Drinking Water Quality Profile of Mohokare Local Municipality

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Declaration

I, Karabo Joseph Maqeba, hereby declare that the research study entitled ‘Drinking Water Quality Profile of Mohokare Local Municipality’ was conducted at the Central University of Technology, Free State under the supervision of Dr Leana Esterhuizen and Mrs Irene Mokgadi.

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 thesis has been submitted for any research degree or diploma to any other University/Institute.

……………………….

Karabo Joseph Maqeba

I certify that the above statement is correct

………………………..

Dr Leana Esterhuizen

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First and foremost, I would like to express my gratitude to God for strength, blessings and guidance throughout the completion of this dissertation. I am deeply grateful to my supervisor, Dr Leana Esterhuizen, for her guidance, support and for being a remarkable woman whose strength I deeply admire.

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I dedicate this dissertation to my beloved late parents. Though I never had the chance to know them, I continue to feel their love and presence in my life. I owe a huge debt of gratitude to my grandparents, Selatile Jeremiah Setai and Sennelo Lydia Setai, for raising me with unwavering love and guidance.

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Abbreviations and Acronyms

α	Alpha
AMD	Acid Mine Drainage
ANOVA	Analysis of Variance
CCME-WQI	Canadian Council of Ministers of the Environment Water Quality Index
CFU	Colony Forming Unit
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
E. coli	Escherichia coli
EHPs	Environmental Health Practitioners
GHGs	Greenhouse gasses
HWTS	Household water treatment and safe storage
ICP-OES	Inductively Coupled Plasma Optical Emission Spectroscopy
IGS	Institute for Groundwater Studies
MPN	Most Probable Number
NED	N-1 naphthyl ethylenediamine dihydrochloride
Pt-Co	Platinum Cobalt
RX	Rouxville
SANS	South African National Standards
SDGs	Sustainable Development Goals
SM	Smithfield
TA	Total Alkalinity
TC	Total Coliform

TOC	Total Organic Carbon
UN	United Nations
UV	Ultra-violet
WHO	World Health Organisation
WQI	Water Quality Index
WTPs	Water Treatment Plants
WSAs	Water Services Authorities
WSPs	Water Services Providers
ZN	Zastron

Abstract

Introduction: Access to safe drinking water in South African municipalities continues to be a struggle. The study aimed to assess the drinking water quality of Rouxville (RX), Smithfield (SM) and Zastron (ZN) in Mohokare Local Municipality in the Free State. Mohokare Local Municipality's Blue drop score was 27.58% in 2023, indicating poor performance.

Mohokare Local Municipality has had a concerning Blue Drop score over the years with a concerning score of 27.58% in 2023. This study aims to profile the drinking water quality of the municipality to provide insights into factors that may contribute to its poor Blue Drop performance.

Methodology: Drinking water samples were collected monthly from 14 sample sites over a period of three years. Water samples were then analysed by the Institute for Groundwater Studies (IGS) at the University of the Free State, Bloemfontein for water quality assessment. The drinking water samples were assessed based on 10 water quality properties including colour, alkalinity, fluoride, nitrite, nitrate, sulphate, aluminium, total organic carbon, total coliform, and *E. coli*. The data was statistically analysed and compared to drinking water quality standards set by SANS 241 (2015). The Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) was also used to determine the overall water quality of the sample sites.

Results: The findings revealed that several sample sites had non-compliant values when compared to SANS 241 (2015). Particularly concerning were high values of total coliforms in multiple sample sites, indicating the presence of potential pathogens in the water system. Fluoride, nitrate and sulphate values were within acceptable limits across all three sampling years. The CCME-WQI revealed that the drinking water quality of Mohokare Local Municipality was either classified as Marginal or Fair, indicating that the water quality may be occasionally or frequently threatened.

Conclusion: The study supports the low Blue Drop score obtained by the Municipality and contends that urgent interventions, including maintenance of the water treatment plants (WTPs), are required to improve the water quality. Poor drinking water quality may cause waterborne illnesses such as diarrhoea, which is the leading cause of infant mortality. The indicators for water treatment effectiveness such as total coliform

and *E. coli* were poor, indicating that the municipality requires assistance with the water quality management and treatment processes.

Chapter 1

Introduction

1.1. Introduction

Water is an essential natural resource without which humans and animals cannot survive (Halder and Islam, 2015; Abdel-Satar, Ali and Goher, 2017; Gupta, Pandey and Hussain, 2017). Safe and adequate supply of water is crucial for good health, recreation, welfare, wildlife, and aquatic life (Omran, 2011; Stats SA, 2016). However, various environmental and anthropogenic factors, such as erosion and sedimentation, industrial effluents and agricultural runoff have a significant impact on surface water, which in turn influences drinking water quality.

Surface water is water in rivers, lakes, streams, and ponds. Surface water is an essential component of the hydrological system and provides around 85% of the fresh water consumed in South Africa (Tesfaye and Breuer, 2024). In South Africa, surface water is mostly used, rivers being the most common source of water. Around 70% of South Africa's gross domestic product is supported by rivers (Avenant et al., 2024). Although they are the most common source of water in South Africa, rivers are typically seasonal and contaminated (Geris et al., 2022).

Surface water in South Africa can be contaminated by various activities, including industrial effluents, agricultural runoff containing pesticides and fertilizers, untreated sewage, as well as improper waste disposal practices (Uyigue, Omonigbehin and Ajayi, 2022). Moreover, natural factors such as erosion and sedimentation can also affect water quality (Issaka and Ashraf, 2017).

Many areas in the world are characterised by acute shortage of water supply (Halder and Islam, 2015). Moreover, significant changes in urban, industrial and population growth exacerbate water scarcity and threaten water quality (Gupta, Pandey and Hussain, 2017). Consequently, access to sufficient clean water remains limited due to water sources that are increasingly polluted by industrial, agricultural, and municipal effluent (Halder and Islam, 2015). The rapid urban growth impacts the quality of surface water and continues to deteriorate the water quality, and this affects both humans and aquatic life (Gupta, Pandey and Hussain, 2017). It is estimated that a range of water-borne diseases affect millions of people each year, while infectious diarrhoeal and other waterborne illnesses are the leading causes of infant mortality and malnutrition (Stats SA, 2016; Lin, Yang and Xu, 2022).

The deterioration of surface water impacts negatively on human health. It also undermines the basic human right to access safe and clean water for drinking, sanitation, and daily activities (Du Plessis, 2022).

Access to clean drinking water is recognised as a basic human right in South Africa, and South Africa is also a signatory to the Sustainable Development Goals (SDGs). SDGs are 17 global goals adopted by the United Nations (UN) in 2015 as part of the 2030 agenda for sustainable development (Arora and Mishra, 2019). In South Africa, Sustainable Development Goal (SDG) 6 focuses on ensuring availability and sustainable management of water and sanitation for all South African citizens.

In light of the concerning Blue Drop score for the Mohokare Local Municipality, which highlights significant deficiencies in drinking water quality, this study aims to profile the drinking water quality of the municipality to provide insights into factors that may contribute to its poor Blue Drop performance. Mohokare Local Municipality (Zastron, Smithfield and Rouxville) Blue Drop scores have consistently declined over the years. The municipality's scores have decreased in comparison to previous years, including 2011, 2012, and 2014, culminating in the worst recorded performance in 2023, with a concerning score of 27.58% and failing to achieve the minimum target of 95% required for Blue Drop certificate(DWS, 2023).

1.2. Aims and Objectives

The quality of drinking water is a crucial factor for human health. The drinking water quality of selected sampling sites in Zastron, Smithfield and Rouxville needs to be studied comprehensively.

Aim: The study aims to profile the drinking water quality of the selected sampling sites in Mohokare Local Municipality in the Free State.

Objectives:

- To assess the water quality of Mohokare Local Municipality

- To measure water quality in terms of chemical, physical and microbial properties
- To develop a water quality index for Mohokare Local Municipality
- To provide recommendations

1.3. Layout of the dissertation

The dissertation is divided into 5 chapters, and the chapters cover the following topics:

Chapter 1: Introduction

This chapter includes the background, aims and objectives of the study.

Chapter 2: Literature Review

This chapter includes the description of Mohokare Local Municipality, drinking water quality, the impact of environmental factors, regulatory standards, water quality parameters and water quality index.

Chapter 3: Materials and Methods

This chapter will describe the methods and materials that were used to obtain physical, chemical, and microbiological parameters results as well as the WQI.

Chapter 4: Analysis of results

This chapter presents the results for physical, chemical, and microbiological parameters obtained from the sampling sites in Zastron, Smithfield and Rouxville.

Chapter 5: Discussion and Conclusion

This chapter presents the discussions and conclusions on the findings of the study.

References:

Mendeley was the referencing manager used in this thesis

Chapter 2

Literature review

2.1. Introduction

Water is essential for all living species. It is used for agriculture, recreation, and human consumption (Ringler et al., 2022). In 2010, The United Nations (UN) General Assembly recognized the right of every human being to have access to adequate water for personal and domestic use. Water is not only crucial for health, but also crucial for poverty reduction, food security, ecosystems and education (United Nations, 2023).

