three years. ANDM is both a water services authority and a water services provider. The duty of this district municipality is to ensure that consumers of drinking water have access to efficient, affordable, economical and sustainable drinking water services (DWAF, 1997).

In this study, the drinking water quality of five towns in ANDM was assessed. These towns were Mount Ayliff, Mount Frere, Matatiele, Mbizana, and Ntabankulu. The drinking water quality was assessed in terms of physical, chemical and microbiological parameters. The physical parameters that were assessed included turbidity, pH, temperature and electrical conductivity (EC). The chemical parameters that were assessed in this study were total dissolved solids (TDS) and free residual chlorine. For the microbiological parameters, *Escherichia coli* (*E. coli*) and coliform bacteria were assessed. A water quality index (WQI) was also calculated for each of the drinking water sampling points.

3.2. Study area

The study area is located in the rural ANDM, which lies within the Eastern Cape Province of South Africa. ANDM is surrounded by the Kingdom of Lesotho and several district municipalities of the Eastern Cape and KwaZulu-Natal. The Kingdom of Lesotho lies on the northern border, the Ugu District Municipality on the eastern border, the Harry Gwala District Municipality on the north-eastern border, the O.R. Tambo District Municipality on the southern border and Joe Gqabi District Municipality lies on the western border.

ANDM comprises four local municipalities. These local municipalities are Umzimvubu, Matatiele, Mbizana, and Ntabankulu. The two towns, Mount Ayliff, and Mount Frere make up Umzimvubu Local Municipality, with Mount Ayliff being the district headquarters, while Matatiele, Mbizana, and Ntabankulu are each single-town local municipalities (ANDM SDBIP, 2013). The size of the geographic area of ANDM is 11,119 km^2, with a population of approximately 801,400 (StatsSA, 2011). The size of Umzimvubu Local Municipality is 2,506 km^2 (23% coverage of district area), Matatiele Local Municipality covers 4,352 km^2 (39% coverage of district area), Mbizana Local Municipality covers 2,806 km^2 (25% coverage of district area) and Ntabankulu Local Municipality occupies 1,455 km^2 (13% coverage of district area) (StatsSA, 2011).

Approximately 50% of communities in the local municipalities of ANDM are supplied with drinking water from six water distribution networks (WDNs). The Umzimvubu Local Municipality has independent WDNs at both Mount Ayliff and Mount Frere. In the Matatiele Local Municipality, there are two WDNs, named Maluti/Belfort and Matatiele. Both Mbizana and Ntabankulu have one WDN, namely, Nomlacu and Ntabankulu respectively. The WDNs of ANDM receive bulk water from surface water sources, which treats the water before delivery to the reservoirs of the networks. Drinking water is delivered from the reservoirs to consumers through distribution network pipes. People living in the more urban areas of the towns have access to drinking water through household water pipe connections. A substantial component of the ANDM community does not receive household water through pipe connections, but from standpipes that are strategically positioned within each community. Figure 3.1 provides maps of the study area.

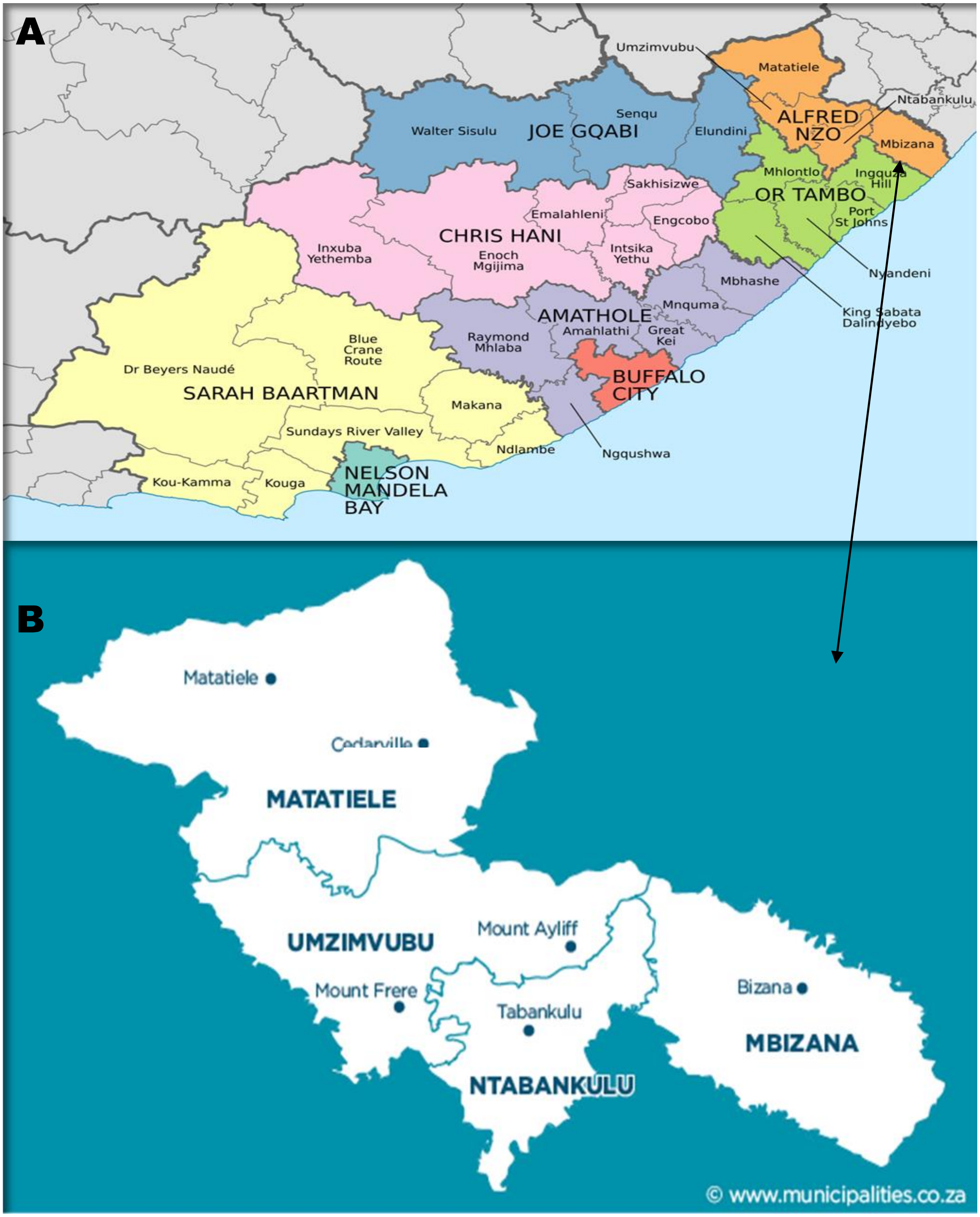


Figure 3.1 Maps of the study area. A. Map of the Eastern Cape Province in South Africa. B. Map of Alfred Nzo District Municipality showing the different local municipalities.

3.3. Study design

The study was conducted in five phases in the five towns of ANDM, namely, Mount Ayliff, Mount Frere, Matatiele, Mbizana, and Ntabankulu. In the first phase, the five towns were scouted to identify appropriate drinking water sampling points. In the second phase, drinking water samples were collected from the different drinking water sampling points, after which the drinking water was analysed in terms of the eight drinking water quality parameters (Phase 3). In Phase 4, the drinking water quality data were analysed. First, the data were statistically analysed and thereafter the water quality indices (WQI) calculated for each of the drinking water sampling points. In Phase 5, the results of the research project were interpreted and conclusions reached. Figure 3.2 provides a flow diagram of the study design of the research project.

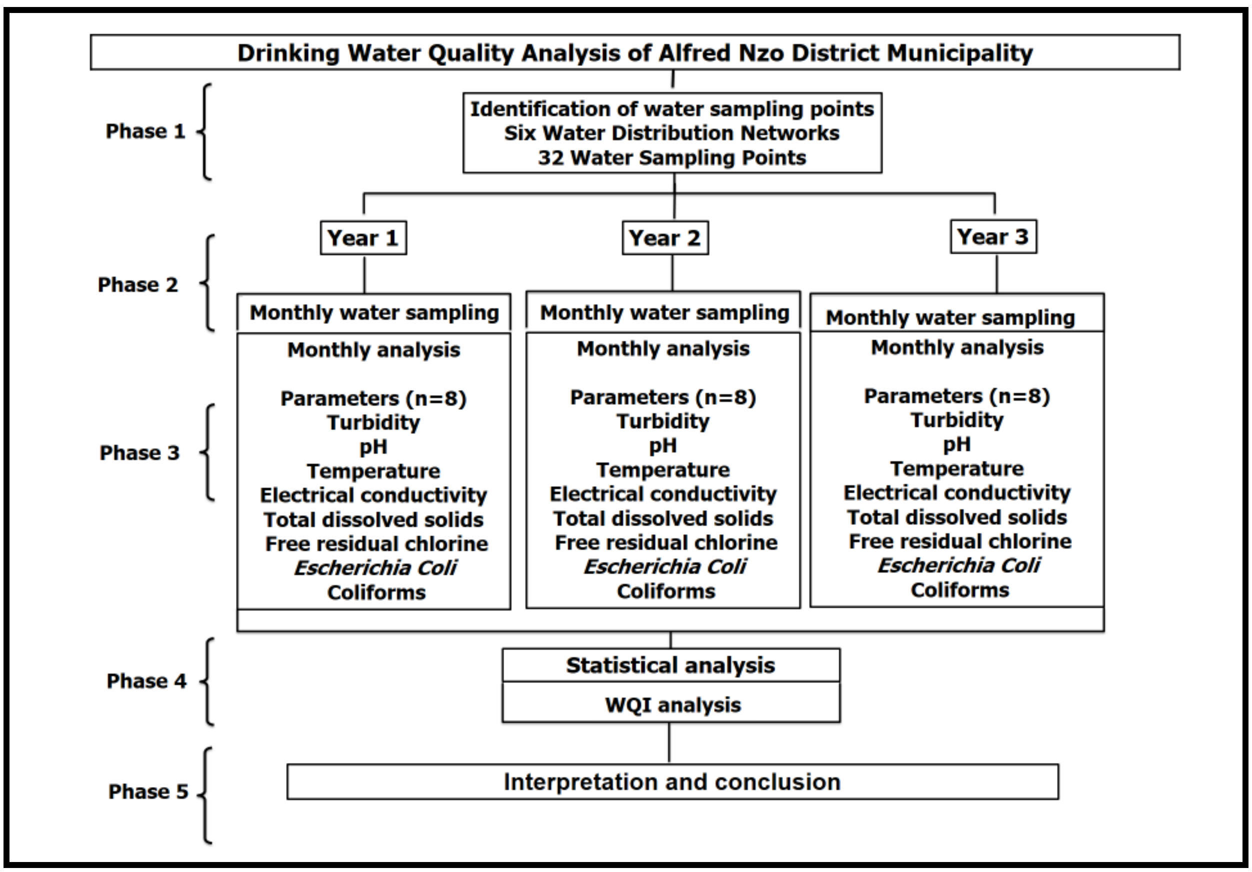


Figure 3.2 Schematic representation of the study design.

3.4. Phase 1: Identification of drinking water sampling points

Several drinking water sampling points were identified in the four local municipalities of ANDM. One drinking water sampling point was identified at each of the six water treatment plants (WTPs). These sampling points were located at the end of the treatment process, at the control point in each of the WTPs, where final treated raw water could be collected. Several end-user water sampling points were randomly identified in each of the WDN while ensuring that the end-user water sampling points were representative of the WDN. The number of end-user water sampling points in each of the WDNs was determined as suggested by SABS (2015) that there should be one water sampling point per approximately 10,000 inhabitants. Each of the six drinking water sampling points at the different WTPs was named with an abbreviation of the town or the name of the WDN, together with the abbreviation WTP; for example, MAWTP described the drinking water sampling point at the WTP of Mount Ayliff. Each of the end-user water sampling points was named with the abbreviation of the town or the name of the WDN, together with the abbreviation SP and a unique number; for example, MASP1 described end-user water sampling point number 1 of the Mount Ayliff WDN. Table 3.1 provides a list of all the drinking water sampling points with their respective coordinates.

Table 3.1 Drinking water sampling points within water distribution networks.

WDN	WSP	WSA	Coordinates
MA	MAWTP	Mount Ayliff WTW	30° 49′ 16, 95″S 29° 22′ 37.33″E
	MASP1	Mount Ayliff Town	30° 48′ 16, 46″S 29° 22′ 16.89″E
	MASP2	Santombe	30° 48′ 55, 29″S 29° 21′ 37.20″E
MF	MFWTP	Mount Frere WTW	30° 54′ 37, 91″S 28° 58′ 45.70″E
	MFSP3	Mount Frere Town	30° 53′ 53, 39″S 28° 58′ 55.10″E
	MFSP4	Chane	30° 51′ 53, 27″S 29° 31′ 82.01″E
	MFSP5	Mbodleni	30° 52′ 22, 08″S 29° 15′ 61.24″E

WDN	WSP	WSA	Coordinates
	MFSP6	Tholeni	30° 52′ 12, 93″S 29° 20′ 26.80″E
	MFSP7	Mntwana	30° 52′ 34, 24″S 29° 21′ 37.20″E
	MFSP8	Ncunteni	30° 53′ 53, 39″S 29° 20′ 12.52″E
	MFSP9	Lubhacweni	30° 57′ 30, 33″S 28° 58′ 35.29″E
	MFSP10	Nkwazini	30° 58′ 20, 85″S 28° 56′ 39.94″E
MT	MTWTP	Matatiele WTW	30° 20′ 49, 95″S 28° 48′ 31.17″E
	MTSP11	Matatiele Town	30° 20′ 35, 37″S 28° 48′ 59.06″E
MB	MBWTP	Maluti/ Belfort WTW	30° 11′ 19, 03″S 28° 43′ 39.08″E
	MBSP12	Mafube	30° 12′ 43, 27″S 28° 44′ 14.41″E
	MBSP13	Matewu	30° 12′ 17, 05″S 28° 41′ 47.50″E
	MBSP14	Nchodu	30° 13′ 14, 39″S 28° 45′ 24.39″E
	MBSP15	Ramhlakoana	30° 16′ 19, 91″S 28° 47′ 20.08″E
	MBSP16	Jabavu	30° 15′ 30, 07″S 28° 46′ 13.86″E
	MBSP17	Descur	30° 12′ 12, 29″S 28° 42′ 18.61″E
	MBSP18	Mekhakhaneng	30° 12′ 24, 72″S 28° 43′ 32.52″E
	MBSP19	Maluti town	30° 12′ 24, 72″S 28° 43′ 32.52″E
NO	NOWTP	Nomlacu WTW	30° 50′ 45, 27″S 29° 46′ 31.03″E
	NOSP20	Nomlacu	30° 50′ 35, 10″S 29° 46′ 48.87″E
	NOSP21	Manzayoni	30° 44′ 22, 12″S 29° 46′ 45.61″E
	NOSP22	Horren	30° 46′ 37, 17″S 28° 48′ 59.06″E
	NOSP23	Mbobheni	30° 49′ 49, 37″S 29° 46′ 38.06″E
	NOSP24	Mazizini	30° 48′ 20, 00″S 29° 46′ 14.56″E
NT	NTWTP	Ntabankulu WTW	30° 58′ 23, 34″S 29° 18′ 45.05″E
	NTSP25	Mbangweni	30° 57′ 35, 19″S 29° 18′ 13.90″E
	NTSP26	Ntabankulu Town	30° 56′ 44, 69″S 29° 18′ 40.44″E

WDN = water distribution network; WSP = water sampling point; WSA = water sampling area; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

A total of 32 drinking water sampling points, including the WTP drinking water sampling points, were identified. The location of all the drinking water sampling points within the six WDNs, is presented in Figure

3.3. These drinking water sampling points included the WTPs, urban areas with household supply facilities, as well as community standpipe sampling points.