South Africa is a water-scarce nation, receiving a mean annual precipitation of 497mm/year, which is almost 50% less than the global average of 860mm/year (Potgieter, 2010). The water-scarcity significantly impacts the water sources. Water sources include dams, lakes, wells or rivers. Water sources are heavily affected by climate change and urbanisation, and this poses a huge challenge for access to safe drinking water (Miller and Hutchins, 2017; Ferdowsi et al., 2024).

Goal seven of the Millennium Development Goals (MDGs) sought to ensure environmental sustainability (United Nations, 2015a) . This included the target of halving the number of people with no sustainable access to safe drinking water by 2015. This target was met and 2.6 billion people gained access to improved drinking water sources between 1990 and 2015 (Kasker, 2024). South Africa made significant progress towards the goal. However, water quality issues and water treatment infrastructure maintenance remain a challenge. In recognition of these challenges, the nations of the world met in September 2015 at the UN in New York and adopted the Sustainable Development Goals (SDGs), the successor framework to the MDGs (Jaiyesimi, 2016). Among the targeted 17 SDGs, SDG 6 (Clean Water and Sanitation for all) is a key for poverty reduction, economic growth and environmental sustainability (Rajendrakumar et al., 2025). South Africa’s delivery of SDG 6 is also marked by challenges, it is struggling to protect its freshwater ecosystems, the country’s water-related ecosystems are chronically under-protected, and the water quality levels are declining due to increased pollution and the poor management of wastewater infrastructure (Libala, Nyingwa and Griffin, 2021).

Poor drinking water quality is linked to transmission of diseases that can be harmful to the health of the public. Out of every 100 patients in emergency care hospitals, 7 patients in high-income countries and 15 patients in low- and middle-income countries will acquire at least one health care-associated infection during their hospital stay due to the lack of good quality water (Haque et al., 2020). In South Africa, nearly half of water supply systems pose acute human health risks because of bacteria or pathogens in the drinking water supply (du Plessis, 2023).

The constitution (section 24 of the Bill of Rights, Constitution of the Republic of South Africa (Act No. 108 of 1996), the National Water Act (Act No. 36 of 1998), the Water Services Act (Act No. 108 of 1997) and the National Health Act (Act No. 61 of 2003) are among the legislations that seek to address the significant challenges posed by poor quality of water in South Africa and safeguard the water quality, as well as public health.

2.2. Drinking water sources

South Africa is classified as a semi-arid country with an average rainfall of approximately 450mm, which is well below the global average of 860mm per year (Danso-Abbeam et al., 2021). The country's major water catchment areas are typically located in the highest regions of the landscape that receive the most rainfall. The healthy functioning of these regions is vital for downstream users and ecosystems, as they are dependent on them to sustain good water quality (WWF, 2013). South Africa's main source of water supply is surface water, providing just under 11 000 m^3/a, and groundwater only providing 10% of that volume (DWS, 2007)

Surface water is water that collects on the surface of the earth, including rivers, lakes and dams (Syeed et al., 2023). Approximately 70% of South Africa's gross domestic product relies on water from the Limpopo, Inkomati, Pongola and Orange Rivers, which collectively drain two thirds of the land area (DWAF, 2004). The Orange River is the most significant river in South Africa. It is the longest river and a major contributor to irrigation, drinking water supply, and hydroelectric power generation in the country.

Lakes are natural bodies of water, where flow from one or more rivers is blocked by a natural barrier (Roth, 2024). Lakes make up less than one percent of the earth's surface area. In South Africa, the major lakes are Lake Chrissie, Lake St Lucia, Lake Sibaya and Zeekoevlei. Lake Sibaya is South Africa’s largest freshwater lake with a surface area of approximately 58 km² (Nsubuga, Mearns and Adeola, 2013). The country’s lakes play a vital role in providing drinking water in regions where groundwater is scarce.

Groundwater is water that is found in the pore spaces and fractures of rocks and sediment beneath the earth's surface (Idris et al., 2018). Groundwater makes up one point six nine percent of all water that is found on earth. Most South African rivers receive about 40% of their flow from groundwater, which helps maintain river flow and prevents them from drying up (Bonthuys and van Vuuren, 2024). Groundwater is an important water source, and over sixty percent of community water supply in South Africa is from groundwater (Nkuna, Mamakoa and Mothetha, 2014).

2.3. Water use

Although water is one of the most abundant substances on earth (Silva, 2023), only 2.5% is fresh water and less than 1% of this 2.5% amount of freshwater is accessible (Mishra, 2023). The most apparent uses of water for people include drinking, cooking, bathing and cleaning. Sectors such as agriculture, energy and mining industry require water to operate effectively (Cacciuttolo and Valenzuela, 2022).

In South Africa, the agricultural sector is one of the largest consumers of water. The uses within the sector are very diverse and primarily include irrigation, pesticide and fertilizer application, and the maintenance of livestock (Pengelly, Shai and Kuschke, 2021). Irrigation supports approximately 25-30% of the country’s agricultural production. Although irrigated agriculture consumes a significant portion of South Africa’s available water resources, the importance of this sector for food security is widely recognized (Bonthuys, 2018).

South Africa’s energy sector, especially the electricity sector, is currently experiencing significant changes as a result of social, economic and environmental pressures (Ukoba, Jen and Yusuf, 2025). Water is a key component of electricity generation. This is commonly known as hydroelectricity. South Africa has a combination of small hydroelectricity stations and pumped water storage schemes, including the Drakensberg Pumped Storage Scheme (Eskom, 2017; Ngancha, Numbi and Kusakana, 2024).

The mining industry often intercepts useable groundwater, sometimes exceeding the required amount needed for its own operations, which can lead to flooding in mine workings (Arenas-Collao et al., 2024). In the mining industry, water is generally used for extraction activities such as drilling, blasting, crushing of the ore and transporting of the ore. It is also used for activities such as cooling of equipment, the generation of steam, scrubbing of gases and slurrying of materials (McKenzie et al., 2010).

2.4. Water pollution

2.4.1. Introduction

Water pollution refers to when harmful substances, such as chemicals or microorganisms contaminate a stream, river, lake, or other body of water, diminishing its quality and making it harmful to humans and the environment (NRDC, 2023). Water pollution is the main cause of water crises in the world. Global water quality is at risk due to industrial activities, agricultural practices, urban areas and mining operations (Kiliç, 2021). In an arid country like South Africa, water pollution has far-reaching impacts on all aspect of life, ranging from the availability of clean drinking water to the preservation of biodiversity in our rivers and oceans, causing neurodevelopmental issues, psychiatric disorders and other waterborne diseases (Nabeel Sharif et al., 2025).

2.4.2. Sources of water pollution

In South Africa, the quality of available drinking water sources are often compromised due to ineffective municipal wastewater management systems which often result in direct discharge into rivers causing large scale pollution, sewage from informal settlements that lack adequate sanitation facilities and waste from intensive animal production systems, industries, hospitals or the mining sector (Du Plessis et al., 2021).

Pollutants enter water sources from two main sources; point sources and non-point sources. Point source pollution occurs when a pollutant is discharged at a specific source that is identifiable, such as a leaking pipe or polluted water leaving a factory

(Ducrotoy, 2024). Non-point source pollution is pollution that is not easily identifiable and comes from many places. Non-point source pollution comes from three main areas, including urban-industrial, agricultural, and atmospheric runoff (González-Varo et al., 2013).

2.4.3. Natural factors causing water pollution

Geological factors, as well as rainfall, are among the main causes of natural pollution in water bodies. The geology of an area plays a key role in determining the overall quality of its water resources (Jude et al., 2024). The dominant geological formations generally influence the physicochemical properties of both surface and groundwater in a given area (Baba and Gündüz, 2017). Geology influences the volumes of surface runoff and the rates and quantities of infiltration, in addition to surface water quality. Groundwater can interact with rocks and sediments, altering its chemical composition. For instance, base exchange softening (process where calcium and magnesium ions in groundwater are replaced by sodium ions using clay minerals) can potentially increase fluoride concentrations in groundwater (Chelnokov et al., 2022). Geological factors also control the distribution of structural belts, which in turn affect groundwater flow, recharge and discharge (Alsharhan and Rizk, 2020).

Natural pollution also occurs through rainfall by carrying contaminants into water bodies by runoff. These contaminants can infiltrate groundwater and accumulate in streams and rivers (NOAA, 2019). The heavy surface runoff combined with the fast-flowing rivers leads to increased dissolved oxygen, turbidity, total sulphide, hydrogen sulphide, and nitrite-nitrogen in rivers following rainfall (Ling et al., 2017). Rainwater runoff can also contain arsenic from a variety of sources, including industrial waste. Inorganic arsenic is a confirmed carcinogen and represents the most widespread chemical contaminant in drinking water globally (Patel et al., 2023).

Naturally occurring pollutants originate from substances that are already present in the environment, rather than from chemicals or other hazardous materials manufactured by humans. Natural processes that affect water quality include weathering of rocks, evapotranspiration, depositions caused by wind, soil leaching, runoff influenced by hydrological factors, and biological activities in aquatic ecosystems. These natural processes often lead to changes in water pH and alkalinity, as well as an increase in phosphorus levels, and high concentrations of sulphates (Khatri and Tyagi, 2015).