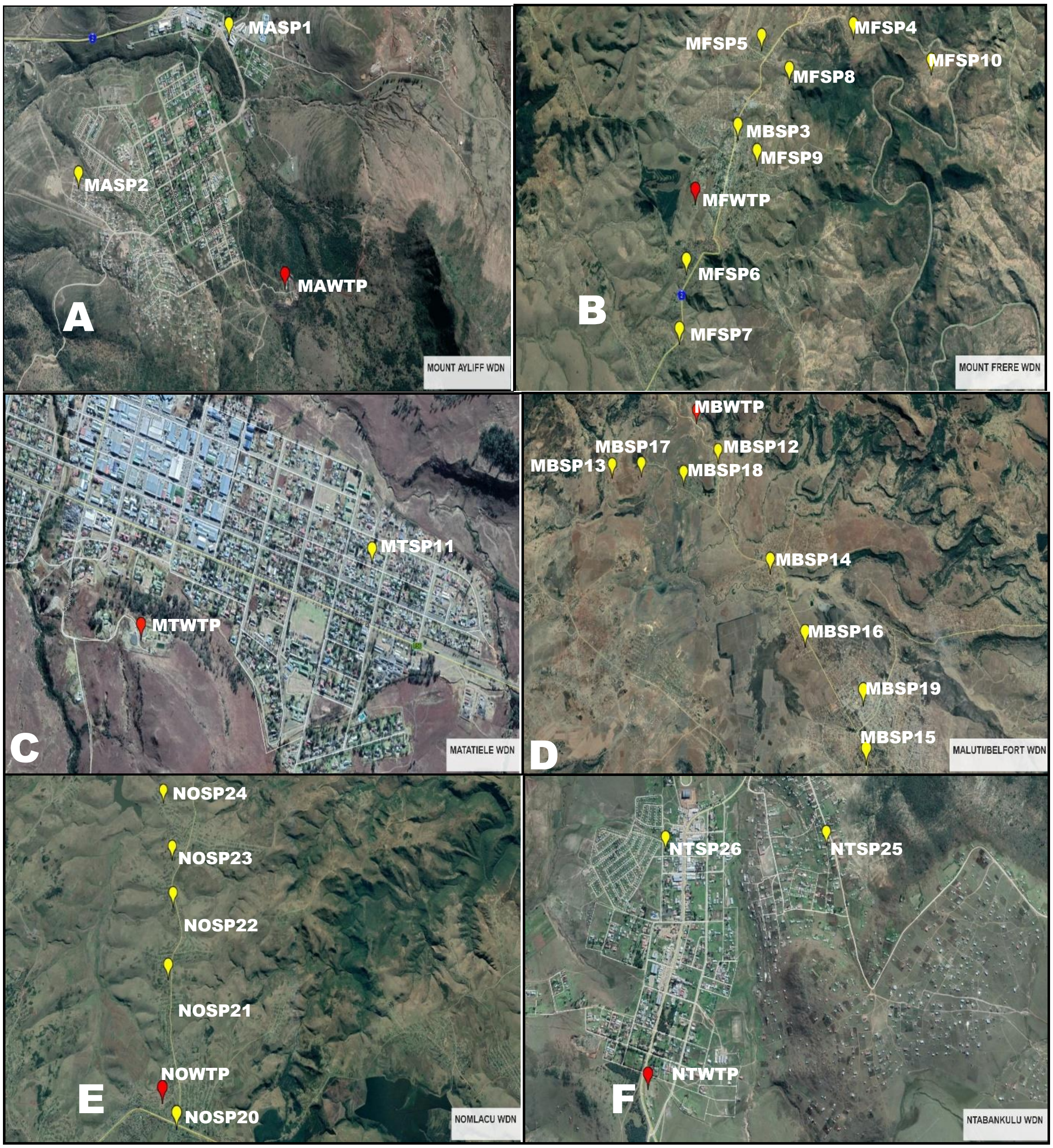


Figure 3.3 Maps of drinking water sampling points in different WDNs. A. Mount Ayliff WDN. B. Mount Frere WDN. C. Matatiele WDN. D. Maluti/Belfort WDN. E. Nomlacu WDN. F. Ntabankulu WDN. (Red bullets indicate WTPs water sampling points; yellow bullets indicate end-user water sampling points).

3.5. Phase 2: Drinking water sampling

Drinking water sampling was undertaken monthly, over three years. The collection, storage, and transportation of drinking water samples were executed according to the sampling protocol as recommended by the Quality of Domestic Water Supplies Volume 2: Sampling Guide (DWAF, 2005).

At each sampling point, the stagnant water in the interior of a tap nozzle was first flushed by running the tap for three minutes. Thereafter, the tap nozzle was disinfected by flaming it with a burner until the water in the nozzle boiled. Before collecting a drinking water sample, a tap was cooled by running the water gently for two minutes. For the microbiological analyses, 500 mL of drinking water was collected in a sterile bottle by holding the bottle in one hand and removing the screw cap with the other hand. This drinking water sample bottle was then sealed and labelled appropriately with a unique sample identification number and date. The 500 mL drinking water sample bottle was then placed in a cooler box with ice packs and transported to the laboratory. At the laboratory, these drinking water samples were sent for microbiological analysis. After collecting a drinking water sample at a particular sampling point for microbial analysis, 500 mL of drinking water was collected in a beaker and used to measure the respective physical and chemical parameters on-site.

3.6. Phase 3: Analysis of drinking water samples

Drinking water quality was analysed in terms of physical, chemical and microbiological parameters. The measurements were analysed on-site and in the laboratory on a monthly basis. Five parameters were analysed on-site and two parameters were analysed in the laboratory. The researcher was involved in taking of samples, on-site analysis and conveying samples to the outsourced accredited laboratory. From the laboratory, the results were communicated via email.

This study considered and selected drinking water parameters that were adopted by ANDM to determine their trend performance for Blue Drop programme. In addition, this study also considered physical, chemical and microbiological parameters that have acute, chronic, aesthetic and operational risk in drinking water such as *E. coli* for acute risk, chlorine for chronic risk and turbidity for aesthetic and operational risk (SABS, 2015). Lastly, the study has considered common parameters that may or are likely to exceed limits where water treatment works fail to remove them for example turbidity and *E. coli* (Mashele, 2016).

3.6.1. On-site analysis

Several physical and chemical parameters were measured and analysed on-site. These measurements included the measurements of turbidity, pH, temperature, electrical conductivity (EC) and free residual chlorine (FRC). Turbidity was analysed by using a battery-operated Hach 2100P turbidity meter in the following manner:

1. The instrument was switched on and its calibration verified by placing a clean sample cell containing a calibration solution of <100 nephelometric turbidity units (NTU) in the instrument's cell compartment.

2. A drinking water sample was poured from the 500 mL beaker into a clean Hach sample cell and filled to 10 mL mark. The sample cell was then cleaned with a soft cloth to remove fingerprints and watermarks before putting it in the Hach 2100P turbidity meter to measure the turbidity.

3. The calibration sample cell was then removed and replaced with a sample cell containing a drinking water sample.

4. After closing the sample cell compartment, the “read” button was pressed and the turbidity reading recorded in NTU.

The pH and temperature measurements at each drinking water sampling point were determined by placing the probe of a handheld pH meter directly into the 500 mL beaker containing a drinking water sample. After swirling the probe for a few seconds, the pH and temperature readings were recorded after the reading on the instrument had stabilised.

EC was determined on-site by using a battery-operated Hach conductivity meter, which uses a digital intelliCAL^{TM} probe. EC was determined on-site in the following manner:

1. The probe of the Hach conductivity meter was attached to the instrument and tightened.

2. The Hach conductivity meter probe was rinsed with distilled water and then immersed in the 500 mL beaker containing a drinking water sample.
3. Thereafter, the instrument was switched on, the appropriate mode key selected, and the EC reading recorded.

The TDS measurements were calculated from the EC measurements. TDS measurements were calculated using the following formula (EPA, 2001):

$$Total\ dissolved\ solids\ (mg/l)\ = electrical\ conductivity\ (\mu S/cm)\ X\ 0.67 \qquad (1)$$

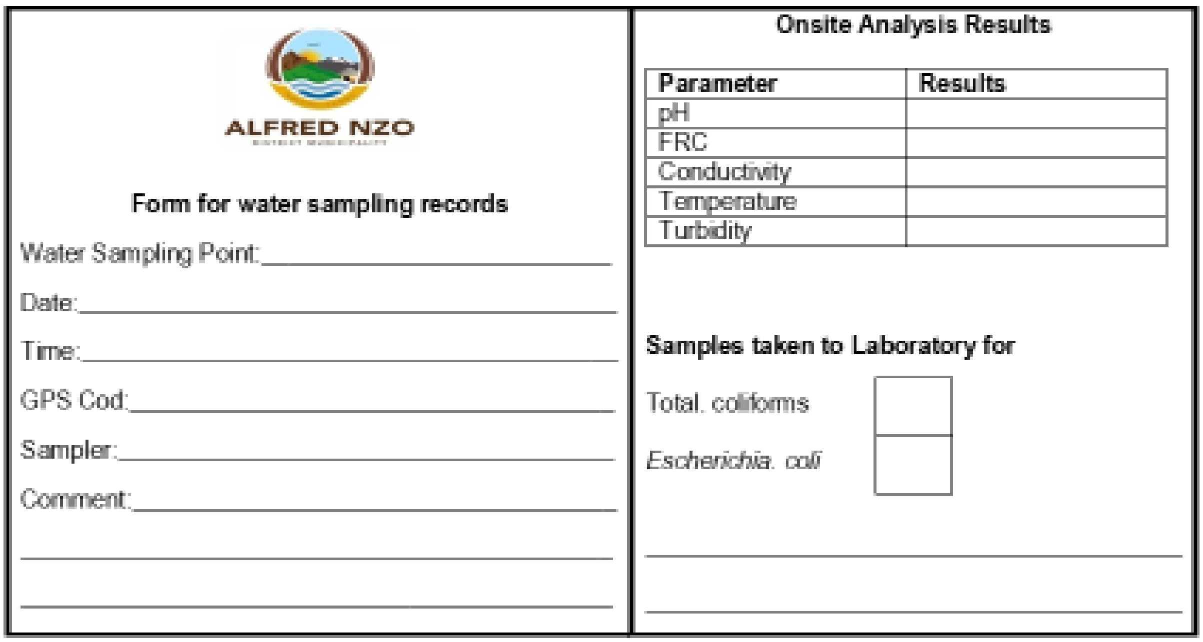
FRC was determined on-site by using a battery-operated Hach DR/820 colorimeter in the following manner:

1. A sample of drinking water was poured into a clean Hach sample cell and filled to 10 mL mark.
2. One sachet of free chlorine reagent was then added to the sample cell containing drinking water sample.
3. A control sample was prepared by pouring distilled water into a clean Hach sample cell and filled to 10 mL mark.
4. The instrument was switched on, after which the control sample cell containing distilled water was inserted into the instrument and the zero button pressed.
5. After removing the control sample cell from the instrument, the prepared sample cell containing drinking water sample was placed in the Hach colorimeter and FRC reading recorded.

Figure 3.4 provides pictures of the respective instruments that were used for the on-site measurements.

Figure 3.4 Hach instruments. A. 2100P turbidity meter. B. conductivity meter. C. DR/820 colorimeter. D. pH meter.

A data collection form was devised to record all on-site measurements taken from the respective drinking water sampling points. The respective physical and chemical parameter measurements were recorded at each drinking water sampling point on the data collection form (Figure 3.5). These data were later transferred to Microsoft Excel spreadsheets and analysed.


ALFRED NZO

Form for water sampling records

Water Sampling Point:____________________

Date:____________________

Time:____________________

GPS Cod:____________________

Sampler:____________________

Comment:____________________

Onsite Analysis Results

Parameter	Results
pH	
FRC	
Conductivity	
Temperature	
Turbidity	

Samples taken to Laboratory for

Total. coliforms ☐

Escherichia. coli ☐

Figure 3.5. Data collection form.

3.6.2. Laboratory analysis

The microbial drinking water analyses were performed in the laboratory within 48 hours of drinking water sample collection. *E. coli* and coliforms bacteria were counted in the laboratory using the IDEXX (Colilert 18) Quanti-Tray™ method. The Colilert 18 method is a biotechnological detection approach, which uses the multi-well most probable number (MPN) method. The method incorporates a defined substrate medium which contains θ-nitrophenyl-β-D-galactopyranoside (ONPG) and 4-methyumbelliferyl-β-D–glucuronide (MUG). After incubating a sample at 37°C for 18 hours, coliforms produced wells with a yellow colour due to the production of β-galactosidase, while *E. coli* produced blue fluorescent wells as a result of the action of β-glucuronidase under UV light (Figure 3.6).

A **B**

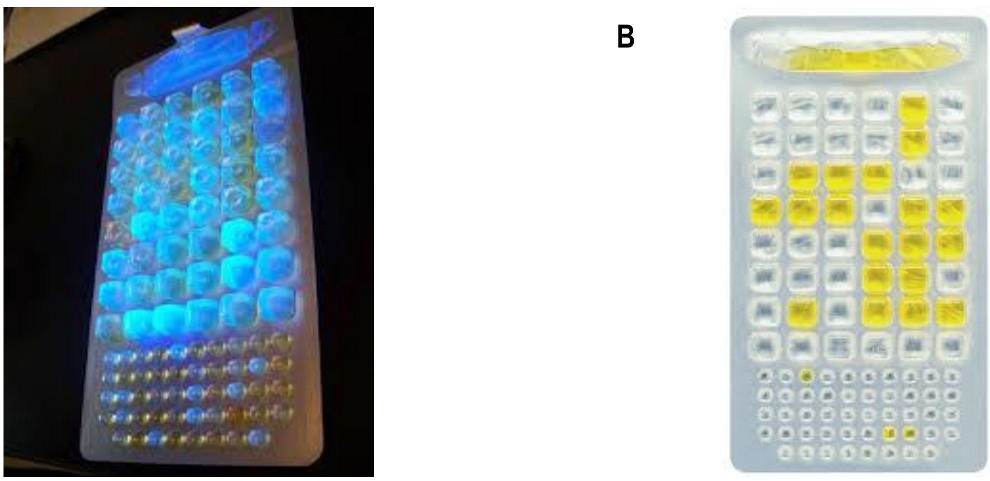


Figure 3.6 97-wel Quanti-Tray™2000. A. 97-wel Quanti-Tray™2000 showing blue fluorescent wells, indicating the presence of E. coli. B. 97-wel Quanti-Tray™2000 showing the yellow wells, indicating the presence of coliforms.

The Colilert 18 method that was used to measure the presence of *E. coli* and coliforms bacteria in the drinking water samples was as follows:

1. A drinking water sample was decanted from the 500 mL microbial drinking water sample bottle into a sterile 100 mL drinking water sample bottle.

2. One sachet of Colilert 18 medium powder was then added to the 100 mL drinking water sample bottle and shaken for a few minutes to dissolve.

3. The site name and number were written on the back of the 97-wel Colilert 18 Quanti-Tray™2000 tray using a permanent marker. Thereafter, the 100 mL drinking water sample was poured into the 97-wel Colilert 18 Quanti-Tray™2000.

4. The 97-wel Colilert 18 Quanti-Tray™2000 tray was then heat-sealed.

5. The 97-wel Colilert 18 Quanti-Tray™2000 tray was then incubated for 18 hours at 37 ºC.

The number of colony-forming units (CFU) of *E. coli* and coliform bacteria present in each 100 mL drinking water samples was determined by using the Quanti-Tray®2000 Most Probable Number (MPN) table. The MPN was determined similar to the following example:

1. The Quanti-Tray®2000 tray was passed under a UV light. The number of large and small fluorescent wells was then counted. For example, seven large and five small fluoresced wells. The MPN of *E. coli* was determined from the MPN table by matching the number of large and small yellow wells on the MPN table. The MPN for *E. coli* bacteria for this example was determined to be 12.8 (Figure 3.7).

2. For coliform bacteria, the number of large red wells was matched against the number of small red wells. For example, if 15 large wells and 12 small wells were counted after incubation of a drinking water sample, the large and small wells were matched on the MPN table as demonstrated in Figure 3.7. The MPN for coliforms for this example was 32.1.