Other natural pollutants include manganese, uranium, radon, calcium, lithium, fluoride, and arsenic. Among these, fluoride and arsenic are particularly notable, as arsenic is commonly found in the atmosphere, water, and soil. More than 100 million people in 50 countries are affected by the adverse effects of arsenic pollution in water (López Porras and Allard, 2025).

2.4.4. Anthropogenic activities causing water pollution

Anthropogenic activities are defined as human activities carried out intentionally (Gill and Malamud, 2017). The most important activities include agriculture, landfills, sewage and mining (Earle, 2020). These activities pollute water and are harmful to aquatic ecosystems.

Agriculture, responsible for 70% of water withdrawals globally, plays a significant role in contributing to water pollution (Zahoor and Mushtaq, 2023) . Pesticides and fertilizers used in agriculture can pollute both groundwater and surface water, along with organic waste from livestock, antibiotics, and processing by-products from plantation crops (Mateo-Sagasta, Zadeh and Turral, 2018). These pollutants attach to soil particles and wash into water bodies through runoff generated by rainfall (Zahoor and Mushtaq, 2023).

Landfills cause pollution through a process called leachate, a liquid that filters through the landfill and transports harmful chemicals formed from different types of waste at a specific site (Dagwar and Dutta, 2024). Leachate contaminates groundwater and surface water. Leachate contains dissolved organic and inorganic compounds, such as ammonia, calcium, magnesium, sodium, chlorides, iron, and heavy metals (Wdowczyk and Szymańska-Pulikowska, 2020). Among the chemicals found in leachate, mercury, lead, chromium, cadmium, and arsenic have been the most common heavy metals that are responsible for causing human poisoning (Balali-Mood et al., 2021).

Sewage is water containing human waste, industrial discharge, and debris including sanitary products, condoms, and plastic (Wdowczyk and Szymańska-Pulikowska, 2020). Globally, 80% of wastewater flows back into the environment without being treated or reused, resulting in approximately 1.8 billion people relying on contaminated source of drinking water with faeces (Ijoma et al., 2022). Water pollution from sewage typically results from sewage spills from Wastewater Treatment Works (WWTWs), broken wastewater reticulation system, and failing pump stations.

The mining sector in South Africa plays a pivotal role in driving economic growth and providing employment opportunities (Adjasi and Yu, 2021). However, despite its substantial economic contributions, it is also recognised as the largest single source of pollution in the country and contributes significantly to acid mine drainage, which is one of the country's serious environmental issues (Chetty, Pillay and Humphries, 2021). Mining operations have four main impacts on water quality, including acid mine drainage (AMD), heavy metal contamination and leaching, processing chemicals pollution, and erosion and sedimentation. AMD is a harmful runoff produced when metallic compounds in a coal mine waste undergo oxidation, resulting in acidic streams enriched with iron and sulphate (Ojonimi et al., 2021). The runoff can also leach toxic metals such as copper and aluminium, from surrounding rocks and soils, posing a significant threat to water bodies. Heavy metal pollution occurs when metals like arsenic, cobalt, copper, cadmium, lead, silver, and zinc, which are commonly found in excavated rock, come into contact with water. Metals are then leached downstream into water bodies as water flows over the rock surface, causing water pollution. Pollution from chemical processing is pollution that occurs when chemical agents such as sulphuric acid or cyanide, which are used to extract target minerals from ore, leach, leak from a mine site into water bodies. Both sulphuric acid and cyanide are highly toxic and very dangerous in water bodies. Larger amounts of sulphuric acid lower the pH of water, making it acidic. Cyanide is a compound which reacts rapidly with other chemical elements and it can also form different compounds (Kwaansa-Ansah et al., 2017). Many compounds in water bodies are harmful because they disrupt the natural balance of aquatic ecosystems and can impact human health. Open pit mining, through the removal of vegetation and soil, heightens the risk of soil erosion and this can lead to increased sedimentation in nearby water bodies such as rivers. Consequently, this can affect water quality and disrupt the natural flow of rivers (Chernos et al., 2022).

2.5. Effects of water pollution

2.5.1. Introduction

Pollution refers to the harmful alteration that occurs to one of the environmental components such as water, soil and air. Water resources are affected by different types of pollution. Water pollution is just as harmful as air and soil pollution. All of these forms of pollution negatively impact the lives of humans and animals, and also harm the environment (Hadi Hassan Al-Taai, 2021). Although significant progress has been made, billions of people still lack access to safe drinking water, sanitation, and hygiene (Nischal, 2019). Polluted water and poor sanitation are associated with the spread of diseases like cholera, diarrhoea, and hepatitis A, among others (Maliji et al., 2023). In South Africa, the most significant water quality issue in surface water is faecal contamination, along with the harmful pathogens that are present in surface water close to densely populated areas. In groundwater, the most prevalent issues are elevated levels of nitrites or nitrates and fluoride that are related to underground faecal contamination of groundwater (Ummah, 2019). Water pollution in South Africa presents significant health hazards, including water-related illnesses and exposure to harmful substances such as heavy metals, resulting in health issues ranging from diarrhoeal diseases to cancer (Sibanda, Selvarajan and Tekere, 2015; Khabo-Mmekoa, Genthe and Momba, 2022). Water pollution in South Africa not only affects health, but it also has a detrimental impact on agriculture and the environment.

2.5.2. Health effects of water pollution

Water pollution is a major issue caused by various pollutants. Consuming, coming into contact with, or using polluted water for washing can have adverse effects on human health (Babuji et al., 2023). It is estimated that around 1.4 million people die annually as a result of poor sanitation, poor hygiene, or polluted drinking water (WHO, 2023). Diseases associated with pathogens in water, such as cholera, typhoid, infectious hepatitis, and polio, among others, cause a significant number of fatalities. Many of these water-borne diseases are due to the presence of faeces in water (Forstinus et al., 2016), which is very common in South Africa. Cholera and typhoid are two common waterborne diseases in South Africa, as the country has experienced epidemics in the recent past caused by both (Sekgobela and Sibanda, 2024). Cholera is an acute intestinal disease caused by a bacterium called *Vibrio cholera*. The disease affects people and is characterised by symptoms including watery diarrhoea, discomfort of the abdomen, and anorexia, which cause mild to severe gastrointestinal illness, dehydration, and death if untreated (Kachienga et al., 2024). In South Africa, a total of 10 confirmed cholera cases, including one death have been reported since the 5th of February 2023. All cases were reported in Gauteng Province (NICD, 2023). Typhoid fever is an infection caused by a bacterium called *Salmonella Typhi*, which can be life-threatening. Infected individuals experience symptoms such as prolonged fever, fatigue, headache, and nausea, among others. Severe cases may lead to death (Gouda, 2024)**.**

Chemicals such as arsenic and copper in drinking water pose the greatest threat to public health. Long-term exposure to arsenic from drinking water can cause cancer and has also been associated with cardiovascular disease and diabetes (Karachaliou et al., 2022) . Long-term exposure to high levels of copper over many years can cause liver damage and death (Sailer et al., 2024).

2.5.3. Environmental effect

When rivers are polluted, global warming potentially increases from two to ten times (Keegan, 2021). The sediment, nutrients, and bacteria that are collecting on the bottom of surface water such as rivers, result in the emission of greenhouse gases (GHGs) as a result of the natural decomposing process. High nutrient concentrations such as total nitrogen, organic carbon, total phosphorus, and the low oxygen in rivers caused by algae due to pollution are the significant influencing factors for CO_2, N_2O, and CH_4 emissions (Upadhyay, Prajapati and Kumar, 2023). The greenhouse gases increase the temperature of the earth by trapping the sun's heat in the atmosphere and this process is called the greenhouse effect. As the temperature increases and the weather changes, the homes of plants and animals will be affected, and this could cause the loss of some animal and plant species (Salatin, 2022).

2.5.4. Agricultural effect

Agriculture is the most substantial factor of non-point source pollution to surface water and groundwater and it is also a victim of water pollution (FAO, 2024)**.** With the use of pesticides and chemicals in agriculture, water becomes polluted. This leads to a loss of soil fertility, which consequently results in reduction in the availability of food. Water polluted by fertilizers and pesticides can be responsible for slow growth, poor quality of the crop, and can also lead to death of the plants. Pesticides, including insecticides, herbicides, and fungicides, are on top of the list of environmental toxicants threatening nature (Ahmed et al., 2021). The impact of these pesticides and fertilizers can also expose livestock to unnecessary risks. Fertilizers that are commonly used in farms contain nitrogen as nitrate, because nitrate is easily taken up by plants (Yara, 2020). The fertilizers are washed into rivers and water bodies through runoff and soil erosion. Rivers and water bodies containing toxic levels of nitrate from fertilizers may cause acute poisoning of livestock (Kallenbach and Evans, 2014). Pigs are highly susceptible to oral intake of nitrite because they cannot convert the nitrite to ammonia (Cockburn et al., 2013).