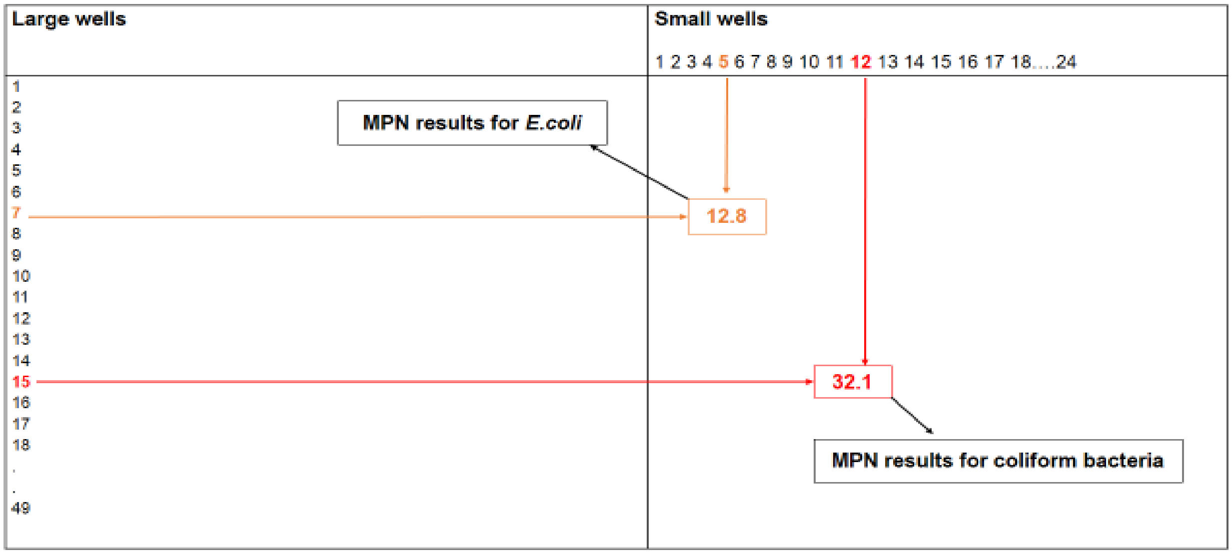


Figure 3.7 Determination of the most probable number (MPN) of E. coli and coliform bacteria using the MPN table.

3.7. Phase 4: Analysis of data

The physical, chemical and microbiological measurements were analysed by performing statistical analysis and calculating WQI.

3.7.1. Statistical analysis of drinking water quality data

The drinking water quality measurements obtained from the 32 drinking water sampling points were entered into Microsoft Excel spreadsheets for statistical analyses. The physical, chemical and microbiological measurements were statistically analysed by determining the descriptive statistics and by performing inferential tests, which included analyses of variance (ANOVAs) and Tukey HSD Post Hoc tests. ANOVA tests were performed on the measurements to ascertain if there were any differences between the three sampling years. Tukey HSD Post Hoc tests were performed on the measurements where ANOVA tests were significant.

3.7.2. Calculation of the drinking water quality index

A search of the literature was undertaken to identify WQIs that assess the overall quality of a drinking water sample. Three of the most popular WQIs were sourced based on the following section criteria: applicability to drinking water quality; represent the physical, chemical and microbiological quality of drinking water; and flexibility in that index should be adjustable to different needs and conditions of the project (Esterhuizen, 2014). Thereafter, the most appropriate WQI was selected for this study based on a scoring point system devised by Esterhuizen (2014). The scoring points addressed five criteria, namely: WQI should include physical, chemical and microbiological parameters; WQI should include multiple water sampling rounds; and WQI should demonstrate ease of calculation (Table 3.2). This scoring point system revealed that the Canadian Council of Ministers of the Environment Water Quality Index (CCME–WQI) was the most appropriate WQI to use because it was the only WQI that allowed for multiple rounds of measurements (CCME, 2001).

Table 3.2 Scores of the reviewed water quality index (Esterhuizen, 2014).

WQI characteristics	CCME-WQI (2001)	W-WQI (1985)	WA-WQI (1972)
Includes physical parameters	Yes	Yes	Yes
Includes chemical parameters	Yes	Yes	Yes
Includes microbiological parameters	Yes	No	No
Includes different sampling rounds	Yes	No	No
Ease of interpretation	Yes	Yes	Yes
Score out of 5	**5**	**3**	**3**

The calculation of the CCME–WQI values involved calculating three main factors, namely, the scope (F_1), frequency (F_2) and the amplitude (F_3), in the following manner:

Calculation of F_1 (scope): F_1 expresses the percentage of parameters that did not comply with the limits (failed parameters) (CCME, 2001).

$$F_1 = \left(\frac{Number\ of\ failed\ parameters}{Total\ number\ of\ parameters}\right) \times 100 \qquad (2)$$

Calculation of F_2 (frequency): F_2 represents the percentage of analytical results that did not meet the proposed limits (failed results) (CCME, 2001).

$$F_2 = \left(\frac{Number\ of\ failed\ results}{Total\ number\ of\ results\ over\ three\ years}\right) \times 100 \qquad (3)$$

Calculation of F_3 (amplitude): F_3 represents the difference between the non-compliant results and the proposed limits (CCME, 2001).

$$F_3 = \left(\frac{nse}{0.01\ nse\ + 0.01}\right) \qquad (4)$$

An excursion is calculated for each failed test results as follows:

There are three possible ways of determining the excursion (CCME, 2001).

a. If the results must not exceed the limits:

$$Excursion_i = \left(\frac{Failed\ test\ results}{Limit\ of\ the\ parameter}\right) - 1 \qquad (5)$$

b. If the results must not be lower than the limits:

$$Excursion_{i} = \left(\frac{Limit\ of\ the\ parameter}{Failed\ test\ results}\right) - 1 \quad (6)$$

c. If the limit is zero (equal to zero):

$$Excursion_{i} = Failed\ test\ results \quad (7)$$

The normalised sum of all excursions (nse) is calculated as follows:

$$nse = \frac{\sum_{i}^{n} = 1}{\sum_{x}^{u} Total\ number\ of\ results_{x}} \quad (8)$$

Where n = number of failed parameters and u = total number of measurements over a period of three years.

With the three factors in place, the WQI was then calculated in the following manner:

$$CCME\text{-}WQI = 100 - \left(\frac{\sqrt{F_1{}^2 + F_2{}^2 + F_3{}^2}}{1.732}\right) \quad (9)$$

After the WQIs were calculated, the drinking water quality condition for each site was classified using a five-point rating scale proposed by Esterhuizen (2014). The description and health effects that were suggested by the Department of Water Affairs and Forestry (DWAF, 2001), were used to describe the water quality (Table 3.3).

Table 3.3 WQI rating, description and health effects.

WQI Rating Esterhuizen (2014)	CCME–WQI (2001)	Description (DWAF, 2001)	Health effects (DWAF, 2001)
Excellent	>95 – 100	Ideal drinking water quality	No effects, thus suitable for human consumption
Good	>80 – ≤95	Good drinking water quality	Rare instances of sub-clinical effects. Suitable for human consumption
Poor	>65 – ≤80	Marginal drinking water quality	May cause effects in some individuals in sensitive groups. However, may be used without health effects by the majority
Very poor	>45 – ≤65	Poor drinking water quality	Poses a risk of chronic health effects, especially in babies, children and the elderly
Drinking water unsuitable for drinking	0 – 45	Unfit for human consumption	Severe acute health effects, even with short-term use.

Chapter 4

Drinking Water Quality Results

4.1. Introduction

This study was carried out to analyse the drinking water quality of six water distribution networks (WDNs) of the Alfred Nzo District Municipality (ANDM). The drinking water quality analysis was conducted on a monthly basis over three years. The drinking water quality of the 32 identified water sampling points was analysed in terms of physical, chemical and microbiological parameters. The physical parameters that were analysed were turbidity, pH, temperature and electrical conductivity (EC). The chemical parameters that were analysed in this study were total dissolved solids (TDS) and free residual chlorine (FRC). The microbiological parameters were counts of *Escherichia coli* (*E. coli*) and coliform bacteria. 32 drinking water samples analysed monthly over a period of three years which gives a total of 1152 drinking water samples analysed.

The measurements of the respective drinking water quality parameters were compared with drinking water quality standards as prescribed by the South African Bureau of Standards (2015). All the measurements were also statistically analysed by determining the descriptive statistics and appropriate inferential statistical tests. The inferential statistical tests included analyses of variance (ANOVAs) and Tukey HSD Post Hoc tests. ANOVA tests were performed on the measurements to ascertain if there were any differences in the drinking water quality parameter measurements amongst the three sampling years. Tukey HSD Post Hoc tests were performed on the measurements where ANOVA tests were significant.

4.2. Physical drinking water quality

The physical parameters that were analysed were turbidity, pH, temperature, and EC. The measurements of the physical parameters were then compared to the SANS 241 standards (SABS, 2015) for compliance. Descriptive statistics were also calculated for the three sampling years.

4.2.1. Turbidity

During the three sampling years, most turbidity measurements demonstrated non-compliant values when compared to the SANS 241 standards (SABS, 2015). During Year 2, the percentage compliance of turbidity measurements was the lowest of the three sampling years (Table 4.1). When considering the turbidity measurements over the three years, only two drinking water sampling points, NTSP25, and NTSP26 of Ntabankulu (NT) WDN demonstrated 100% overall compliance with the SANS 241 standards (SABS, 2015). A major concern was the poor overall performance of the WTP at Mount Ayliff (MA) WDN.

Table 4.1 Summary statistics of monthly turbidity measurements over three years.

WDN	WSP	Year 1 Turbidity (limit ≤ 1 NTU)			Year 2 Turbidity (limit ≤ 1 NTU)			Year 3 Turbidity (limit ≤ 1 NTU)			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	C overall (%)
MA	MAWTP	0,20	1,90	1,03	0,10	3,10	1,29	0,20	1,90	1,03	31,00
	MASP1	0,50	1,90	1,01	0,20	1,50	0,84	0,50	1,90	1,01	58,00
	MASP2	0,10	1,50	0,38	0,20	1,80	0,98	0,10	1,50	0,38	72,00
MF	MFWTP	0,10	0,90	0,54	0,10	9,40	1,42	0,10	0,90	0,54	91,00
	MFSP3	0,10	1,20	0,57	0,20	3,20	0,92	0,10	1,20	0,57	92,00
	MFSP4	0,10	1,90	0,35	0,20	1,10	0,70	0,10	0,60	0,35	83,00
	MFSP5	0,10	1,20	0,39	0,30	1,90	1,05	0,10	1,20	0,39	83,00
	MFSP6	0,20	1,20	0,51	0,20	1,00	0,50	0,20	1,20	0,51	92,00

WDN	WSP	Year 1 Turbidity (limit ≤ 1 NTU)			Year 2 Turbidity (limit ≤ 1 NTU)			Year 3 Turbidity (limit ≤ 1 NTU)			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	C overall (%)
	MFSP7	0,10	1,10	0,40	0,10	1,20	0,60	0,10	1,10	0,40	83,00
	MFSP8	0,20	2,20	0,48	0,20	0,90	0,53	0,20	0,90	0,48	94,00
	MFSP9	0,10	2,40	0,40	0,10	0,70	0,48	0,10	0,80	0,40	97,00
	MFSP10	0,30	1,80	0,42	0,30	1,40	0,71	0,30	0,70	0,42	89,00
MT	MTWTP	0,10	0,50	0,27	0,10	2,10	0,64	0,10	0,50	0,27	94,00
	MTSP11	0,10	0,50	0,33	0,10	1,60	0,58	0,10	0,50	0,33	97,00
MB	MBWTP	0,10	1,00	0,47	0,30	1,20	0,81	0,10	1,19	0,47	92,00
	MBSP12	0,10	1,00	0,50	0,10	2,21	0,62	0,10	2,21	0,50	92,00
	MBSP13	0,10	1,00	0,77	0,47	2,94	0,88	0,10	2,94	0,77	89,00
	MBSP14	0,20	1,00	0,81	0,30	1,50	1,43	0,20	5,30	0,81	83,00
	MBSP15	0,20	1,00	0,82	0,20	1,50	0,99	0,20	1,00	0,82	86,00
	MBSP16	0,30	5,30	0,63	0,30	8,90	2,29	0,30	1,00	0,63	78,00
	MBSP17	0,10	9,20	0,37	0,30	9,40	1,68	0,10	0,90	0,37	78,00
	MBSP18	0,10	1,80	0,69	0,20	2,80	1,29	0,10	1,80	0,69	75,00
	MBSP19	0,10	1,10	0,43	0,40	3,10	1,12	0,10	1,10	0,43	78,00
NO	NOWTP	0,20	0,90	0,52	0,26	1,20	0,76	0,20	0,90	0,52	97,00
	NOSP20	0,10	0,80	0,26	0,20	1,10	0,70	0,10	0,80	0,26	97,00
	NOSP21	0,10	1,00	0,65	0,10	1,93	0,81	0,10	1,20	0,65	83,00
	NOSP22	0,10	1,00	0,53	0,20	2,30	0,82	0,10	1,10	0,53	83,00
	NOSP23	0,10	0,90	0,63	0,10	1,50	0,86	0,10	0,90	0,63	89,00
	NOSP24	0,10	1,30	0,64	0,30	9,40	1,67	0,10	0,80	0,55	78,00
NT	NTWTP	0,10	0,80	0,55	0,70	1,40	1,04	0,10	0,80	0,43	86,06
	NTSP25	0,10	0,80	0,43	0,60	1,00	0,87	0,10	0,90	0,40	100,00
	NTSP26	0,10	0,90	0,40	0,50	0,90	0,73	0,10	0,80	0,50	100,00
C (%) over WSP		87,46			74,45			92,17			85,00

WDN = water distribution network; WSP = water sampling point; C (%) = compliance percentage; C overall (%) = compliance overall percentage; Min = minimum; Max = maximum; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

4.2.2. pH

During the three sampling years, most pH measurements demonstrated compliant values when compared to the SANS 241 standards (SABS, 2015). Only one of the 32 end-user water sampling points, NOSP24 of the Nomlacu (NO) WDN, demonstrated pH values during Year 2 that exceeded the recommended SANS 241 standards (SABS, 2015) (Table 4.2).

Table 4.2 Summary statistics of monthly pH measurements over three years.

WDN	WSP	Year 1 pH (limit ≥ 5 to ≤ 9.7 pH units)			Year 2 pH (limit ≥ 5 to ≤ 9.7 pH units)			Year 3 pH (limit ≥ 5 to ≤ 9.7 pH units)			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	C overall (%)
MA	MAWTP	7,10	8,10	7,60	7,00	8,30	7,55	6,90	8,30	7,41	100,00
	MASP1	7,00	8,10	7,53	7,10	8,30	7,89	7,10	8,30	8,01	100,00
	MASP2	7,10	8,30	7,91	6,90	8,30	7,61	7,30	8,30	8,08	100,00
MF	MFWTP	7,10	8,30	7,58	7,30	8,90	8,12	6,90	8,80	7,95	100,00
	MFSP3	7,00	8,40	7,75	7,10	8,90	8,12	6,80	8,10	7,58	100,00
	MFSP4	7,60	8,80	7,98	6,90	8,80	7,73	6,90	7,80	7,31	100,00
	MFSP5	6,80	8,20	7,61	6,60	7,90	7,57	6,70	8,30	7,43	100,00
	MFSP6	7,00	8,80	7,84	7,20	8,80	7,78	7,20	8,30	7,76	100,00
	MFSP7	6,90	8,30	7,53	6,90	8,50	7,60	6,70	8,30	7,63	100,00
	MFSP8	6,90	8,90	8,03	6,80	8,20	7,70	7,70	8,80	7,94	100,00
	MFSP9	7,00	8,10	7,58	7,10	8,90	7,96	7,10	8,90	7,82	100,00
	MFSP10	6,10	7,90	7,41	7,10	7,90	7,55	6,90	7,90	7,66	100,00
MT	MTWTP	6,60	8,10	7,60	7,30	8,10	7,86	7,20	8,30	7,76	100,00
	MTSP11	7,10	8,10	7,60	7,40	8,10	7,86	7,30	8,70	7,98	100,00
MB	MBWTP	7,60	8,80	8,14	7,30	8,80	8,08	6,80	8,50	7,65	100,00
	MBSP12	6,70	8,90	7,93	7,20	8,90	8,38	6,90	8,80	8,04	100,00
	MBSP13	6,80	8,30	7,54	7,20	8,70	7,95	7,10	9,80	7,78	100,00
	MBSP14	7,00	8,30	7,74	7,00	8,70	7,78	7,60	8,80	7,83	100,00
	MBSP15	7,20	8,20	7,72	6,80	9,60	7,77	6,90	8,30	7,34	100,00

WDN	WSP	Year 1 pH (limit ≥ 5 to ≤ 9.7 pH units)			Year 2 pH (limit ≥ 5 to ≤ 9.7 pH units)			Year 3 pH (limit ≥ 5 to ≤ 9.7 pH units)			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	C overall (%)
	MBSP16	7,30	8,10	7,71	6,90	8,90	7,97	6,90	8,70	7,68	100,00
	MBSP17	6,10	8,30	7,33	6,90	9,70	7,81	6,80	8,60	7,80	100,00
	MBSP18	7,00	8,70	7,45	7,60	9,60	8,23	7,30	8,90	8,28	100,00
	MBSP19	7,40	8,90	8,11	6,90	8,60	7,74	7,10	9,20	7,97	100,00
NO	NOWTP	7,10	7,80	7,45	6,20	8,60	7,64	7,20	8,40	7,62	100,00
	NOSP20	6,90	8,90	7,67	6,00	8,80	7,96	7,70	8,60	8,13	100,00
	NOSP21	7,20	8,10	7,60	6,30	9,10	8,23	6,90	9,00	7,67	100,00
	NOSP22	6,90	7,90	7,47	6,90	9,10	8,03	6,90	8,90	7,68	100,00
	NOSP23	7,50	8,90	8,14	7,20	8,90	7,94	7,60	8,90	8,15	100,00
	NOSP24	7,00	8,60	7,65	6,50	9,80	8,15	6,70	8,90	7,78	97,00
NT	NTWTP	7,00	7,90	7,53	7,20	8,10	7,73	7,20	8,80	7,89	100,00
	NTSP25	7,00	7,90	7,40	6,20	8,80	7,71	7,20	8,80	7,89	100,00
	NTSP26	7,10	8,10	7,68	5,90	7,90	7,33	7,10	8,30	7,79	100,00
C (%) over WSP		100,00			99,74			100,00			99,91

WDN = water distribution network; WSP = water sampling point; C (%) = compliance percentage; C overall (%) = compliance overall percentage; Min = minimum; Max = maximum; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

4.2.3. Temperature

All temperature measurements demonstrated compliant values when compared to the SANS 241 standards (SABS, 2015) over the three sampling years. The lowest temperature value was recorded at MBSP14 drinking water sampling point of Maluti/Belfort (MB) WDN in Year 2 (Table 4.3). The highest temperature of 25 °C was recorded at several sampling points during the study period, particularly in Year 1.