2.6. Drinking Water Treatment

Lack of safe water, sanitation and hygiene is still the world's most urgent health issue. If improved, the global disease burden can be prevented (Wolf et al., 2023). Water treatment and diseases are closely related; untreated water contains various invisible microbes that can cause fatal diseases (Olaolu, 2014). Water treatment is the process of removing chemical, biological, and physical substances that can be harmful to humans from water to make it safe for domestic use (Pakharuddin et al., 2021). A variety of treatment processes are commonly used to remove contaminants from drinking water including filtration, coagulation and flocculation, and disinfection (Water Research Commission, 2002; Razali et al., 2023).

2.6.1. Coagulation and flocculation

Coagulation and flocculation processes are used to separate the suspended solids from water (Yu, 2025). Coagulation is the process by means of which the colloidal particles in water are destabilised so that they form flocs through the process of flocculation that can be readily separated from the water. The separation process is done by sedimentation and sand filtration. Flocs formed during coagulation and flocculation settle from the water and this process is called sedimentation (Deng et al., 2022).

2.6.2. Filtration

Filtration is a process that removes chemical and biological contaminants, reduces the concentration of particulate matter, including suspended particles, parasites, and bacteria, among others, from contaminated water to produce safe and clean water for drinking or any other purpose (Mao, 2016). The particles are removed by the sand grains and are retained in the bed of sand, while clean water flows out from the bottom of the sand bed. Sand filtration processes can either be rapid (RSF) or slow (SSF); RSF is used in conventional water treatment, and SSF is normally used for relatively small-scale conventional treatment plants (Abdiyev et al., 2023).

2.6.3. Disinfection

Water disinfection remains the most commonly used method globally to preserve public health from waterborne diseases (Postigo and Richardson, 2021). Disinfection of drinking water is the treatment process that destroys disease-causing microorganisms, or pathogens, found in the water supply (Obayomi et al., 2024). Disinfection of water entails the addition of the required amount of a disinfectant such as chlorine gas (commonly used disinfectant) to the water and allowing contact between the water and disinfectant for a predetermined period of time (under specified conditions of pH and temperature). Other methods used for disinfection of water include boiling of the water or radiation with ultra-violet light (Sah et al., 2023).

2.6.4. Household water treatment and safe storage (HWTS)

Sustainable Development Goal (SDG) 6.1 aims to achieve universal and equitable access to safe and affordable drinking water for all by 2030 (United Nations, 2015b). Its main focus is on the type of infrastructure available and it emphasises the quality of the service that must be delivered, including the safety of drinking water. This necessitates ensuring that water safety risks are minimised from catchment to consumer, including in households where unsafe collection, storage and handling can result in contamination (WHO, 2019). Therefore, this highlights the importance of HWTS. The HWTS can reduce the risk of diarrhoeal disease by as much as 61% when HWTS methods are consistently and correctly used (Merton, 2018). Various household water treatment (HWT) methods can be used including solar disinfection (SODIS), ceramic filter and bio-sand filter (Stubbé et al., 2016). SODIS entails using ultraviolet (UV) radiation in sunlight to kill micro-organisms in the water. The method is very useful and inexpensive compared to commercial filters, which are relatively expensive for small-scale treatment of water (WHO, 2019).

Ceramic filters are considered to be a lower-cost option than other common filtration methods. Ceramic water filters are made from locally available materials, making them affordable to most households in low-income countries (Chaukura et al., 2023). Ceramic filtration removes microorganisms physically from water by a combination of both size exclusion and adsorption; it is typically not effective against viruses. The ceramic filter structure is made up of clay and combustible material, such as rice husks, that provide a porous structure through which water is filtered under gravity (WHO, 2019).

2.7. Water quality assessment

2.7.1. Introduction

Assessing water quality is important because it directly impacts human consumption and health. Assessing water quality determines whether the water quality complies with the standards, consequently determining if it is suitable or not for the intended purpose (Roy, 2018). To assess water quality, three main water quality parameters are measured, including physical, chemical and biological parameters (Batina and Krtalić, 2024). The steps to measure water quality include the selection of parameters, the selection of methods, precision and accuracy of method selected as per requirement, and sample tracking procedures (Roy, 2018). The quality of the water used for consumption must meet specific parameters. The Water Services Act mandates that all Water Service Providers (WSPs) must comply with the national standards when they supply drinking water to citizens to ensure safety (Republic of South Africa, 1997). One of these key standards is South African National Standards (SANS), which regulates the quality of drinking water and sets strict limits on various parameters. It is important that the physical, chemical and biological parameters meet the drinking water quality standards set by SANS (Ndlangamandla, Sukdeo and Mukwakungu, 2024).

2.7.2. Physical parameters

Physical parameters of water signify the appearance and physical characteristics of the water (Syeed et al., 2023). Physical parameters of water quality are the measurable characteristics of water that relate to its physical properties. These parameters provide significant insight into the condition of water, which can affect its quality and effectiveness. Physical parameters include turbidity, taste and odour, colour, electrical conductivity (EC), salinity, total dissolved solids (TDS) and temperature (Lesa Chundu et al., 2024).

2.7.2.1. Measurement of physical parameters

Taste and odour are important indicators of water quality. Taste and odour that is unpleasant is normally caused by a range of chemicals, including organic compounds, minerals, and metals (Abdel-Satar, Ali and Goher, 2017). The sources of taste and odour are usually metabolites of algae and bacteria, discharging of industrial products and raw materials into the surface waters, and chemical reactions during the water treatment process (Karimpour Zahraei, Salemi and Schmidt, 2021).

Colour in water is mainly an aesthetic concern of water quality. Water that is coloured gives the appearance of being unpalatable; however, the water may be safe for consumption. Notwithstanding that, colour also indicates the presence of organic substances including algae. It is also used as a quantitative assessment of the presence of potentially hazardous materials in water (Shah, 2017). Colour is normally measured by comparing the water sample with standard colour solutions, using the platinum cobalt method (Pt-Co) (Omer, 2019). The spectrophotometric method is another method that can be used to measure colour (Aleixander-Tudo et al., 2017).

EC estimates the amount of dissolved salts in water. The more dissolved salts in water bodies, the higher the conductivity (Pal et al., 2015). EC is an indirect indicator of pollution; higher EC values are commonly associated with the presence of domestic sewage due to an increase in the chloride ion concentration (de Sousa et al., 2014). Conductivity shows significant relationship with TDS (Bhateria and Jain, 2016). Both parameters are used to describe salinity level. They are correlated and usually expressed as TDS = k EC (in 25^0C). It is more complex to obtain the measurement of TDS than EC. Consequently, EC is more commonly measured because it is easy and inexpensive (Rusydi, 2018).

2.7.3. Chemical parameters

Drinking water must not pose a chemical risk for public health. There are many chemicals that occur in drinking water, but only few can lead to health problems resulting from a single exposure (Herschy, 2012). The high amount of some chemicals in water can cause health problems for the consumers (Table 2.1) (Khodadadi et al., 2016). To test water quality, chemical parameters including alkalinity, fluoride, nitrite, nitrate, aluminium, and total organic carbon (TOC), among others are used (Deshmukh, Patil and Sawant, 2012).

Table 2.1 Water chemicals that are of concern to human health

Chemical	Health Effects
Chromium	Metallic chromium, trivalent chromium, and hexavalent chromium are the three forms of chromium that occur in nature. Hexavalent chromium impacts the body negatively (Georgaki and Charalambous, 2023). Chromium Ingestion of 1–5g can cause severe gastrointestinal disorders and death after a cardiovascular shock (WHO, 1996).
Cadmium	Kidneys are the most vulnerable organs with the chronic oral exposure to Cadmium. The exposure is typically through contaminated water. Cadmium affects the resorption function of the proximal tubules, which can lead tubular proteinuria (Rasin et al., 2025) .
Mercury	Mercury is naturally found in soil, air and water. Mercury is toxic to human health; small exposure can cause serious health problems. Overexposure can cause problems with the thyroid gland and gastrointestinal tract, and can lead to death in some cases (Kumar Verma, Singh Sankhla and Kumar, 2018)
Lead	Lead is important and dangerous to the environment at the same. It is highly toxic and can affect most of the organs in the body (Wani, Ara and Usmani, 2015). It is a cumulative general poison and long-term exposure can cause acute proximal tubular dysfunction and encephalopathy (Sachdeva et al., 2018).

Arsenic	Arsenic is introduced into water bodies through mine waste. Populations consuming arsenic contaminated water show signs of chronic arsenicism, including dermal lesions such as hyper- and hypopigmentation, peripheral neuropathy, skin cancer, bladder and lung cancers and peripheral vascular disease (WHO, 2011).

2.7.3.1. Measurement of chemical parameters

Alkalinity is a water parameter that measures the acid-neutralising capacity of water (Iticha, Mosley and Marschner, 2025). Alkalinity of the water is mainly because of the presence of bicarbonates, carbonates, hydroxides, potassium, calcium and magnesium. It is measured by hydrochloric acid (HCl) titration, in the presence of indicators including phenolphthalein and methyl orange (Dhoke, 2023).

High amounts of fluoride ions in drinking water may cause adverse health consequences such as dental discoloration and skeletal fluorosis (Dar and Kurella, 2022). To measure fluoride concentration in water, methods including ion-selective electrodes, spectrophotometric, and UV–visible spectroscopy are used (Moradia et al., 2019).

The presence of both nitrate and nitrite is considered as an indicator of sewage water pollution (Marhamati et al., 2020). When nitrate is consumed through water, it metabolizes into bioactive nitrite and absorbed into the bloodstream, causing serious health effects including cancer (Claon et al., 2024). To measure nitrate and nitrite, the spectrophotometric method is commonly used (Kurt et al., 2012).

Total organic carbon (TOC) is a parameter that acts as an indicator to estimate the amount of organic content that is in a water sample (Shetty and Goyal, 2022). TOC determines the degree of pollution that is in the drinking water (Pandey and Satpute, 2021). The concentration of TOC in drinking water should generally be <10 mg/L (SANS, 2015). Any concentration of TOC present in water is dangerous to the body and it causes the water to be unsafe for consumption (Pandey and Satpute, 2021). To measure TOC, methods including combustion with non-dispersive infrared (NDIR) detection, catalytic oxidation with NDIR detection, persulphate, and ultraviolet (UV) (Shetty and Goyal, 2022).

2.7.4. Microbiological parameters

The microbiological assessment of water is used globally to monitor and control the quality of different types of water including drinking water (Wen et al., 2020) . In terms of microbiological compliance in South Africa, 35% of the water supply systems in the country fall under the critical risk category (DWS, 2022). To ensure that drinking water is microbiologically safe for human consumption, there must be no pathogens in the water at the point of use. To ensure that water is free from pathogens, microbial parameters are used to identify contaminants. The most commonly used microbiological parameters to assess water quality are *Escherichia coli* (*E. coli*) and total coliform (SANS, 2015).

2.7.4.1. Measurement of microbiological parameters

E. coli is an indicator of faecal pollution and it provides the best bacterial indication of faecal contamination in drinking water (Odonkor and Ampofo, 2013). Faecal contamination of water is a significant health issue. To measure *E. coli*, the Most Probable Number (MPN) method and Membrane Filter (MF) technique are used (Pal, 2014).

Total coliforms in water samples can indicate the presence of a biofilm or may indicate treatment ineffectiveness (Verhille, 2013). Biofilms are a significant source of pathogenic microorganisms, which cause various waterborne illnesses (Simões and Simões, 2014). The most probable number (MPN) method is commonly used to measure total coliforms (Titilawo et al., 2019). Other methods include the multiple-tube fermentation technique (MTF), membrane filter (MF) technique and molecular methods (Pal, 2014).

2.7.4.2. The most probable number (MPN)

MPN is a broth culture-based method that involves serial dilution of samples in suitable test media. It estimates the viable count of bacteria in a sample by inoculating broth in 10 fold dilutions (Onyeaka and Nwabor, 2022). Positive or negative results are used to estimate quantitative values by culturing multiple portions of the original sample in order to determine if microorganisms are present (positive) or absent (negative) in each sample (Chandrapati and Williams, 2014).

2.7.4.3. Multiple-tube fermentation method (MTF)

The MTF method is a three-stage procedure in which the results are statistically expressed in terms of MPN stages, including the presumptive stage, confirmed stage, and completed test (Akhlaghi et al., 2018). The presumptive stage is a stage where a series of tubes are incubated, resulting in the formation of gas that indicates a positive presumptive test. If any gas formation occurs, the inoculation process of the samples should start immediately, and this procedure is a confirmed stage, known as confirmation stage. If bacteria are present in the culture colonies and gas formation occurs, the completed test is then finalised (Nurani, Abdul and Lau, 2018). The disadvantage of the MTF method is that it is slow and it also is not *E. coli* specific (Rompré et al., 2018).

2.7.4.4. The membrane filter method (MF)

The MF method is used to analyse bacteria in water samples from different sources (Forster and Pinedo, 2016). It allows large sample volumes to be analysed and it is the easiest and fastest method that does not need complex laboratory instruments (Kemper et al., 2023). 100ml water samples are filtered onto a membrane for incubation. Bacteria cells will then grow into colonies that will be counted (Verhille, 2013). Colony count gives an insight into the level of background bacteria (Kemper et al., 2023).

2.7.4.5. Molecular method

Molecular methods used to analyse microbial pathogens in water include conventional end-point polymerase chain reaction (PCR), real-time quantitative PCR (qPCR), multiplex qPCR (mqPCR), digital droplet PCR (ddPCR), Deoxyribonucleic acid (DNA) microarray, loop-mediated isothermal amplification (LAMP) and high-throughput next-generation DNA sequencing (HT-NGS) (Paruch, 2022). The commonly used molecular methods are qPCR and mqPCR. Real time PCR (qPRC) is a quantitative measurement of DNA, in which only one DNA sequence is amplified in each reaction (Avery et al., 2013). Steps to prepare qPRC experiment include designing of primers to amplify DNA sequences, a selection of detection method such as SYBR Green and TaqMan probes, planning of control reactions, and the method to analyse data such as absolute and relative quantification, which are two commonly used methods to analyse qPCR data (Dymond, 2013). Multiplex qPCR (mqPRC) is used to identify *Campylobacter* in water (Botes, Kwaadsteniet and Cloete, 2013). It also uses primers to amplify multiple DNA sequences in single reaction. This is done in one tube and one amplification program for all amplicons (Davidson, 2019).

2.8. Water Quality Index (WQI)

Management of water quality requires the collection and analysis of large water quality datasets that can be very difficult to evaluate. The Water Quality Index (WQI) model is a tool that evaluates surface water quality. It uses aggregation techniques that convert large water quality datasets into a single value or index (Uddin, Nash and Olbert, 2021). WQI provides a number that expresses the overall quality of water, at a specific location and time, based on several water quality parameters. Its main objective is to turn complicated water quality data into information that is easily understandable (Dua and Anish, 2009; Sarker et al., 2025). WQI typically involves four stages including (1) the parameter selection, (2) transforming raw data into common scale, (3) providing weights and the last stage is (4) aggregation of sub-index values to compute the overall water quality index (Chidiac et al., 2023). There are currently over 35 WQI models that have been used globally by different countries to evaluate surface water quality, and 82% of the models have been used to assess river water quality (Uddin, Nash and Olbert, 2021).

WQI was first developed by Horton (1965), it is a tool that is used to describe water quality. Water quality indices that are commonly used globally include the US National Sanitation Foundation Water Quality Index (NSFWQI) (Brown et al., 1970). NSFWQI classifies surface water resources according to their water quality and it consists of nine parameters, including percentage of dissolved oxygen (DO), pH, biochemical oxygen demand, turbidity, nitrate, temperature, faecal coliform and total phosphate (Noori et al., 2019). Other water quality indices include the Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), British Columbia Water Quality Index (BCWQI), and Oregon Water Quality Index (OWQI). The majority of these indices are derived from the WQI developed by the U.S National Foundation (NSF) (Şener, Şener and Davraz, 2017).

2.9. Legislation and monitoring of drinking water

Section 24 of the South African Constitution (Act No. 108 of 1996) states that everyone has the right to have access to an environment that is not harmful to their health or well-being, including a constant supply of clean, safe drinking water (Republic of South Africa, 1996). In South Africa, policies and regulations that are based on international standards govern the monitoring and management of the quality of drinking water (Rivett, Champanis and Wilson-Jones, 2013). Various stakeholders, including water services authorities (WSAs), Department of Water Affairs and Forestry (DWAF), Department of Health (DoH), Department of Provincial and Local Government and civil society, are responsible for monitoring and managing the quality of drinking water in South Africa (Hodgson and Manus, 2006).

The Water Services Act (Act No. 108 of 1997) and the National Water Act (NWA) (Act No. 36 of 1998) are the two laws that play a crucial role in South Africa's water security (Kruger et al., 2022). The Water Services Act stipulates that all South Africans should have access to basic water supply and sanitation, and this applies equally in urban and rural settlements (Republic of South Africa, 1997). Water services authorities (WSAs) are responsible for ensuring access to both water supply services and sanitation services (Algotsson et al., 2009). WSAs must comply with SANS 241 and subsequent updated versions when testing and treating drinking water supplied to a household. All WSAs must have a sampling plan which includes the list of water quality parameters to be sampled, sampling locations and the sampling frequency as described in the Water Services Act (Act No. 108 of 1997). SANS 241 states the minimum requirements for drinking water to be considered safe for human consumption.

The National Water Act (NWA) (Act No. 36 of 1998) was published in 1998. The NWA ensures that South Africa's water resources are protected, used, conserved, developed, managed and controlled (Viljoen et al., 2022). Mismanagement of water resources in South Africa affects everyone. Those who live in poor areas are mostly affected because they are unable to access proper drinking water and sanitation (Molobela and Sinha, 2011).