Table 4.3 Summary statistics of monthly temperature measurements over three years.

WDN	WSP	Year 1 Temperature (limit ≤ 25 °C)			Year 2 Temperature (limit ≤ 25 °C)			Year 3 Temperature (limit = ≤ 25 °C)			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	C overall (%)
MA	MAWTP	10,00	25,00	17,67	13,00	25,00	18,75	15,00	20,00	19,92	100,00
	MASP1	10,00	25,00	18,17	13,00	25,00	18,83	15,00	22,00	20,33	100,00
	MASP2	10,00	25,00	17,83	13,00	25,00	18,75	16,00	22,00	20,50	100,00
MF	MFWTP	12,00	25,00	18,33	15,00	23,00	19,38	15,00	24,00	20,08	100,00
	MFSP3	12,00	25,00	18,58	15,00	23,00	20,17	13,00	23,00	20,25	100,00
	MFSP4	11,00	25,00	18,67	15,00	23,00	20,17	13,00	23,00	21,00	100,00
	MFSP5	11,00	25,00	18,33	15,00	23,00	20,50	14,00	24,00	20,42	100,00
	MFSP6	11,00	25,00	19,00	15,00	24,00	19,92	14,00	24,00	20,75	100,00
	MFSP7	11,00	25,00	19,00	15,00	24,00	20,00	13,00	24,00	19,92	100,00
	MFSP8	12,00	25,00	18,83	15,00	23,00	19,67	13,00	24,00	20,42	100,00
	MFSP9	13,00	25,00	18,92	14,00	22,00	20,08	13,00	23,00	20,42	100,00
	MFSP10	12,00	25,00	18,42	15,00	22,00	19,91	12,00	23,00	20,50	100,00
MT	MTWTP	15,00	21,00	18,83	11,00	24,00	19,67	6,00	24,00	19,08	100,00
	MTSP11	15,00	22,00	18,83	12,00	24,00	19,58	12,00	24,00	19,91	100,00
MB	MBWTP	13,00	24,00	18,42	16,00	25,00	19,67	11,00	24,00	19,08	100,00
	MBSP12	15,00	24,00	19,33	17,00	25,00	20,33	11,00	25,00	19,50	100,00
	MBSP13	13,00	25,00	19,00	16,00	24,00	20,00	10,00	24,00	19,41	100,00
	MBSP14	16,00	24,00	18,83	0,50	23,00	17,96	11,00	24,00	19,17	100,00
	MBSP15	15,00	25,00	19,00	16,00	24,00	19,41	12,00	23,00	17,00	100,00
	MBSP16	15,00	24,00	19,42	17,00	23,00	20,00	10,00	24,00	19,67	100,00
	MBSP17	15,00	25,00	19,00	16,00	24,00	19,92	11,00	25,00	20,10	100,00
	MBSP18	15,00	25,00	19,42	17,00	25,00	20,42	11,00	25,00	20,10	100,00
	MBSP19	16,00	24,00	19,25	17,00	25,00	19,93	9,00	24,00	17,67	100,00
NO	NOWTP	17,00	25,00	19,67	17,00	25,00	19,67	9,00	23,00	19,42	100,00
	NOSP20	15,00	25,00	19,33	18,00	24,00	19,83	9,00	23,00	19,75	100,00
	NOSP21	16,00	25,00	19,50	17,00	24,00	19,83	9,00	24,00	19,92	100,00
	NOSP22	17,00	22,00	19,83	16,00	24,00	19,50	9,00	24,00	20,00	100,00
	NOSP23	18,00	23,00	20,17	18,00	23,00	19,42	9,00	24,00	20,58	100,00

WDN	WSP	Year 1 Temperature (limit ≤ 25 °C)			Year 2 Temperature (limit ≤ 25 °C)			Year 3 Temperature (limit = ≤ 25 °C)			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	C overall (%)
	NOSP24	15,00	23,00	18,67	18,00	24,00	19,83	9,00	23,00	20,42	100,00
NT	NTWTP	14,00	24,00	17,83	15,00	24,00	19,75	9,00	22,00	19,50	100,00
	NTSP25	14,00	24,00	17,50	16,00	23,00	19,75	9,00	20,00	19,00	100,00
	NTSP26	14,00	23,00	17,50	17,00	23,00	19,75	9,00	23,00	19,08	100,00
C (%) over WSP		100,00			100,00			100,00			100,00

WDN = water distribution network; WSP = water sampling point; C (%) = compliance percentage; C overall (%) = compliance overall percentage; Min = minimum; Max = maximum; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

4.2.4. Electrical conductivity

During the three sampling years, all EC measurements demonstrated compliant values when compared to the SANS 241 standards (SABS, 2015). The highest EC value of 35 mS/m was recorded at the MBSP13 drinking water sampling point of Maluti/Belfort (MB) WDN in Year 3 (Table 4.4). This EC value was approximately double that of the annual mean value for the MBSP13 drinking water sampling point, which falls within the SANS 241 standards (SABS, 2015). The lowest EC measurement was recorded at the MTWTP drinking water sampling point of Matatiele (MT) WDN in Year 3.

Table 4.4 Summary statistics of monthly electrical conductivity measurements over three years

WDN	WSP	Year 1 Electrical conductivity (limit ≤ 170 mS/m)			Year 2 Electrical conductivity (limit ≤ 170 mS/m)			Year 3 Electrical conductivity (limit ≤ 170 mS/m)			
		Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**C overall (%)**
MA	MAWTP	14,00	20,00	17,92	5,70	20,00	16,02	16,00	19,00	18,25	100,00
	MASP1	13,00	21,00	17,41	5,50	20,00	16,41	16,00	19,00	17,92	100,00
	MASP2	14,00	19,00	17,83	5,10	19,00	15,35	18,00	23,00	19,08	100,00
MF	MFWTP	11,00	18,00	14,67	15,00	23,00	18,08	15,00	21,00	17,75	100,00
	MFSP3	11,00	20,00	15,50	14,00	21,00	17,50	13,00	19,00	16,25	100,00
	MFSP4	7,00	18,00	14,08	14,00	18,00	16,42	14,00	19,00	15,42	100,00
	MFSP5	11,00	20,00	15,92	16,00	20,00	17,83	14,00	21,00	16,91	100,00
	MFSP6	14,00	19,00	17,33	14,00	21,00	16,83	15,00	25,00	17,75	100,00
	MFSP7	12,00	20,00	15,00	15,00	20,00	17,25	13,00	23,00	16,91	100,00
	MFSP8	11,00	19,00	14,92	13,00	22,00	16,08	13,00	19,00	16,08	100,00
	MFSP9	13,00	19,00	16,33	10,00	20,00	17,08	13,00	21,00	16,83	100,00
	MFSP10	8,90	19,00	14,41	8,20	19,00	14,77	12,00	18,00	16,00	100,00
MT	MTWTP	15,00	21,00	18,83	11,00	24,00	19,67	6,00	24,00	19,08	100,00
	MTSP11	15,00	22,00	18,83	12,00	24,00	19,58	12,00	24,00	19,91	100,00
MB	MBWTP	13,00	23,00	18,42	6,00	23,00	17,92	14,00	23,00	20,00	100,00
	MBSP12	12,00	22,00	17,83	11,00	24,00	18,67	13,00	27,00	19,83	100,00
	MBSP13	17,00	30,00	19,08	6,00	19,00	15,58	11,00	35,00	19,50	100,00
	MBSP14	15,00	22,00	18,00	6,00	21,00	13,50	14,00	26,00	17,92	100,00
	MBSP15	12,00	23,00	18,25	9,00	23,00	15,83	14,00	22,00	18,00	100,00
	MBSP16	17,00	30,00	20,42	6,00	22,00	14,08	17,00	22,00	19,17	100,00
	MBSP17	13,00	21,00	17,50	6,00	21,00	15,58	16,00	21,00	18,58	100,00
	MBSP18	12,00	21,00	17,67	8,00	21,00	16,00	14,00	20,00	17,91	100,00
	MBSP19	14,00	30,00	19,67	6,00	20,00	16,16	16,00	20,00	18,50	100,00
NO	NOWTP	13,00	19,00	16,58	6,00	21,00	16,41	13,00	21,00	18,67	100,00
	NOSP20	13,00	19,00	17,33	13,00	24,00	18,17	13,00	23,00	15,45	100,00
	NOSP21	12,00	19,00	16,00	6,00	21,00	16,08	12,00	23,00	16,50	100,00
	NOSP22	14,00	19,00	16,75	6,00	20,00	16,42	14,00	21,00	15,83	100,00
	NOSP23	12,00	19,00	15,33	9,00	21,00	16,58	11,00	22,00	15,33	100,00

WDN	WSP	Year 1 Electrical conductivity (limit ≤ 170 mS/m)			Year 2 Electrical conductivity (limit ≤ 170 mS/m)			Year 3 Electrical conductivity (limit ≤ 170 mS/m)			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	C overall (%)
	NOSP24	11,00	17,00	13,33	6,00	32,00	18,92	13,00	22,00	17,00	100,00
NT	NTWTP	12,00	19,00	16,58	9,00	19,00	15,83	14,00	21,00	17,58	100,00
	NTSP25	11,00	20,00	14,50	12,00	19,00	15,75	13,00	21,00	16,42	100,00
	NTSP26	12,00	19,00	14,67	10,00	19,00	16,00	15,00	20,00	16,92	100,00
C (%) over WSP		100,00			100,00			100,00			100,00

WDN = water distribution network; WSP = water sampling point; C (%) = compliance percentage; C overall (%) = compliance overall percentage; Min = minimum; Max = maximum; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

4.3. Chemical drinking water quality

The chemical parameters that were analysed were TDS and FRC. The chemical parameter measurements were compared to the SANS 241 standards (SABS, 2015) for compliance. Descriptive statistics were also calculated for the three sampling years.

4.3.1. Total dissolved solids

During the three sampling years, all TDS calculations demonstrated compliant values when compared to the SANS 241 standards (SABS, 2015). Of all the TDS calculations, three values of the Maluti/Belfort (MB) WDN exceeded 200 mg/L. The lowest TDS value was recorded at the MASP2 drinking water sampling point of Mount Ayliff (MA) WDN in Year 2 (Table 4.5).

Table 4.5 Summary statistics of monthly total dissolved solids measurements over three years.

WDN	WSP	Year 1 Total dissolved solids (limit ≤ 1200 mg/L)			Year 2 Total dissolved solids (limit ≤ 1200 mg/L)			Year 3 Total dissolved solids (limit ≤ 1200 mg/L)			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	C overall (%)
MA	MAWTP	93,80	134,00	112,00	38,20	134,00	107,40	107,20	127,30	122,30	100,00
	MASP1	87,10	140,70	110,20	36,90	134,00	109,90	107,20	127,30	120,00	100,00
	MASP2	93,80	127,30	112,40	34,20	127,30	102,80	120,60	154,10	128,90	100,00
MF	MFWTP	73,70	120,60	91,70	100,50	154,10	121,20	100,50	147,00	120,00	100,00
	MFSP3	73,70	134,00	98,30	93,80	140,70	117,20	87,10	127,30	108,90	100,00
	MFSP4	46,90	120,60	85,30	93,80	120,60	110,00	93,80	127,30	103,30	100,00
	MFSP5	73,70	134,00	100,10	107,20	134,00	119,50	93,80	140,70	113,30	100,00
	MFSP6	93,80	127,30	106,60	93,80	140,70	112,80	100,50	167,50	118,90	100,00
	MFSP7	80,40	134,00	93,50	100,50	134,00	115,60	87,10	154,10	113,30	100,00
	MFSP8	73,70	127,30	91,40	87,10	147,40	107,80	87,10	127,30	107,80	100,00
	MFSP9	87,10	127,30	100,40	67,00	134,00	114,50	87,10	140,70	112,80	100,00
	MFSP10	59,63	127,30	88,00	54,90	127,30	98,90	80,40	120,60	108,70	100,00
MT	MTWTP	107,20	134,00	112,60	34,20	154,10	97,80	87,10	127,30	113,90	100,00
	MTSP11	80,40	127,30	98,20	54,90	167,50	98,40	107,20	127,30	112,80	100,00
MB	MBWTP	87,10	154,10	113,80	40,20	154,10	120,00	93,80	154,10	134,00	100,00
	MBSP12	80,40	147,40	113,00	73,70	160,80	125,10	87,10	180,90	132,90	100,00
	MBSP13	113,90	201,00	119,30	40,20	127,30	104,40	73,70	234,50	130,70	100,00
	MBSP14	100,50	147,40	112,00	40,20	140,70	90,50	93,80	174,20	120,00	100,00
	MBSP15	80,40	154,10	114,70	60,30	154,10	106,10	93,80	147,40	120,60	100,00
	MBSP16	113,90	201,00	128,20	40,20	147,40	93,80	113,90	147,40	128,40	100,00
	MBSP17	87,10	140,70	108,70	40,20	140,70	104,40	107,20	140,70	124,50	100,00
	MBSP18	80,40	140,70	109,30	53,60	140,70	107,20	93,80	134,00	120,00	100,00
	MBSP19	93,80	201,00	124,20	40,20	134,00	108,30	107,20	134,00	124,00	100,00
NO	NOWTP	87,10	127,30	104,60	40,20	140,70	116,70	87,10	140,70	125,10	100,00
	NOSP20	87,10	127,30	109,60	87,10	160,80	121,70	87,10	154,10	103,30	100,00
	NOSP21	80,40	127,30	99,60	40,20	140,70	107,80	80,40	154,10	110,60	100,00
	NOSP22	93,80	127,30	103,70	40,20	134,00	110,00	93,80	140,70	106,10	100,00
	NOSP23	80,40	127,30	96,70	60,30	140,70	111,10	73,70	147,40	102,70	100,00

WDN	WSP	Year 1 Total dissolved solids (limit ≤ 1200 mg/L)			Year 2 Total dissolved solids (limit ≤ 1200 mg/L)			Year 3 Total dissolved solids (limit ≤ 1200 mg/L)			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	C overall (%)
	NOSP24	73,70	113,90	83,30	40,20	214,40	126,70	87,10	147,40	113,90	100,00
NT	NTWTP	80,40	127,30	105,10	60,30	127,30	106,10	93,80	140,70	117,80	100,00
	NTSP25	73,70	134,00	88,10	80,40	127,30	105,50	87,10	140,70	110,00	100,00
	NTSP26	80,40	127,30	88,70	67,00	127,30	107,20	100,50	134,00	113,30	100,00
C (%) over WSP		100,00			100,00			100,00			100,00

WDN = water distribution network; WSP = water sampling point; C (%) = compliance percentage; C overall (%) = compliance overall percentage; Min = minimum; Max = maximum; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabanku

4.3.2. Free residual chlorine

During the three sampling years, all FRC measurements demonstrated compliant values when compared to the SANS 241 standards (SABS, 2015). However, of concern were the zero values recorded over the three years at most of the WDNs. Only the two smallest WDNs, Mount Ayliff (MA) and Matatiele (MT), showed the presence of free chlorine in their drinking water distribution networks over the three years. The highest FRC value was recorded at NTSP26 drinking water sampling point of Ntabankulu (NT) WDN in Year 3 (Table 4.6).