The Department of Water and Sanitation (DWS) (formerly known as the Department of Water Affairs) initiated a guideline for water quality monitoring which is known as the drinking water quality (DWQ) in 2005. Due to the negative cases of poor water quality, the DWS then introduced a program called the Blue Drop Certification in 2008 (Edokpayi et al., 2020). The Blue Drop certification program measures and compares WSAs and their providers (Water Services Providers) based on the results of the performance according to the minimum requirements that must be met to effectively manage water within the municipality. Municipalities that do not meet the requirements are penalised and those that meet the requirements are rewarded (DWAF, 2011). The Blue Drop certification programme helps the WSAs and providers to identify the water treatment works that must be improved. The Blue Drop assessment is based on five key performance areas, including capacity management, financial management, drinking water quality risk management, technical management, and drinking water quality compliance. The assessments are conducted by water quality specialists as lead assessors (Edokpayi et al., 2020).

Environmental health Practitioners (EHPs) are an important part of environmental health services, which include monitoring water quality (Republic of South Africa, 2009). EHPs are health officers who are appointed in terms of section 80 of the National Health Act (Act No. 61 of 2003) and registered as such in terms of the Health Professions Act (Act No. 56 of 1974). The EHPs' mandate as part of Municipal Health Services within the District and Metropolitan Municipalities is to monitor public drinking water quality, which is also the responsibility of the Department of Water and Sanitation (DWS). The reviewed studies highlight that water monitoring in South Africa is a serious concern due to shortage of EHPs as well as operating tools and funding to collect sufficient number of samples for representative sampling of the areas (Maselela, Mokgobu and Mudau, 2024; Curtis et al., 2025).

2.10. Conclusion

Water is essential for all living species. Good drinking water quality is important to health, but due to anthropogenic activities, the quality of drinking water is deteriorating. Household water treatment methods can help reduce waterborne diseases at a household level. Monitoring drinking water quality is important to identify contaminants that should be treated to ensure good public health. EHPs play a crucial role in water monitoring to facilitate safe drinking water in collaboration with WSAs and WSPs.

Chapter 3

Materials and methods

3.1. Introduction

The study was conducted to assess the water quality of Zastron (ZN), Rouxville (RX), and Smithfield (SM) in Mohokare Local Municipality in the Free State. Chemical, physical, and microbiological properties were measured to determine the quality of drinking water. In total, 10 water quality properties were assessed at 5 sampling sites in RX, 4 sampling sites in ZN, and 5 sampling sites in SM. The properties assessed included colour, alkalinity, fluoride, nitrite, nitrate, sulphate, aluminium, total organic carbon, total coliform, and *E. coli*.

3.2. Study design

The study design was divided into three stages. Stage 1 involved the identification of sampling sites at the Mohokare Local Municipality and selecting suitable sampling sites for this study. Stage 2 involved the collection of secondary water quality data in the form of data sheets from the Mohokare Local Municipality's Environmental Health Practitioner (EHP). These data sheets contained chemical, physical, and microbiological properties of drinking water samples analysed at the Institute for Groundwater Studies (IGS) at the University of the Free State, Bloemfontein. Stage 3 involved statistical analysis and interpretation of the secondary water quality data obtained from the EHP.

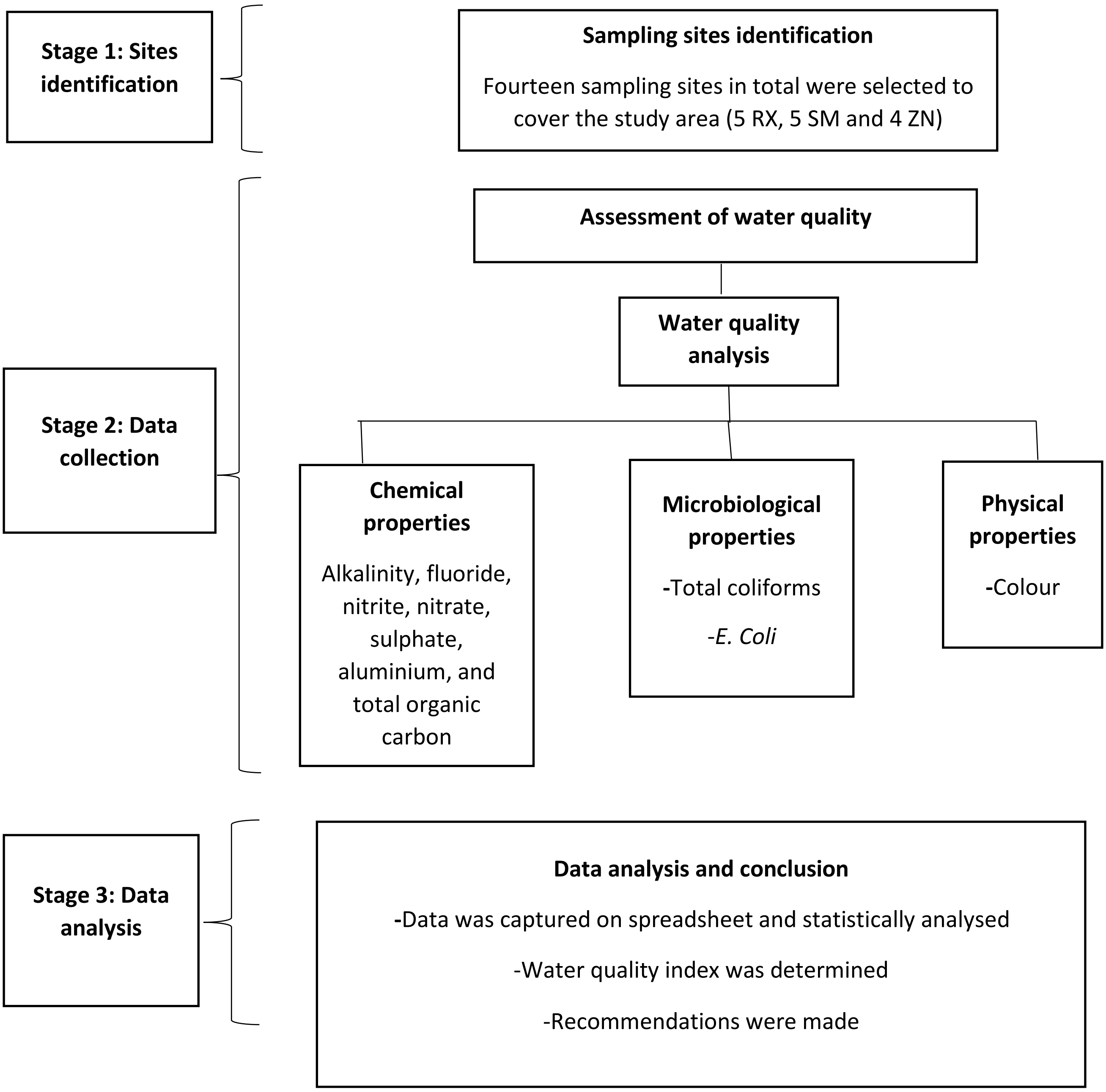

Figure 3.1 Study design

3.2.1. Identification of sites

This stage involved the identification of appropriate sampling sites within the study area. The sampling sites were identified in collaboration with Mohokare Local Municipality officials and an Environmental Health Practitioner. A total of 14 sampling sites were identified; 5 samplings sites were identified at Rouxville, 4 sampling sites were identified at Zastron, and 5 sampling sites were identified at Smithfield in the Mohokare Local Municipality.

3.2.2. Data collection

The water samples were collected monthly during both dry and wet seasons from 14 sample sites over a period of three years, the water samples collected at each sampling site were conveyed to IGS laboratory in Bloemfontein for water quality assessment. The water quality properties assessed included 7 chemical properties, two microbiological properties, and one physical property. The chemical properties selected were alkalinity, fluoride, nitrite, nitrate, sulphate, aluminium, and total organic carbon. The microbiological properties selected were total coliform, and *E. coli*. The physical property selected was colour.

3.2.3. Data analysis

The water quality data that was obtained from the Mohokare Local Municipality was captured on an Excel spreadsheet for analysis. Water quality index (WQI) was used to combine water quality parameters data into one numerical value so that comparison could be made to the standard limits for compliance. Recommendations were then made for the sites that were not complying.

3.3. Study area

3.3.1. Sampling sites, area, description of sites and the motivation for the choice of the sites

Table 3.1 Rouxville

Sampling Site	Area	Coordinate	Description of vicinity	Motivation for the choice of site
RX1	Rouxville Water Treatment Plant	30°23'26.4"S 26°50'12.4"E	Rouxville Water Treatment Plant	To determine the final quality of water before being discharged into the water distribution network

RX2	Rouxville Municipality	30°25'00.3"S 26°50'02.4"E	Rouxville Municipality	Sampling point representing one section of the town to determine the quality of water in the distribution network serving the population of the area
RX3	NG Kerk Rouxville	30°24'59.4"S 26°50'06.0"E	NG Kerk Rouxville	Sampling point representing one section of the town to determine the quality of water in the distribution network serving the population of the area
RX4	Rouxville Police Station	30°25'13.2"S 26°50'03.2"E	Rouxville Police Station	Sampling point representing one section of the town to determine the quality of water in the distribution network serving the population of the area
RX5	Roleleathunya Library	30°24'32.9"S 26°49'49.9"E	Albert Nzula Library	Sampling point representing one section of the town to determine the

				quality of water in the distribution network serving the population of the area

Table 3.2 Zastron

Sampling Site	Area	Coordinate	Description of vicinity	Motivation for the choice of site
ZN1	Zastron Water Treatment Works	30°18'05.8"S 27°04'13.2"E	Zastron Water Treatment Facility	To determine the final quality of water before being discharged into the water distribution network
ZN2	Mohokare Local Municipality	30°18'07.0"S 27°05'10.0"E	Mohokare Local Municipality	Sampling point representing one section of the town to determine the quality of water in the distribution network serving the population of the area
ZN3	Distribution Network	30°18'05.4"S 27°05'08.4"E	Distribution Network (Fire Hydrant)	Sampling point representing one section of the town to determine the quality of water in the distribution network serving the population of the area
ZN4	Matlakeng Clinic	30°17'44.5"S 27°05'38.9"E	Matlakeng Clinic	Sampling point representing one section of the town to determine the quality of water in the distribution network

				serving the population of the area

Table 3.3 Smithfield

Sampling Site	**Area**	**Coordinate**	**Description of vicinity**	**Motivation for the choice of site**
SM1	Smithfield Water Treatment Plant	30°11'42.7"S 26°31'33.9"E	Smithfield Water Treatment Plant	To determine the final quality of water before being discharged into the water distribution network
SM2	Mohokare Local Municipality	30°12'42.2"S 26°31'50.8"E	Mohokare Local Municipality	Sampling point representing one section of the town to determine the quality of water in the distribution network serving the population of the area
SM3	Distribution Network (Fire Hydrant)	30°12'38.0"S 26°31'58.8"E	Distribution Network (Fire Hydrant)	Sampling point representing one section of the town to determine the quality of water in the distribution network serving the population of the area
SM4	Thembalethu Clinic	30°12'45.8"S 26°32'10.4"E	Thembalethu Clinic	Sampling point representing one section of the town to determine the quality of water in the distribution

				network serving the population of the area
SM5	Stoffel Coetzee District Hospital	30°13'03.1"S 26°31'24.4"E	Stoffel Coetzee District Hospital	Sampling point representing one section of the town to determine the quality of water in the distribution network serving the population of the area
*				

3.3.2. Sampling site location

A total of 14 sampling sites were identified; 5 sampling sites in Rouxville (Figure 3.2), 4 sampling sites in Zastron (Figure 3.3), and 5 sampling sites in Smithfield (Figure 3.4) were identified and flagged, as indicated in the maps below. The 5 Sampling sites identified in Rouxville were Rouxville water treatment plant, Roleleathunya library, NG Kerk, Police Station, and Rouxville Municipality. The 4 sampling sites identified in Zastron were Matlakeng Clinic, distribution network (fire hydrant), Zastron water treatment, and Mohokare Local Muicipality. The 5 sampling sites identified in Smithfield were Smithfield water treatment plant, distribution network (fire hydrant), Mohokare Local Municipality, Thembalethu Clinic, and Stoffel Coetzee District Hospital.

Figure 3.2 Rouxville map with the 5 identified sample sites

Figure 3.3 Zastron map with the 4 identified sample sites

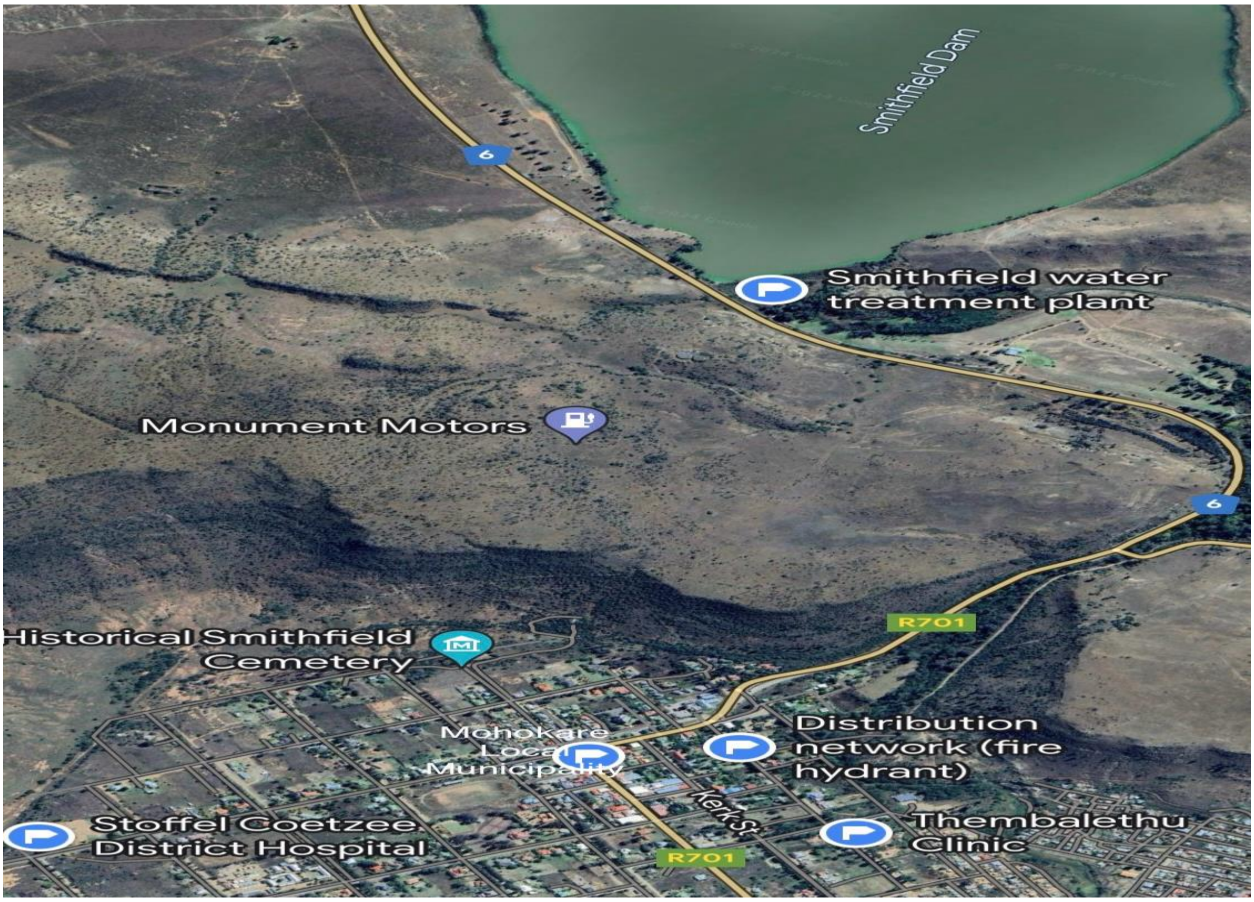

Figure 3.4 Smithfield map with 5 identified sample sites

3.4. Water quality assessment

In this study, a range of equipment and analytical methods were used to evaluate the drinking water quality. The drinking water quality was assessed against the limits specified in SANS 241 (SANS, 2015). The measurements for chemical, physical and microbiological water properties were performed at the Institute for Groundwater Studies (IGS) Laboratory services at the University of The Free State in Bloemfontein.

3.4.1. Measurements of physical properties

In this study, the physical water quality property measured at IGS was colour. To measure colour, Hach DR 3900 (Figure 3.5) and spectrophotometric method were used. To measure colour in water using a spectrophotometric method with the Hach DR 3900, the first step was to prepare the water samples of 10ml; the samples were then placed into the spectrophotometer cuvettes and inserted into the instrument after calibration; the intensity of the light transmitted through the water samples at various wavelengths was then measured, and the Hach DR 3900 with its software was then able to analyse spectral data and determine the colour of water samples.

Figure 3.5 Hach DR 3900

3.4.2. Measurements of chemical properties

3.4.2.1. Measurements of Aluminium, sulphate, and fluoride

The equipment used to measure aluminium and sulphate was Teledyne Leeman Prodigy 7 (Figure 3.6) and the method used was ICP-OES. Using Teledyne Leeman Prodigy 7 with ICP-OES method, the samples were first filtered so that the particulates could be removed, standard solutions of aluminium and sulphate were prepared and used for calibration, and lastly the samples were put through the ICP-OES instrument for detection of aluminium and sulphate concentrations. The equipment used to measure fluoride was Hach DR 3900 (Figure 3.5) and the method used was spectrophotometric.

Figure 3.6 Teledyne Leeman Prodigy 7

3.4.2.2. Measurements of alkalinity, nitrite and nitrate

The equipment used for the above-mentioned chemical properties was Systea easychem 200 (Figure 3.7) and the method used was spectrophotometric. For the alkalinity measurement, a strong acid was added to the sample to titrate the alkaline components such as carbonates, bicarbonates, and hydroxides to a specified pH endpoint. The amount of acid consumed during the titration was then quantified with the usage of a pH indicator and this value was converted into alkalinity units. For nitrite and nitrate, specific reagents were added to the samples to react with both compounds, producing colour changes that were then measured by the spectrophotometer to determine their concentrations. For nitrite, N-1 naphthyl ethylenediamine dihydrochloride (NED) was the reagent used and Griess reagent was used for nitrate.