Table 4.6 Summary statistics of monthly free residual chlorine measurements over three years.

WDN	WSP	Year 1 Free residual chlorine (limit ≤ 5 mg/L)			Year 2 Free residual chlorine (limit ≤ 5 mg/L)			Year 3 Free residual chlorine (limit ≤ 5 mg/L)			
		Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**C overall (%)**
MA	MAWTP	0,70	1,00	0,90	0,40	1,30	0,93	0,90	1,00	0,93	100,00
	MASP1	0,20	0,50	0,38	0,30	0,50	0,39	0,30	0,50	0,43	100,00
	MASP2	0,30	0,40	0,33	0,10	0,40	0,26	0,20	0,40	0,29	100,00
MF	MFWTP	0,30	1,00	0,78	0,30	1,00	0,84	0,30	1,00	0,78	100,00
	MFSP3	0,30	0,90	0,42	0,30	1,00	0,84	0,20	0,50	0,36	100,00
	MFSP4	0,10	0,30	0,17	0,00	0,30	0,23	0,10	0,30	0,23	100,00
	MFSP5	0,10	0,30	0,23	0,10	0,40	0,22	0,20	0,30	0,23	100,00
	MFSP6	0,10	0,30	0,18	0,00	0,50	0,24	0,00	0,30	0,18	100,00
	MFSP7	0,10	0,40	0,21	0,00	0,40	0,23	0,10	0,40	0,27	100,00
	MFSP8	0,10	0,30	0,21	0,00	0,40	0,23	0,10	0,30	0,20	100,00
	MFSP9	0,10	0,30	0,22	0,10	0,40	0,27	0,20	0,40	0,28	100,00
	MFSP10	0,10	0,30	0,17	0,00	0,40	0,19	0,10	0,30	0,23	100,00
MT	MTWTP	0,40	0,90	0,64	0,30	1,00	0,62	0,50	1,00	0,77	100,00
	MTSP11	0,20	0,50	0,36	0,01	0,60	0,34	0,20	0,30	0,38	100,00
MB	MBWTP	0,10	1,00	0,71	0,12	1,00	0,82	0,60	1,00	0,93	100,00
	MBSP12	0,10	0,40	0,25	0,06	0,50	0,33	0,20	0,50	0,37	100,00
	MBSP13	0,00	0,30	0,13	0,10	0,40	0,24	0,10	0,30	0,23	100,00
	MBSP14	0,10	0,60	0,23	0,03	0,60	0,26	0,20	0,30	0,26	100,00
	MBSP15	0,00	0,20	0,11	0,10	1,30	0,30	0,00	0,20	0,15	100,00
	MBSP16	0,00	0,30	0,17	0,00	0,30	0,23	0,20	0,60	0,27	100,00
	MBSP17	0,01	0,60	0,18	0,10	0,40	0,21	0,10	0,40	0,28	100,00
	MBSP18	0,10	0,30	0,18	0,10	0,30	0,22	0,10	0,30	0,21	100,00
	MBSP19	0,00	0,30	0,17	0,10	0,90	0,31	0,10	0,50	0,24	100,00
NO	NOWTP	0,70	1,00	0,88	0,12	1,00	0,74	0,60	1,00	0,90	100,00
	NOSP20	0,30	0,60	0,40	0,06	0,40	0,31	0,10	0,40	0,33	100,00
	NOSP21	0,10	0,50	0,29	0,10	0,30	0,22	0,10	0,40	0,25	100,00
	NOSP22	0,10	0,40	0,25	0,03	0,30	0,19	0,10	0,30	0,20	100,00
	NOSP23	0,00	0,40	0,18	0,10	0,40	0,18	0,10	0,30	0,17	100,00

WDN	WSP	Year 1 Free residual chlorine (limit ≤ 5 mg/L)			Year 2 Free residual chlorine (limit ≤ 5 mg/L)			Year 3 Free residual chlorine (limit ≤ 5 mg/L)			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	C overall (%)
	NOSP24	0,10	1,00	0,40	0,00	0,30	0,19	0,10	0,40	0,24	100,00
NT	NTWTP	0,20	0,80	0,38	0,30	0,90	0,40	0,30	0,90	0,50	100,00
	NTSP25	0,10	0,30	0,16	0,10	0,40	0,25	0,00	0,30	0,18	100,00
	NTSP26	0,00	0,20	0,10	0,03	0,30	0,17	0,10	4,00	0,49	100,00
C (%) over WSP		100,00			100,00			100,00			100,00

WDN = water distribution network; WSP = water sampling point; C (%) = compliance percentage; C overall (%) = compliance overall percentage; Min = minimum; Max = maximum; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

4.4. Microbiological drinking water quality

The presence of *E. coli* and coliform bacteria in the drinking water samples were assessed for all drinking water sampling points. These measurements were then compared to the SANS 241 standards (SABS, 2015) to determine compliance. Descriptive statistics were also calculated for the three sampling years.

4.4.1. *Escherichia coli*

During the three sampling years, most *E. coli* counts exceeded the SANS 241 standards (SABS, 2015). Only eight of the 32 drinking water sampling points demonstrated 100% overall compliance. Of concern were the four WTPs (Mount Ayliff, Matatiele, Maluti/Belfort and Ntabankulu) that demonstrated non-compliant *E. coli* counts (Table 4.7). The highest *E. coli* count of >1000 mg/L was recorded at the MFSP10 drinking water sampling point of Mount Frere (MF) WDN in Year 3. This exceptionally high measurement was checked and confirmed.

Table 4.7 Summary statistics of monthly E. coli numbers over three years.

WDN	WSP	Year 1 *E. coli* (limit = 0 mg/L)			Year 2 *E. coli* (limit = 0 mg/L)			Year 3 *E. coli* (limit = 0 mg/L)			
		Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**C overall (%)**
MA	MAWTP	0,00	0,00	0,00	0,00	4,00	0,33	0,00	0,00	0,00	97,00
	MASP1	0,00	0,00	0,00	0,00	2,00	0,17	0,00	0,00	0,00	97,00
	MASP2	0,00	0,00	0,00	0,00	6,00	0,50	0,00	0,00	0,00	97,00
MF	MFWTP	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00
	MFSP3	0,00	0,00	0,00	0,00	5,00	0,42	0,00	0,00	0,00	97,00
	MFSP4	0,00	0,00	0,00	0,00	2,00	0,17	0,00	0,00	0,00	97,00
	MFSP5	0,00	0,00	0,00	0,00	4,00	0,33	0,00	0,00	0,00	97,00
	MFSP6	0,00	0,00	0,00	0,00	1,00	0,08	0,00	0,00	0,00	97,00
	MFSP7	0,00	0,00	0,00	0,00	4,00	0,33	0,00	0,00	0,00	97,00
	MFSP8	0,00	0,00	0,00	0,00	3,00	0,25	0,00	0,00	0,00	97,00
	MFSP9	0,00	0,00	0,00	0,00	1,00	0,08	0,00	0,00	0,00	97,00
	MFSP10	0,00	0,00	0,00	0,00	5,00	0,42	0,00	1046,00	87,17	97,00
MT	MTWTP	0,00	0,00	0,00	0,00	2,00	0,17	0,00	0,00	0,00	97,00
	MTSP11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00
MB	MBWTP	0,00	1,00	0,08	0,00	0,00	0,00	0,00	0,00	0,00	97,00
	MBSP12	0,00	3,00	0,25	0,00	0,00	0,00	0,00	0,00	0,00	97,00
	MBSP13	0,00	0,00	0,00	0,00	6,00	1,50	0,00	0,00	0,00	92,00
	MBSP14	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00
	MBSP15	0,00	1,00	0,08	0,00	2,00	0,17	0,00	2,00	0,17	92,00
	MBSP16	0,00	1,00	0,08	0,00	0,00	0,00	0,00	0,00	0,00	97,00
	MBSP17	0,00	1,00	0,08	0,00	2,00	0,17	0,00	0,00	0,00	95,00
	MBSP18	0,00	2,00	0,17	0,00	2,00	0,25	0,00	1,00	0,08	89,00
	MBSP19	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00
NO	NOWTP	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00
	NOSP20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00
	NOSP21	0,00	0,00	0,00	0,00	6,00	0,50	0,00	0,00	0,00	97,00
	NOSP22	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00
	NOSP23	0,00	0,00	0,00	0,00	1,00	0,08	0,00	1,00	0,08	95,00

WDN	WSP	Year 1 *E. coli* (limit = 0 mg/L)			Year 2 *E. coli* (limit = 0 mg/L)			Year 3 *E. coli* (limit = 0 mg/L)			
		Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**C overall (%)**
	NOSP24	0,00	1,00	0,08	0,00	2,00	0,17	0,00	0,00	0,00	97,00
NT	NTWTP	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	97,00
	NTSP25	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00
	NTSP26	0,00	8,00	0,67	0,00	0,00	0,00	0,00	0,00	0,00	97,00
C (%) over WSP		97,92			94,28			98.96			97,06

WDN = water distribution network; SP = water sampling point; C (%) = compliance percentage; C overall (%) = compliance overall percentage; Min = minimum; Max = maximum; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

4.4.2. Coliform bacteria

During the three sampling years, most coliform bacterial counts exceeded the SANS 241 standards (SABS, 2015). The highest coliforms value of 2,419, 00 mg/L (the maximum possible count of the *97-wel Quanti-Tray^{TM}2000 method*) was recorded at MFSP10 drinking water sampling point of Mount Frere (MF) WDN in Year 3, and at MBSP15 and MBSP19 drinking water sampling points of Maluti/Belfort (MB) WDN in Year 2. This exceptional high measurement was checked and confirmed. Coliform bacteria counts demonstrated fluctuation between three sampling years (Table 4.8). Year 1 and Year 3 showed similar overall compliance results (95, 02 and 96, 85 respectively), which was in contrast with Year 2 (90, 78).

Table 4.8 Summary statistics of monthly coliform bacteria measurements over three years.

WDN	WSP	Year 1 Coliform bacteria (limit ≤ 10 mg/L)			Year 2 Coliform bacteria (limit ≤ 10 mg/L)			Year 3 Coliform bacteria (limit ≤ 10 mg/L)			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	C overall (%)
MA	MAWTP	0,00	0,00	0,00	0,00	161,00	13,75	0,00	4,00	0,33	97,00
	MASP1	0,00	0,00	0,00	0,00	248,00	20,83	0,00	2,00	0,17	97,00
	MASP2	0,00	8,00	0,67	0,00	205,00	18,08	0,00	18,00	1,50	89,00
MF	MFWTP	0,00	1,00	0,08	0,00	24,00	2,17	0,00	2,00	0,17	97,00
	MFSP3	0,00	11,00	0,92	0,00	192,00	16,00	0,00	0,00	0,00	95,00
	MFSP4	0,00	6,00	0,50	0,00	166,00	15,00	0,00	27,00	2,30	95,00
	MFSP5	0,00	8,00	0,67	0,00	167,00	14,17	0,00	3,00	0,25	97,00
	MFSP6	0,00	185,00	15,83	0,00	205,00	17,75	0,00	8,00	0,67	95,00
	MFSP7	0,00	5,00	0,42	0,00	313,00	26,08	0,00	0,00	0,00	97,00
	MFSP8	0,00	2,00	0,17	0,00	248,00	20,67	0,00	1,00	0,08	97,00
	MFSP9	0,00	411,00	36,92	0,00	238,00	20,17	0,00	4,00	0,33	97,00
	MFSP10	0,00	17,00	2,00	0,00	157,00	14,67	0,00	2,419,00	202,60	89,00
MT	MTWTP	0,00	8,00	0,67	0,00	6,00	0,50	0,00	0,00	0,00	100,00
	MTSP11	0,00	66,00	5,50	0,00	42,00	3,50	0,00	0,00	0,00	95,00
MB	MBWTP	0,00	159,00	16,58	0,00	4,00	0,33	0,00	14,00	1,17	92,00
	MBSP12	0,00	37,00	3,25	0,00	46,00	3,83	0,00	46,00	3,83	92,00
	MBSP13	0,00	21,00	4,17	0,00	102,00	9,92	0,00	17,00	1,42	83,00
	MBSP14	0,00	23,00	2,08	0,00	136,00	12,92	0,00	19,00	1,58	89,00
	MBSP15	0,00	3,00	0,33	0,00	2,419,00	403,67	0,00	6,00	0,50	94,00
	MBSP16	0,00	37,00	3,25	0,00	47,00	4,58	0,00	0,00	0,00	94,00
	MBSP17	0,00	15,00	2,08	0,00	110,00	10,25	0,00	3,00	0,25	94,00
	MBSP18	0,00	29,00	2,42	0,00	96,00	12,75	0,00	57,00	4,75	89,00
	MBSP19	0,00	37,00	3,92	0,00	2,419,00	403,17	0,00	0,00	0,00	92,00
NO	NOWTP	0,00	5,00	0,42	0,00	0,00	0,00	0,00	0,00	0,00	100,00
	NOSP20	0,00	3,00	0,25	0,00	70,00	5,83	0,00	70,00	5,83	94,00
	NOSP21	0,00	0,00	0,00	0,00	102,00	8,50	0,00	0,00	0,00	97,00
	NOSP22	0,00	0,00	0,00	0,00	136,00	16,25	0,00	59,00	4,92	92,00
	NOSP23	0,00	4,00	0,42	0,00	11,00	0,91	0,00	11,00	0,92	94,00

WDN	WSP	Year 1 Coliform bacteria (limit ≤ 10 mg/L)			Year 2 Coliform bacteria (limit ≤ 10 mg/L)			Year 3 Coliform bacteria (limit ≤ 10 mg/L)			
		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	C overall (%)
	NOSP24	0,00	9,00	1,17	0,00	110,00	9,67	0,00	6,00	0,50	97,00
NT	NTWTP	0,00	3,00	0,25	0,00	0,00	0,00	0,00	2,00	0,17	100,00
	NTSP25	0,00	4,00	0,33	0,00	10,00	1,00	0,00	10,00	0,83	100,00
	NTSP26	0,00	11,00	1,25	0,00	7,00	0,67	0,00	29,00	2,41	94,00
C (%) over WSP		95,02			90,78			96,85			94,50

WDN = water distribution network; WSP = water sampling point; C (%) = compliance percentage; C overall (%) = compliance overall percentage; Min = minimum; Max = maximum; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

4.5. Comparison of drinking water quality measurements over three years

ANOVA tests were performed on the measurements of the different drinking water quality parameters to ascertain if significant differences existed at a particular drinking water sampling point amongst the three years. The monthly mean values of the three years at a particular sampling point were used in the respective ANOVA tests. In instances where ANOVA tests resulted in significant outcomes, a Tukey HSD Post Hoc test was performed to establish which pair of years differed from one another.

The ANOVA tests revealed that no significant differences existed at any of the drinking water sampling points for temperature and were thus not reported on separately. Also, ANOVA tests were not performed on the *E. coli* and coliform bacteria measurements, because of the presence of multiple zero values.

4.5.1. Turbidity

The ANOVA tests revealed that 14 drinking water sampling points demonstrated significant differences between one or two pairs of years at an α = 0.05. At 10 of the 14 drinking water sampling points that produced significant ANOVA tests, the Tukey HSD Post Hoc tests revealed that differences were recorded between Year 2 and Year 3 (Table 4.9).

Table 4.9 Statistical comparison results of turbidity over a period of three years.

WDN	WSP	SS	MS	f	p	Significant years
MA	MAWTP	11,84	5,92	5,26	0,01	Y1-Y2
	MASP1	2,01	1,00	2,60	0,09	NS
	MASP2	1,48	2,96	5,21	0,01	Y1-Y3, Y2-Y3
MF	MFWTP	6,24	3,12	1,39	0,26	NS
	MFSP3	0,78	0,39	1,44	0,25	NS
	MFSP4	0,74	0,37	3,47	0,04	Y2-Y3
	MFSP5	0,17	0,09	0,60	0,06	NS
	MFSP6	0,25	0,12	0,83	0,44	NS
	MFSP7	0,33	0,16	0,97	0,39	NS
	MFSP8	0,74	0,37	0,39	0,68	NS
	MFSP9	0,53	0,26	0,95	0,40	NS
	MFSP10	0,83	0,42	3,45	0,04	Y2-Y3
MT	MTWTP	0,80	0,40	3,50	0,01	Y2-Y3
	MTSP11	0,20	0,41	2,17	0,13	NS
MB	MBWTP	0,70	0,40	3,10	0,10	NS
	MBSP12	0,10	0,00	0,20	0,90	NS
	MBSP13	0,50	0,20	0,60	0,60	NS
	MBSP14	4,50	2,20	1,60	0,20	NS
	MBSP15	2,10	1,10	10,80	0,01	Y1-Y2, Y1-Y3
	MBSP16	0,80	0,40	3,50	0,01	Y1-Y2
	MBSP17	11,80	5,90	2,80	0,80	NS
	MBSP18	4,80	2,40	7,20	0,01	Y1-Y2, Y2-Y3

WDN	WSP	SS	MS	f	p	Significant years
	MBSP19	3,50	1,70	6,30	0,01	Y1-Y2, Y2-Y3
NO	NOWTP	0,70	0,40	3,90	0,03	Y1-Y2
	NOSP20	1,30	0,70	8,32	0,00	Y1-Y2, Y2-Y3
	NOSP21	1,20	0,60	2,90	0,07	NS
	NOSP22	0,60	0,30	2,10	0,14	NS
	NOSP23	0,90	0,50	6,00	0,01	Y2-Y3
	NOSP24	7,70	3,80	1,60	0,22	NS
NT	NTWTP	2,20	1,10	8,23	0,01	Y2-Y3
	NTSP25	1,30	0,70	5,03	0,01	Y2-Y3
	NTSP26	0,30	0,20	3,06	0,06	NS

SS = sum of squares; MS = mean square; f = f statistic; p = probability; S = significant at α = 0.05; NS = non-significant at α = 0.05; Y1 = year one; Y2 = year two; Y3 = year three; WDN = water distribution network; WSP = water sampling point; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

4.5.2. pH

The ANOVA tests revealed that nine drinking water sampling points demonstrated significant differences between one or two pairs of years at an $\alpha = 0.05$. At six of the nine drinking water sampling points that produced significant ANOVA tests, the Tukey HSD Post Hoc tests revealed that differences were recorded between Year 2 and Year 3 (Table 4.10).

Table 4.10 Statistical comparison results of pH over a period of three years.

WDN	WSP	SS	MS	f	p	Significant years
MA	MAWTP	0,20	0,10	0,70	0,50	NS
	MASP1	1,50	0,70	4,60	0,02	Y1-Y3
	MASP2	1,30	0,60	5,20	1,30	Y2-Y3
MF	MFWTP	0,80	0,40	1,90	0,16	NS
	MFSP3	1,80	0,90	4,00	0,03	Y2-Y3

WDN	WSP	SS	MS	f	p	Significant years
	MFSP4	2,80	0,40	8,40	0,01	Y1-Y3, Y2-Y3
	MFSP5	0,20	0,10	0,60	0,57	NS
	MFSP6	0,00	0,00	0,10	0,91	NS
	MFSP7	0,10	0,00	0,10	0,91	NS
	MFSP8	0,70	0,30	1,60	0,21	NS
	MFSP9	0,90	0,50	1,20	0,31	NS
	MFSP10	1,80	0,90	0,80	0,46	NS
MT	MTWTP	0,40	0,20	1,30	0,30	NS
	MTSP11	0,90	0,50	4,40	0,02	Y2-Y3
MB	MBWTP	1,70	0,90	3,40	0,05	NS
	MBSP12	1,30	0,70	1,80	0,18	NS
	MBSP13	1,00	0,50	2,30	0,11	NS
	MBSP14	0,10	0,00	0,10	0,88	NS
	MBSP15	1,30	0,60	2,30	0,11	NS
	MBSP16	0,60	0,30	1,20	0,31	NS
	MBSP17	1,90	0,90	2,10	0,14	NS
	MBSP18	5,20	2,60	8,60	0,01	Y1-Y2, Y2-Y3
	MBSP19	0,80	0,40	1,90	0,16	NS
NO	NOWTP	0,20	0,10	0,30	0,72	NS
	NOSP20	1,30	0,60	1,70	0,20	NS
	NOSP21	2,70	1,30	4,30	0,02	Y1-Y2
	NOSP22	2,00	1,00	2,80	0,08	NS
	NOSP23	0,30	0,20	0,60	0,57	NS
	NOSP24	2,50	1,20	2,30	0,11	NS
NT	NTWTP	0,70	0,40	3,50	0,04	Y1-Y2
	NTSP25	0,30	0,20	0,70	0,52	NS
	NTSP26	1,30	0,70	3,40	0,04	Y2-Y3

SS = sum of squares; MS = mean square; f = f statistic; p = probability; S = significant at α = 0.05; NS = non-significant at α = 0.05; Y1 = year one; Y2 = year two; Y3 = year three; WDN = water distribution network; WSP = water sampling point; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

4.5.3. Electrical conductivity

The ANOVA tests revealed that five of the 32 drinking water sampling points demonstrated significant differences between one or two pairs of years at an $\alpha = 0.05$. The Tukey HSD Post Hoc tests revealed that four of five drinking water sampling points demonstrated significant differences between all pairs of years, while at drinking water sampling point NOSP24 of Nomlacu (NO) WDN, Year 1 and Year 2 differed significantly. The Tukey HSD Post Hoc tests revealed that MFWTP of Mount Frere (MF) WDN was the only drinking water sampling point that demonstrated a significant difference between two pairs of years at the WTP. No significant differences could be established for all drinking water sampling points of the WDN of Matatiele (MT) and Ntabankulu (NT) (Table 4.11).

Table 4.11 Statistical comparison results of electrical conductivity over a period of three years.

WDN	WSP	SS	MS	f	p	Significant years
MA	MAWTP	34,60	17,30	2,50	0,10	NS
	MASP1	14,20	7,10	0,90	0,41	NS
	MASP2	86,70	43,30	7,10	0,01	Y1-Y2, Y2-Y3
MF	MFWTP	85,20	42,60	8,70	0,01	Y1-Y2, Y1-Y3
	MFSP3	24,50	12,30	1,80	0,19	NS
	MFSP4	32,90	16,40	2,80	0,07	NS
	MFSP5	22,10	11,00	2,30	0,12	NS
	MFSP6	5,10	2,50	0,40	0,69	NS
	MFSP7	35,40	17,70	2,80	0,08	NS
	MFSP8	10,90	5,40	0,80	0,44	NS
	MFSP9	3,50	1,80	0,30	0,77	NS
	MFSP10	16,60	8,30	1,00	0,39	NS
MT	MTWTP	73,30	36,60	2,50	0,10	NS
	MTSP11	28,60	14,30	1,40	0,25	NS
MB	MBWTP	28,40	14,20	1,10	0,34	NS
	MBSP12	24,20	12,10	1,20	0,32	NS

WDN	WSP	SS	MS	f	p	Significant years
	MBSP13	111,10	55,50	2,60	0,09	NS
	MBSP14	159,10	79,50	7,40	0,01	Y1-Y2, Y2-Y3
	MBSP15	42,40	21,20	1,60	0,22	NS
	MBSP16	270,10	135,00	11,10	0,01	Y1-Y2, Y2-Y3
	MBSP17	55,40	27,70	2,80	0,08	NS
	MBSP18	26,10	13,00	1,50	0,25	NS
	MBSP19	76,20	38,10	3,10	0,06	NS
NO	NOWTP	26,40	13,20	1,50	0,23	NS
	NOSP20	51,20	25,60	2,50	0,10	NS
	NOSP21	1,70	0,90	0,10	0,92	NS
	NOSP22	5,20	2,60	0,30	0,74	NS
	NOSP23	12,50	6,30	0,60	0,58	NS
	NOSP24	193,20	96,60	5,90	0,01	Y1-Y2
NT	NTWTP	18,50	9,30	1,30	0,28	NS
	NTSP25	22,70	11,40	1,50	0,23	NS
	NTSP26	30,70	15,40	2,90	0,07	NS

SS = sum of squares; MS = mean square; f = f statistic; p = probability; S = significant at α = 0.05; NS = non-significant at α = 0.05; Y1 = year one; Y2 = year two; Y3 = year three; WDN = water distribution network; WSP = water sampling point; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

4.5.4. Total dissolved solids

The ANOVA tests for TDS revealed significant differences between one or two pairs of years at six drinking water sampling points at an α = 0.05. One of these drinking water sampling points that produced a significant ANOVA test was at the WTP of Mount Frere (MF) WDN. For three of the six drinking water sampling points that produced significant ANOVA tests, including MFWTP drinking water sampling point of Mount Frere (MF) WDN, the Tukey HSD Post Hoc tests revealed significant differences between both pairs of years (Table 4.12).

Table 4.12 Statistical comparison results of total dissolved solids over a period of three years.

WDN	WSP	SS	MS	f	p	Significant years
MA	MAWTP	1344,10	672,00	1,00	0,36	NS
	MASP1	820,20	410,10	0,60	0,54	NS
	MASP2	4225,50	2112,80	3,40	0,05	Y2-Y3
MF	MFWTP	6584,90	3292,40	7,10	0,01	Y1-Y2, Y1-Y3
	MFSP3	2155,70	1077,90	1,90	0,16	NS
	MFSP4	3721,20	1860,60	2,70	0,08	NS
	MFSP5	2323,70	1161,90	2,40	0,10	NS
	MFSP6	962,90	481,40	0,80	0,44	NS
	MFSP7	3544,40	1772,20	3,40	0,06	NS
	MFSP8	2167,10	1083,50	2,20	0,13	NS
	MFSP9	1403,60	701,80	1,30	0,29	NS
	MFSP10	2544,40	1272,20	2,20	0,12	NS
MT	MTWTP	1962,50	981,30	1,00	0,38	NS
	MTSP11	1662,90	831,40	1,20	0,31	NS
MB	MBWTP	2557,70	1278,90	1,10	0,36	NS
	MBSP12	2406,90	1203,40	1,50	0,23	NS
	MBSP13	4263,40	2131,70	1,60	0,22	NS
	MBSP14	5627,40	2813,70	3,40	0,04	Y2-Y3
	MBSP15	1274,00	637,00	0,70	0,52	NS
	MBSP16	9499,40	4749,70	4,90	0,01	Y1-Y2
	MBSP17	2721,10	1360,50	1,80	0,18	NS
	MBSP18	1148,40	574,20	0,80	0,46	NS
	MBSP19	1986,00	993,00	1,10	0,36	NS
NO	NOWTP	5169,60	2584,80	3,20	0,55	NS
	NOSP20	2125,50	1062,80	1,50	0,25	NS
	NOSP21	776,00	388,00	0,50	0,59	NS
	NOSP22	231,70	115,90	0,20	0,84	NS
	NOSP23	1216,70	608,30	0,80	0,46	NS
	NOSP24	11940,20	5970,10	6,50	0,01	Y1-Y2, Y1-Y3
NT	NTWTP	1232,20	616,10	1,00	0,36	NS
	NTSP25	3189,60	1594,80	3,20	0,06	NS

WDN	WSP	SS	MS	f	p	Significant years
	NTSP26	3910,10	1955,00	4,90	0,01	Y1-Y2, Y1-Y3

SS = sum of squares; MS = mean square; f = f statistic; p = probability; S = significant at α = 0.05; NS = non-significant at α = 0.05; Y1 = year one; Y2 = year two; Y3 = year three; WDN = water distribution network; WSP = water sampling point; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

4.5.5. Free residual chlorine

The ANOVA tests for FRC revealed significant differences between sampling years at five of the drinking water sampling points at an α = 0.05. Of the five significant ANOVA tests, only the drinking water sampling point MBSP13 of Maluti/Belfort (MB) WDN showed significant differences between two pairs of years, while the other four are only different in one pair of years (Table 4.13).

Table 4.13 Statistical comparison results of free residual chlorine over a period of three years.

WDN	WSP	SS	MS	f	p	Significant years
MA	MAWTP	0,02	0,01	0,20	0,82	NS
	MASP1	0,02	0,01	1,30	0,28	NS
	MASP2	0,03	0,14	3,20	0,06	NS
MF	MFWTP	0,02	0,01	0,30	0,76	NS
	MFSP3	0,01	0,01	0,10	0,95	NS
	MFSP4	0,03	0,02	2,40	0,10	NS
	MFSP5	0,01	0,01	0,00	0,99	NS
	MFSP6	0,03	0,01	1,30	0,29	NS
	MFSP7	0,02	0,01	1,10	0,36	NS
	MFSP8	0,01	0,01	0,20	0,84	NS
	MFSP9	0,04	0,02	2,10	0,14	NS
	MFSP10	0,03	0,01	2,00	0,15	NS
MT	MTWTP	0,14	0,07	2,10	0,14	NS
	MTSP11	0,02	0,01	0,50	0,60	NS

WDN	WSP	SS	MS	f	p	Significant years
MB	MBWTP	0,30	0,15	2,18	0,13	NS
	MBSP12	0,09	0,04	4,10	0,03	Y1-Y3
	MBSP13	0,09	0,05	6,70	0,00	Y1-Y2, Y1 -Y3
	MBSP14	0,01	0,01	0,30	0,78	NS
	MBSP15	0,24	0,12	3,15	0,06	NS
	MBSP16	0,06	0,03	3,02	0,06	NS
	MBSP17	0,06	0,03	1,84	0,17	NS
	MBSP18	0,01	0,01	0,70	0,49	NS
	MBSP19	0,23	0,11	5,72	0,01	Y1-Y2
NO	NOWTP	0,20	0,10	3,15	0,06	NS
	NOSP20	0,05	0,02	2,89	0,07	NS
	NOSP21	0,03	0,02	1,69	0,20	NS
	NOSP22	1,96	0,98	2,76	0,08	NS
	NOSP23	0,01	0,01	0,01	0,99	NS
	NOSP24	0,30	0,15	3,34	0,05	Y1-Y2
NT	NTWTP	0,10	0,05	1,05	0,36	NS
	NTSP25	0,06	0,03	3,91	0,03	Y1-Y2
	NTSP26	1,03	0,52	1,25	0,30	NS

SS = sum of squares; MS = mean square; f = f statistic; p = probability; S = significant at α = 0.05; NS = non-significant at α = 0.05; Y1 = year one; Y2 = year two; Y3 = year three; WDN = water distribution network; WSP = water sampling point; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

4.6. Comparison of water treatment plants drinking water quality and end-user water sampling points drinking water quality

T-tests were performed on the data of the different drinking water quality parameters to ascertain if significant differences existed between the measurements at a particular WTP and the end-user water sampling points within a particular WDN at an α = 0.05. The monthly mean values of the three years at a particular drinking water sampling point were used in the respective T-tests. T-tests were not performed with the *E. coli* and coliform bacteria data, because of the presence of multiple zero values.

4.6.1. Mount Ayliff water distribution network

The T-tests revealed that some of the parameters demonstrated highly significant differences between the WTP measurements and the end-user water sampling points measurements at an α = 0.05. For turbidity, pH and FRC measurements, all end-user water sampling points differed from the WTP (Table 4.14).

Table 4.14 Comparison of end-user water sampling points and treatment plant drinking water quality at Mount Ayliff WDN.

Parameter	End-user water sampling points ID	T-statistic	p	Significance
Turbidity	MASP1	2,13	0,04	S
	MASP2	3,54	< 0,01**	S
pH	MASP1	-2,94	< 0,01**	S
	MASP2	-3,76	< 0,01**	S
Temperature	MASP1	-0,40	0,69	NS
	MASP2	-0,30	0,77	NS
Electrical conductivity	MASP1	0,23	0,82	NS
	MASP2	-0,04	0,97	NS
Total dissolved solids	MASP1	0,08	0,93	NS
	MASP2	-0,14	0,89	NS
Free residual chlorine	MASP1	20,18	< 0,01**	S
	MASP2	25,23	< 0,01**	S

S = significant at α = 0.05; NS = non-significant at α = 0.05; End-user water sampling points ID = end-user water sampling points point; p = probability; ** = highly significant (< 0.001)

4.6.2. Mount Frere water distribution network

The T-tests revealed that only a few of the parameters demonstrated significant differences between the WTP measurements and the end-user water sampling points measurements. For turbidity and temperature measurements, no significant differences could be established between all the end-user water sampling points and the WTP (Table 4.15). FRC measurements demonstrated significant differences between all the end-user water sampling points measurements and the WTP.

Table 4.15 Comparison of end-user water sampling points and treatment plant drinking water quality at Mount Frere WDN.

Parameter	End-user water sampling points ID	T-statistic	p	Significance
Turbidity	MFSP3	0,42	0,68	NS
	MFSP4	1,17	0,25	NS
	MFSP5	0,50	0,62	NS
	MFSP6	1,43	0,16	NS
	MFSP7	1,29	0,20	NS
	MFSP8	0,99	0,33	NS
	MFSP9	1,61	0,12	NS
	MFSP10	0,94	0,35	NS
pH	MFSP3	1,11	0,27	NS
	MFSP4	2,42	0,02	S
	MFSP5	3,76	0,01	S
	MFSP6	1,370	0,17	NS
	MFSP7	2,99	0,01	S
	MFSP8	0,48	0,63	NS
	MFSP9	1,24	0,22	NS
	MFSP10	3,77	0,01	S
Temperature	MFSP3	-0,30	0,76	NS
	MFSP4	-0,62	0,53	NS
	MFSP5	0,40	0,69	NS
	MFSP6	-0,57	0,57	NS

Parameter	End-user water sampling points ID	T-statistic	p	Significance
	MFSP7	-0,28	0,78	NS
	MFSP8	-0,26	0,79	NS
	MFSP9	-0,48	0,63	NS
	MFSP10	-0,25	0,81	NS
Electrical conductivity	MFSP3	0,66	0,51	NS
	MFSP4	2,50	0,01	S
	MFSP5	-0,10	0,92	NS
	MFSP6	-0,77	0,44	NS
	MFSP7	0,71	0,48	NS
	MFSP8	1,86	0,07	NS
	MFSP9	0,14	0,89	NS
	MFSP10	2,69	0,01	S
Total dissolved solids	MFSP3	0,48	0,63	NS
	MFSP4	2,03	0,05	S
	MFSP5	0,00	1,00	NS
	MFSP6	-0,34	0,74	NS
	MFSP7	0,61	0,54	NS
	MFSP8	1,54	0,13	NS
	MFSP9	0,29	0,77	NS
	MFSP10	2,10	0,04	S
Free residual chlorine	MFSP3	9,50	< 0,01**	S
	MFSP4	10,94	< 0,01*	S
	MFSP5	14,73	< 0,01**	S
	MFSP6	12,35	< 0,01**	S
	MFSP7	14,44	< 0,01**	S
	MFSP8	10,52	< 0,01**	S
	MFSP9	14,29	< 0,01**	S
	MFSP10	14,29	< 0,01**	S

S = significant at α = 0.05; NS = non-significant at α = 0.05; End-user water sampling points ID = end-user water sampling points point; p = probability; ** = highly significant (< 0.001)

4.6.3. Maluti/Belfort water distribution network

The T-tests revealed that only a few of the parameters demonstrated significant differences between the WTP measurements and the end-user water sampling points measurements. For turbidity and temperature measurements, no significant differences could be established between all the end-user water sampling points and the WTP (Table 4.16). FRC measurements demonstrated significant differences between all the end-user water sampling points point measurements and the WTP.

Table 4.16 Comparison of end-user water sampling points and treatment plant drinking water quality at Maluti/Belfort WDN.

Parameter	End-user water sampling points ID	T-statistic	p	Significance
Turbidity	MBSP12	0,21	0,83	NS
	MBSP13	-2,16	0,03	NS
	MBSP14	-1,83	0,07	NS
	MBSP15	-1,39	0,17	NS
	MBSP16	-2,05	0,05	NS
	MBSP17	-1,16	0,25	NS
	MBSP18	-1,61	0,11	NS
	MBSP19	-0,59	0,56	NS
pH	MBSP12	-0,70	0,49	NS
	MBSP13	1,57	0,12	NS
	MBSP14	1,40	0,17	NS
	MBSP15	3,13	0,01	S
	MBSP16	1,85	0,07	NS
	MBSP17	2,88	0,01	S
	MBSP18	0,49	0,63	NS
	MBSP19	1,40	0,17	NS
Temperature	MBSP12	-0,88	0,38	NS
	MBSP13	-0,54	0,59	NS
	MBSP14	0,89	0,38	NS
	MBSP15	0,77	0,44	NS

Parameter	End-user water sampling points ID	T-statistic	p	Significance
	MBSP16	-0,79	0,43	NS
	MBSP17	0,03	0,98	NS
	MBSP18	-1,14	0,26	NS
	MBSP19	0,19	0,85	NS
Electrical conductivity	MBSP12	0,00	1,00	NS
	MBSP13	0,72	0,47	NS
	MBSP14	2,84	0,01	S
	MBSP15	1,65	0,10	NS
	MBSP16	0,94	0,35	NS
	MBSP17	1,92	0,06	NS
	MBSP18	2,03	0,06	NS
	MBSP19	2,03	0,06	NS
Total dissolved solids	MBSP12	-0,17	0,87	NS
	MBSP13	0,55	0,58	NS
	MBSP14	2,09	0,04	S
	MBSP15	1,23	0,22	NS
	MBSP16	0,76	0,45	NS
	MBSP17	1,44	0,16	NS
	MBSP18	1,53	0,13	NS
	MBSP19	0,52	0,61	NS
Free residual chlorine	MBSP12	11,49	< 0,01**	S
	MBSP13	11,49	< 0,01**	S
	MBSP14	12,88	< 0,01**	S
	MBSP15	12,88	< 0,01**	S
	MBSP16	12,88	< 0,01**	S
	MBSP17	14,73	< 0,01**	S
	MBSP18	14,29	< 0,01**	S
	MBSP19	11,49	< 0,01**	S

S = significant at $\alpha = 0.05$; NS = non-significant at $\alpha = 0.05$; End-user water sampling points ID = end-user water sampling points point; p = probability; ** = highly significant (< 0.001)

4.6.4. Nomlacu water distribution network

The T-tests revealed that only a few of the parameters demonstrated significant differences between the WTP measurements and the end-user water sampling points measurements. For temperature and TDS measurements, no significant differences could be established between all the end-user water sampling points and the WTP (Table 4.17). FRC demonstrated a significant difference between all the end-user water sampling points measurements and the WTP.

Table 4.17 Comparison of end-user water sampling points and treatment plant drinking water quality at Nomlacu WDN.

Parameter	End-user water sampling points ID	T-statistic	p	Significance
Turbidity	NOSP20	0,47	0,64	NS
	NOSP21	-0,67	0,51	NS
	NOSP22	-1,60	0,11	NS
	NOSP23	-2,11	0,04	S
	NOSP24	-2,35	0,02	S
pH	NOSP20	-2,04	0,05	NS
	NOSP21	-1,77	0,08	NS
	NOSP22	-1,13	0,26	NS
	NOSP23	-3,24	0,00	S
	NOSP24	-2,12	0,04	NS
Temperature	NOSP20	-0,10	0,92	NS
	NOSP21	-0,42	0,67	NS
	NOSP22	-0,33	0,74	NS
	NOSP23	-0,80	0,43	NS
	NOSP24	-0,09	0,93	NS
Electrical conductivity	NOSP20	0,80	0,43	NS
	NOSP21	1,88	0,06	NS
	NOSP22	1,79	0,08	NS
	NOSP23	2,03	0,01	S
	NOSP24	1,25	0,22	NS

Parameter	End-user water sampling points ID	T-statistic	p	Significance
Total dissolved solids	NOSP20	0,61	0,54	NS
	NOSP21	1,48	0,14	NS
	NOSP22	1,43	0,16	NS
	NOSP23	1,87	0,07	NS
	NOSP24	1,02	0,31	NS
Free residual chlorine	NOSP20	16,23	< 0,01**	S
	NOSP21	16,23	< 0,01**	S
	NOSP22	24,39	< 0,01**	S
	NOSP23	24,39	< 0,01**	S
	NOSP24	14,19	< 0,01**	S

S = significant at α = 0.05; NS = non-significant at α = 0.05; End-user water sampling points ID = end-user water sampling points point; p = probability; ** = highly significant (< 0.001)

4.6.5. Ntabankulu water distribution network

The T-tests revealed that all parameters, except FRC, did not demonstrate significant differences between the WTP measurements and the end-user water sampling points measurements. FRC demonstrated significant differences between both the end-user water sampling points measurements and the WTP (Table 4.18).

Table 4.18 Comparison of end-user water sampling points and treatment plant drinking water quality at Ntabankulu WDN.

Parameter	End-user water sampling points ID	T-statistic	p	Significance
Turbidity	NTSP25	0,45	0,65	NS
	NTSP26	-0,96	0,34	NS
pH	NTSP25	-1,32	0,19	NS
	NTSP26	0,68	0,50	NS

Parameter	End-user water sampling points ID	T-statistic	p	Significance
Temperature	NTSP25	-0,09	0,93	NS
	NTSP26	0,42	0,68	NS
Electrical conductivity	NTSP25	1,73	0,09	NS
	NTSP26	1,34	0,19	NS
Total dissolved solids	NTSP25	1,49	0,14	NS
	NTSP26	1,19	0,24	NS
Free residual chlorine	NTSP25	3,16	0,01	S
	NTSP26	3,16	0,01	S

S = significant at α = 0.05; NS = non-significant at α = 0.05; End-user water sampling points ID = end-user water sampling points point; p = probability

4.7. Comparison of different water distribution networks

Two of the physical parameters, turbidity and pH, were selected as performance indicators of the WTPs; therefore, ANOVA tests were performed to compare the performance of the six WDNs. The monthly mean values of the three years of all the sampling points within a WDN were used in the ANOVA tests. Highly significant differences could be established amongst the WDNs at an α = 0.05 for both the turbidity and pH measurements (Table 4.19).

Table 4.19 Turbidity and pH comparison of the water distribution networks.

Parameter	Source of variation	SS	df	MS	F-statistic	P
Turbidity	Between WDN	28,62	5,00	5,72	8,07	< 0.0001**
	Within WDN	148,92	210,00	0,71		
	Total	177,54	215,00			
pH	Between WDN	6,56	5,00	1,31	6,59	< 0.0001**
	Within WDN	41,79	210,00	0,20		
	Total	48,36	215,00			

WDN = water distribution network; p = probability; ** = highly significant (< 0.001)

Tukey HSD Post Hoc tests were performed to establish which pairs of WDNs differed significantly. For the turbidity, the WTP measurements differed significantly from four of the other WTPs. While all other comparisons were not significant, a particular pattern could be established for the WTP comparisons using the pH measurement. Six of the 15 comparisons proved to be significantly different, although Matatiele did not demonstrate significant differences when compared to the other WTPs (Table 4.20).

Table 4.20 Tukey HSD Post Hoc tests showing significant pairs of water distribution networks.

Turbidity							pH						
WDN	**MA**	**MF**	**MT**	**MB**	**NO**	**NT**	**WDN**	**MA**	**MF**	**MT**	**MB**	**NO**	**NT**
MA							**MA**						
MF	S						**MF**	S					
MA	S	NS					**MT**	NS	NS				
MB	S	NS	NS				**MB**	S	NS	NS			
NO	S	NS	NS	NS			**NO**	NS	S	NS	S		
NT	NS	NS	NS	NS	NS		**NT**	NS	S	NS	S	NS	

WDN = water distribution network; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; NO = Nomlacu; NT = Ntabankulu; S = significant at α = 0.05; NS = non-significant at α = 0.05

4.8. Discussion

High levels of turbidity could represent a key issue concerning the disinfection and microbiological quality. Previous studies have demonstrated an interrelationship between elevated turbidity measurements, the efficiency of chlorination in drinking water and microbiological contamination (WHO, 2011; Daud et al., 2017). Furthermore, high levels of turbidity can protect microorganisms from the effects of disinfection, giving rise to a significant chlorine demand and reducing the performance of disinfection treatments (McOmber, 2017).

Results of the study showed that of the eight physical, chemical and microbiological parameters analysed, four demonstrated non-complaint values when compared to the SANS 241 standards (SABS, 2015). Of the four physical parameters measured, turbidity and pH parameters were non-compliant; however, non-compliance of pH parameter was recorded once in the study. In contrast, all chemical parameters were compliant although FRC parameter was very low, whereas all microbiological parameters were non-compliant. The high level of *E. coli* counts could have been a result of the faecal contamination of drinking water in the WDN, caused by infiltration of faecal matter through water pipe fractures or leakages. Non-compliant values were mostly measured in the second year of study. The findings of the study confirmed the similar studies that reported the association between high turbidity levels, high microbial growth and low levels of FRC (LeChevallier et al., 1981; Momba et al., 2004; Daud et al., 2017; Edokpayi et al., 2018).

Chapter 5

Water Quality Index

5.1. Introduction

A water quality index (WQI) is a mathematical instrument used to assess the status of drinking water quality at convinced times and locations. Various methods for the calculation of the water quality index (WQI) have been designed by several authors to present drinking water quality status (Horton, 1965; Brown et al., 1970; Brown, et al., 1972; Tiwari and Mishra, 1985; CCME, 2001; Sorlini et al., 2013; Shiji et al., 2016; Bereskie et al., 2017; Yousefi et al., 2018). These calculations were designed to determine the overall water quality of water bodies. Therefore, the results of WQI demonstrate whether the water quality poses a potential threat to various uses of water, such as habitat for aquatic life, irrigation water for agriculture and livestock, recreation and aesthetics, and drinking water supplies. WQI can be used by state agencies as well as the general public (Belle, 2015; Galal Uddin et al., 2017).

Several approaches have been introduced to assess the status of drinking water quality. The intention of a WQI is to assess the general state of drinking water depending on a range of predetermined drinking water quality parameters, which are then compared to a regulatory standard (Esterhuizen, 2014). WQI is very useful in generating trends and disseminating technical drinking water quality information (Shiji et al., 2016; Singh and Hussian, 2016; Belle, 2015).

In this study, the Canadian Council of Ministers of the Environment Water Quality Index (CCME–WQI) was used for the assessment of surface drinking water quality (details presented in chapter 3). The drinking water quality measurements were obtained from six water treatment plants (WTPs) and 26 end-user water sampling points in the Alfred Nzo District Municipality (ANDM).

5.2. Drinking water quality assessment with the use of water quality index

The drinking water quality assessment is a critical tool that provides vital information about the drinking water quality. The drinking water quality assessment is based on a number of parameters such as chemical, physical and biological parameters, however, the main problem in water quality assessment is the complexity associated with a large number of measured variables (Shiji et al., 2016). There are various methods used to assess drinking water quality. The use of WQI in assessing drinking water quality determines the suitability of drinking water for human consumption. WQI has been considered as a good drinking water quality assessment approach which reflects spatial variations and monitors drinking water quality levels (Galal Uddin et al., 2017; Yousefi et al., 2018). One of the major advantages of WQI is that it incorporates data from multiple water quality parameters into a single value that rates the quality of drinking water (Brown et al., 1970). This approach was applied to help and to provide ANDM with the information useful for their management strategies at providing drinking water quality suitable for human consumption.

To demonstrate data used for calculations of CCME–WQI values, data of the measurements of eight parameters at one water sampling point were used. This example is presented in Table 5.1.

Table 5.1 Example used to demonstrate CCME–WQI calculations.

Parameters	pH	Temperature	EC	TDS	Turbidity	*E. coli*	Coliform bacteria	FRC
Y1	7,6	17,7	17,92	112	2,3	0	0	0,9
Y2	7,5	18,9	16,02	107	1,3	0,33	13,75	0,9
Y3	7,9	19	18,25	122	1,03	0	0	0,9
Standards	**5- 9,7**	**25**	**170**	**1200**	**1**	**0**	**10**	**5**
Objective count	0	0	0	0	1	1	1	0
Total parameters not meeting Standards	3							
Total number of parameters	8							
F1								**37,5**
Total test not meeting objective	0	0	0	0	3	1	1	0
Sum of test not meeting objective	5							
Total number of tests	24							
F2								**20,83**
Excursion								
Year 1	-0,16	-0,29	-0,99	-0,89	-0,59	-1	-1	-0,55
Year 2	-0,17	-0,24	-0,99	-0,89	-0,77	18,69	18,64	-0,55
Year 3	-0,12	-0,24	-0,9	-0,88	-0,82	-1	-1	-0,1
Sum Excursion	12,83							
nse	**0,53**							
F3								**34,84**
F1+F2+F3 Squares	3053,8							
Square Root	55,26							
CCME-WQI								**68,09**

F1 = scope; F2 = frequency; F3 = amplitude; EC = electrical conductivity; *E. coli* = *Escherichia. coli*; TDS = total dissolved solids; FRC = free residual chlorine; pH = potential hydrogen

5.3. Drinking water quality of the water treatment plants

CCME–WQI values were calculated on the data of the eight drinking water quality parameters to ascertain the overall water quality of the six water treatment plants (WTPs). A CCME–WQI value was calculated for each of the six WTPs by applying the formula of the CCME–WQI (CCME, 2001). The calculated CCME–WQI values of the six WTPs were all equal or less than 80, classifying the drinking water of all the WTPs as poor (CCME, 2001). The CCME–WQI values for six WTPs revealed that none of the WTPs had drinking water of good quality (Table 5.2). Of concern was that all the WTPs delivered drinking water of poor quality. The poor performance of the WTP is of major concern as the communities in Alfred Nzo District Municipality (ANDM) are poor and many are part of the immune compromised group (Health Systems Trust, 2016). Poor water treatment together with maintenance challenges will further put the community at risk (Momba et al., 2006).

Table 5.2 CCME–WQI values and classification of the respective WTPs.

WDN	WSP	WQI value	Water quality classification	Description of water quality
MA	MAWTP	68	Poor	Marginal water quality
MF	MFWTP	79	Poor	Marginal water quality
MT	MTWTP	79	Poor	Marginal water quality
MB	MBWTP	74	Poor	Marginal water quality

WDN	WSP	WQI value	Water quality classification	Description of water quality
NO	NOWTP	80	Poor	Marginal water quality
NT	NTWTP	80	Poor	Marginal water quality

WDN = water distribution network; WSP = water sampling points; WQI = water quality index score; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

5.4. Drinking water quality of the end-user water sampling points

The CCME–WQI was calculated to analyse the overall drinking water quality of the 26 end-user water sampling points. A CCME–WQI value was calculated for each of the 26 end-user water sampling points by applying the formula of the CCME–WQI (CCME, 2001). The CCME–WQI values revealed that the drinking water quality of 26 end-user water sampling points was of poor quality (CCME, 2001). The highest CCME–WQI value of 80 was recorded at MTSP11 water sampling point of Matatiele WDN, NOSP20 water sampling point of Nomlacu WDN and NTSP25 water sampling point of Ntabankulu WDN, of which the lowest CCME–WQI value of 68 was recorded at MBSP18 water sampling point of Maluti/Belfort (MB) WDN. Table 5.3 provides the WQIs of the 26 end-user water sampling points.

Table 5.3 CCME–WQI values and classification of the respective end-user water sampling points.

WDN	WSP	WQI value	Water quality classification	Description of water quality
MA	MASP1	70	Poor	Marginal water quality

WDN	WSP	WQI value	Water quality classification	Description of water quality
	MASP2	75	Poor	Marginal water quality
MF	MFSP3	75	Poor	Marginal water quality
	MFSP4	75	Poor	Marginal water quality
	MFSP5	70	Poor	Marginal water quality
	MFSP6	74	Poor	Marginal water quality
	MFSP7	75	Poor	Marginal water quality
	MFSP8	75	Poor	Marginal water quality
	MFSP9	75	Poor	Marginal water quality
	MFSP10	73	Poor	Marginal water quality
MT	MTSP11	80	Poor	Marginal water quality
MB	MBSP12	79	Poor	Marginal water quality
	MBSP13	79	Poor	Marginal water quality
	MBSP14	75	Poor	Marginal water quality
	MBSP15	73	Poor	Marginal water quality

WDN	WSP	WQI value	Water quality classification	Description of water quality
	MBSP16	75	Poor	Marginal water quality
	MBSP17	69	Poor	Marginal water quality
	MBSP18	68	Poor	Marginal water quality
	MBSP19	75	Poor	Marginal water quality
NO	NOSP20	80	Poor	Marginal water quality
	NOSP21	79	Poor	Marginal water quality
	NOSP22	79	Poor	Marginal water quality
	NOSP23	78	Poor	Marginal water quality
	NOSP24	74	Poor	Marginal water quality
NT	NTSP25	80	Poor	Marginal water quality
	NTSP26	79	Poor	Marginal water quality

WDN = water distribution network; WSP = water sampling points; WQI = water quality index score; MA = Mount Ayliff; MF = Mount Frere; MT = Matatiele; MB = Maluti/Belfort; NO = Nomlacu; NT = Ntabankulu

5.5. Discussion

The CCME–WQI values revealed that the drinking water quality of the six WDNs and 26 end-user water sampling points were of poor quality. The CCME–WQI findings supported the statistically outcome. The poor drinking water quality was due to the non-complaint values of turbidity, *E. coli* and coliform bacteria when compared to the SANS 241 standards (SABS, 2015). These results clearly show that the drinking water in ANDM could pose a risk of health effects mainly to a sensitive group. This infer that the drinking water of ANDM may be used without health effects by the majority of individuals of all ages, but may cause effects to babies, children, elderly and the people with medical conditions (DWA, 2001).

This study demonstrated findings that have been revealed by other studies. The use of CCME–WQI to evaluate drinking water quality has been adopted by other researchers (Khan et al., 2004; Galal Uddin et al., 2017). Both these researchers revealed poor drinking water quality results although drinking water quality parameters differed from the parameters of this study.

Chapter 6

Discussion and Conclusion

6.1. Introduction

This study was undertaken to assess the drinking water quality of the rural areas of Alfred Nzo District Municipality (ANDM). During this study, the drinking water quality from the six water distribution networks (WDNs) of ANDM were assessed in terms of physical, chemical and microbiological parameters. The drinking water quality analysis was conducted on a monthly basis over three years. The drinking water quality measurements were obtained from six water treatment plants (WTPs) and 26 end-user water sampling points. Drinking water quality measurements were compared for compliance with the recommended water quality limits as prescribed by the South African Bureau of Standards (2015). All the measurements were statistically analysed and also analysed with the use of water quality index (WQI) (details presented in chapter 4 and chapter 5).

The provision of clean and safe drinking water is a great challenge in South Africa. Previous studies have shown that most water treatment plants in South Africa do not provide adequate treatment and disinfection of drinking water (Momba et al., 2006; Edokpayi et al., 2018). In contrast, South Africa has made considerable progress in providing piped drinking water and most rural households now have access to piped drinking water. However, drinking water quality may not be safe for human consumption (Health Systems Trust, 2016). It is a worrying factor to note that in the Eastern Cape, drinking water remains to be of poor quality and is typically considered unsafe (Momba et al., 2004).

The government of South Africa has through the Department of Water and Sanitation (DWS), developed a water quality monitoring tool (Blue Drop system) in 2008, which was then transformed into the Integrated Regulatory Information System (IRIS) (DWA, 2012). The first Blue Drop report in 2009 indicated that the national microbiological compliance for South African tap drinking water was measured at 93.3% against the recommended drinking water quality standards as prescribed by (SANS) 241 (2015). There has been a regression since then, as the Blue Drop score had deteriorated from 87.6% in 2012 to 79.6% in 2014. Eastern Cape had a Blue Drop score that declined by 10% from 82% in 2012 to 72% in 2014 and none of the WDNs achieved Blue Drop status (DWS, 2017). Therefore, this study was undertaken to get a better understanding of the drinking water status of ANDM.

6.2. Overall view

Of the eight drinking water quality parameters measured in this study, there were four parameters of concerns. The parameters of concerns as presented in chapter 4 were high turbidity values, low levels of free residual chlorine (FRC) values, high *Escherichia coli* (*E. coli*), and coliform bacteria measurements. This study revealed what was reported by previous research concerning the interrelationship between elevated turbidity, the efficiency of chlorination and the high level of microbiological parameters in drinking water (Momba et al., 2006; WHO, 2011; Daud et al., 2017). The findings of the study confirmed the similar studies that reported the association between high turbidity levels, high microbial growth and low levels of FRC. The theory behind this is that microorganisms detected at the end-user water sampling points may have come from the treated water due to low FRC levels. In addition, high turbidity levels have also been suggested to increase microorganism resistance to disinfectants. This is due to the fact that the microbial agents in water are shielded from disinfection by their attachment to particles. Therefore, this may explain the significantly high effect of turbidity on the presence of microbial agents in final treated water and end-user water sampling points (Momba et al., 2006; Obi et al., 2008).

Turbid waters can be microbiologically contaminated. The inability of WTPs to reduce the turbidity measurements of drinking water to limits that are safe for human consumption has also been reported by previous studies (Momba et al., 2006; Obi et al., 2007; Momba et al., 2009). High levels of turbidity measurements in drinking water affect the microbiological quality of drinking water by encouraging the growth and survival of microorganisms or by decreasing the efficiency of chlorine in water treatment (Momba et al., 2009). Turbidity can carry nutrients to support microorganisms' growth and provides a protective barrier to ensure their survival in the WDN (LeChevallier et al., 1981; Edokipayi et al., 2018). In this study, a high level of turbidity measurements was observed in both WTPs and end-user water sampling points. This finding suggests that the water treatment process is not meeting the required standards, thus posing a threat to human health.

Sufficient FRC measurements in drinking water maintain water quality from the WTP to the end-user water sampling points. The sufficiency of FRC measurements is also affected by its level of concentration, turbidity, temperature and pH measurements (Momba et al., 2004). This study noted that all six WDNs of ANDM had a low level of FRC measurements in the WTPs and end-user water sampling points. This may be due to insufficient chemical chlorine dosing during water treatment (Health Systems Trust, 2016). Low levels of FRC measurements in the WDN may indicate the possibility of post-treatment contamination or inefficiency of a disinfectant and therefore it must be maintained by directly dosing (Momba et al., 2009).

The findings of the study confirmed the connection between a low level of FRC and the detection of microorganisms in drinking water. The findings of Obi et al. (2008) corroborate the findings of this study, microorganisms detected in drinking water quality after treatment processes may have thrived due to a low level of FRC. Previous studies have reported an increased microbiological resistance to disinfection as a result of their attachment to surfaces, particles or other organisms (Momba et al., 2004; Obi et al., 2008; Momba et al., 2009).

This study revealed that the performance of six WDNs at ANDM was not consistent. Highly significant differences were established amongst the WDNs for turbidity and pH measurements at an $\alpha = 0.05$ as shown in Table 4.19. Although pH measurements revealed highly significant, findings determined that pH measurements were within SABS (2015) standards. Highly significant differences indicate that the performance of WDNs for three years was not consistent. Tukey HSD Post Hoc tests revealed that differences were recorded mostly between Year 1 and Year 2. This study noted that non-compliant values were mostly measured in the second year of study. The inconsistency of WTPs performance could be related to inconsistencies of water treatment processes, for example, poor dosing rate. The findings of Momba et al. (2009) revealed that rural WTPs fail to provide drinking water of good quality due to the lack of water treatment processes such as calculation of chlorine dosing.

The Canadian Council of Ministers of the Environment Water Quality Index (CCME–WQI) revealed that drinking water quality of ANDM was poor (68 to 80 CCME–WQI values). The drinking water of poor quality remains vulnerable to waterborne diseases. Socio-economic status and vulnerability to waterborne diseases are the main concerns in rural communities (Edokipayi et al., 2018). Sensitive groups such as individuals who suffer from HIV/AIDS remain vulnerable to waterborne diseases (Health Systems Trust, 2016). A study by the United States President's Emergency Plan for AIDS Relief (2017) highlighted that ANDM is one of the five highest HIV-burdened districts in the Eastern Cape Province, South Africa (United States, 2017). Based on the findings of the study at ANDM, it could be inferred that ANDM communities are vulnerable to waterborne diseases and therefore, an immediate corrective action plan to address identified drinking water quality concerns is necessary.

6.3. Drinking water quality in the Alfred Nzo District Municipality

This study was undertaken to get a better understanding of the drinking water status of ANDM. This study revealed that the quality of drinking water for both WTPs and end-user water sampling points at ANDM were similar as presented in the previous chapters, 4 and 5. Of concern were the non-compliance of turbidity levels, *E. coli,* and coliform bacteria measurements when compared to the SABS (2015) standards and the low level of FRC measurements. High levels of turbidity in drinking water affect the microbial quality of drinking water by encouraging the growth and survival of microorganisms or by decreasing the efficiency of FRC in WDN (Momba et al., 2008).

E. coli is a member of the faecal coliform group. The detection of *E. coli* in drinking water would, therefore, indicate faecal matter and the possible contamination of pathogenic organisms of human origin (Nkwe et al., 2015; Daud et al., 2017). Of concern were the detection of *E. coli* at Mount Ayliff, Matatiele, Maluti/Belfort and Ntabankulu WTPs where water is treated and considered to be safe. The *E. coli* in drinking water could pose a severe threat to human health, such as causing diarrhoeal diseases. Diarrhoeal diseases account for one in nine child deaths worldwide, making diarrhoea the second leading cause of death among children younger than the age of five (Alvarez-Bastida et al., 2018). Diarrhoea is one of the leading causes of morbidity and mortality in South African children (Mkwate et al., 2017). The high level of *E. coli* identified in this study indicates that ANDM communities might be vulnerable to diarrhoeal diseases.

6.4. Concluding remarks

Overall, this study brought to light that the communities of ANDM appear to be in a vulnerable state due to poor standard of drinking water quality. In support of this, the drinking water quality in all WDNs was found to be poor when compared to SABS (2015) standards. Therefore, communities of ANDM live in constant risk of contracting waterborne diseases. A substantial concern is that ANDM is one of the five highest HIV-burdened districts in the Eastern Cape Province (United State, 2017).

This study supports the low Blue Drop score obtained by ANDM since the inception of the Blue Drop certification programme in 2008. The Blue Drop certification programme was introduced as a mainstream regulation means to ensure that WDN complies with SANS 241 standards (SABS, 2015). This study revealed that the overall quality of drinking water in all six WDNs at ANDM indicated poor performance against SABS (2015) requirements. It is inferred that poor drinking water quality contributed to ANDM not to obtain Blue Drop certification.

Poor drinking water quality may compromise the health of the consumers and therefore immediate corrective action is necessary for solving drinking water quality problems that lead to non-compliance. Solving drinking water quality problems requires strategies to prevent, treat and remediate water pollution. Water quality problems arising from developing communities can be managed, using an integrated water quality management strategy. The water quality management strategy should be based on scientific investigation, community involvement, and engineering expertise. This strategy should address challenges such as poorly developed water infrastructure, lack of maintenance and lack of technical capacity for water treatment processes.

6.5. Suggestions for further studies and recommendations

This study identified main concerns regarding the quality of drinking water in ANDM. The identified drinking water quality concerns were poor drinking water quality due to high turbidity values, low FRC values, high *E. coli*, and coliform bacteria measurements. These findings are significant in assisting decision makers in developing plans for future intervention in ANDM. Immediate intervention is necessary to prevent the widespread and long-term use of contaminated drinking water which might lead to human health implications.

This study recommends that ANDM should devise plans to ensure that all six WDNs supply drinking water of good quality which is compliant with SABS (2015) standards. ANDM should implement appropriate control measures in all WDNs to address identified water quality concerns. To implement appropriate control measurements, it is, therefore, necessary to clarify the source related to contamination of drinking water. However, identification of source contaminants is beyond the scope of this study.

In recognition of water quality concerns identified by this study, the following intervention measures are suggested:

1. Further research on drinking water quality management should be conducted. Such research should include scientific investigation of water quality management, risk assessment of WDN from the source to the consumer.

2. In order to address the inconsistency of water treatment processes and to ensure water treatment processes that provide good quality of drinking water, it is important to understand the extent of WTP by conducting a regular review of the processes audit.

3. A study on the practice of dosing of reservoirs in remote areas along the distribution networks should also be conducted to address a constant availability of free residual chlorine in the WDN.

4. It is recommended that Environmental Health Practitioners (EHPs) be involved in the development of drinking water quality monitoring strategy that will address drinking water quality risk to human health. EHPs should also support and conduct periodic training of water analysis to the plant operators.

5. A strategy need to be developed for providing adequate treatment and disinfection of drinking water. Such strategy should ensure the involvement of plant operators to undertake operational monitoring.

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