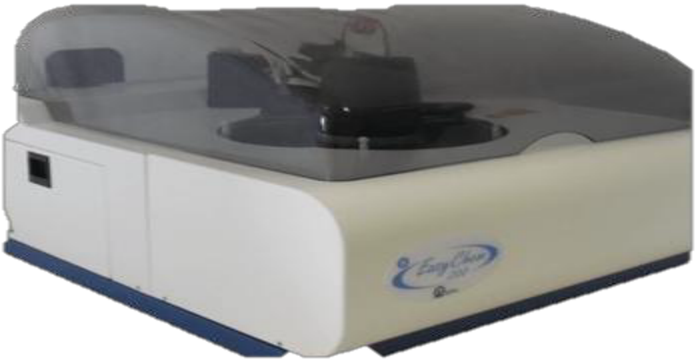

Figure 3.7 Systea easychem 200

3.4.2.3. Measurement of total organic carbon (TOC)

The equipment used for TOC measurement was Analytik Jena multi N/C (Figure 3.8) and the method used was low temp UV. Low temperature UV was used as a pre-treatment step to break down organic compounds into a form that was easily detected and quantified by Analytik Jena multi N/C.

Figure 3.8 Analytik Jena multi N/C

3.4.3. Measurements of microbiological properties

3.4.3.1. Measurements of *E. coli* and total coliforms

The microbiological analysis of *E. coli* and total coliforms was executed at IGS using the IDEXX (Colilert 18) Quanti-Tray^{TM} method. This is a biotechnological detection approach which uses the most probable number (MPN) method. It integrates a defined substrate medium which contains O-nitrophenyl-β-D-galactopyranoside (ONPG) and 4-methylumbelliferyl-β-D-glucuronide (MUG). Total coliform produces a yellow colour caused by the production of β-galactosidase and *E. coli* uses the enzyme called β-glucuronidase to metabolise MUG and produce blue fluorescence. Samples are incubated at 37^{o}C for 18-22 hours. The number of positive wells helps to calculate the MPN.

The IDEXX (Colilert 18) Quanti-Tray^{TM} method was executed at IGS in the following way:

1. 100ml Water samples from the sampling sites were prepared and used for microbiological tests.

2. The Colilert 18 reagent was added to 100ml of the sample water. To allow the reagent to dissolve, the sample was shaken properly and was left to stand for few minutes.

3. 97 well Colilert 18 Quanti-Tray™ 2000 was selected for treated water and it was labelled with the date and sample number.

4. The 100ml water sample solution was poured into the Colilert Quanti-Tray™ 2000 and sealed in the pre-warmer sealer.

5. After the pre-warmer sealer, the Colilert Quanti Tray^{TM} was incubated at 37°C for 22 hours

6. After 22 hours, the Colilert Quanti Tray^{TM} was removed from the incubator and was analysed. The number of yellow-coloured wells was counted to quantify total coliforms, while the number of the fluorescent blue coloured wells was used to quantify *E. coli* with the help of the UV.

3.5. Calculation of Water Quality Index

The Canadian Council of Ministers of the Environmental Water Quality Index (CCME-WQI) was calculated to offer a convenient method for summarising the measurements of various water quality parameters used to assess the drinking water quality of Mohokare Local Municipality. CCME-WQI calculation consists of three measures of variance from selected water quality objectives which are: scope (F1), frequency (F2) and amplitude (F3). F1 represents the number of parameters not meeting water quality guidelines; F2 represents the number of times these guidelines were not met; and F3 represents the amount by which the guidelines were not met. These three factors combine to produce a value between 0 and 100 that represents the overall water quality (CCME, 2001). Below are the formulas used to calculate CCME- WQI:

1. Calculation of the scope F1, which represents the number of parameters that exceeded the standard limit:

$$F_1 = \left(\frac{Number\ of\ failed\ parameters}{Total\ number\ of\ parameters}\right) \times 100 \qquad (1)$$

2. Calculation of the frequency F2, which represents the percentage of measurements that exceeded the standard limit:

$$F_2 = \left(\frac{Number\ of\ failed\ measurements}{Total\ number\ of\ measurements}\right) \times 100 \qquad (2)$$

3. Calculation of the amplitude F3, which measures the extent by which failed test values exceed the guideline:

   a. An excursion for each failed measurement is calculated in the following manner:

      - Where the measurement must not exceed the guideline

$$Excursion_i = \left(\frac{Failed\ measurements}{Limit\ of\ property}\right) - 1 \tag{3}$$

      - Where the measurement must not fall below the guideline

$$Excursion_i = \left(\frac{Limit\ of\ property}{Failed\ measurement}\right) - 1 \tag{4}$$

   b. The normalised sum of excursion (nse) is calculated as follows:

$$nse = \frac{\sum_{i=1}^{n} Excursion\ i}{\sum_{i=1}^{m} Measurements\ i} \tag{5}$$

   c. Calculation of F3, which represents the amplitude:

$$F_3 = \left(\frac{nse}{0.01nse + 0.01}\right) \tag{6}$$

After the above 3 elements were obtained, the CCME-WQI was then calculated in the following manner:

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

The CCME-WQI value was then calculated. The values were then converted into rankings by using the index categorization schema presented in Table 3.4 below.

Table 3.4. CCME WQI categorisation schema

Rank	WQI Value	Description
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels; these index values can only be obtained if all measurements are within objectives virtually all of the time
Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels
Poor	0-44	Water quality is almost always threatened or impaired; conditions usually depart from natural or desirable levels

Chapter 4

Drinking Water Quality Results

4.1. Introduction

The study was conducted to profile the quality of drinking water at Rouxville (RX), Smithfield (SM) and Zastron (ZN) in Mohokare Local Municipality in the Free State. The sites analysed in RX, SM and ZN included various locations (See Figures 3.2 to 3.4). The drinking water quality of the identified sites in RX, SM and ZN was analysed in terms of chemical, microbiological and physical parameters. The chemical parameters that were analysed included Total Alkalinity (TA), nitrite, nitrate, sulphate, aluminium and Total Organic Carbon (TOC). The microbiological parameters that were analysed included Total Coliform (TC) and *Escherichia coli* (*E. coli*). The physical parameter analysed was colour.

The drinking water quality data was compared with drinking water quality standards set by the South African National Standards (SANS) 241 for drinking water. The data was statistically analysed using analysis of variance (ANOVA), followed by Tukey HSD Post Hoc test. ANOVA was performed on the data to assess whether there were any differences in drinking water quality across the three sampling years. Tukey HSD Post Hoc test was then conducted following a significant result to determine specific differences between the years. Water Quality Index (WQI) was also calculated to determine the drinking water quality of the Mohokare Local Municipality (see Table 4.20 for results).

4.2. Chemical drinking water quality

The chemical parameters that were analysed included TA, fluoride, nitrite, nitrate, sulphate, aluminium and TOC. These parameters were compared to the SANS 241 (2015) standards. To summarise and analyse the data, descriptive statistics were calculated over the three sampling years.

4.2.1 Total Alkalinity

During the three sampling years, Year 1 was compliant with no values exceeding the recommended limit (≤ 200mg/L). The highest TA value of 274.14 mg/L was recorded at RX5 in Year 3 (Table 4.1). The lowest TA value was recorded at RX2 in Year 3 (Table 4.1).

Poor overall compliance performance of the sampling sites in SM was a concern, with SM1, SM2, SM3 and SM4 not being compliant in year 3 and SM4 the least compliant of all sampling sites.

Table 4.1 Total Alkalinity statistical summary (Year 1 – Year 3)

	Year 1 Total Alkalinity (Limit ≤ 200 mg/L)				Year 2 Total Alkalinity (Limit ≤ 200mg/L)				Year 3 Total Alkalinity (Limit ≤ 200 mg/L)				Compliance
Sample site	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	C 0verall (%)
RX1	68,26	151,5	94,24	38,50	54,04	165,94	77,31	28,02	98,36	112,01	105,28	4,57	100,00
RX2	59,75	79,21	72,49	7,85	52,05	83,65	67,84	8,07	5,00	197,51	114,72	35,12	100,00
RX3	61,19	80,98	72,96	8,33	52,64	81,64	67,54	8,20	97,20	107,70	105,21	3,95	100,00
RX4	67,42	79,27	75,40	5,39	51,46	84,45	67,80	8,76	100,50	219,75	119,83	40,51	96,00
RX5	59,66	81,19	72,31	8,30	51,20	82,41	67,46	8,91	101,06	274,14	126,48	59,75	96,00
SM1	174,20	181,76	179,95	3,92	162,41	244,12	179,07	21,16	164,99	203,08	189,66	12,24	93,00
SM2	173,71	186,50	180,53	5,31	83,25	197,70	166,48	52,56	122,66	200,38	184,85	26,02	96,00
SM3	162,45	185,66	177,40	8,91	84,15	202,48	168,20	27,66	179,92	207,78	192,84	8,66	93,00
SM4	162,71	184,94	176,68	8,52	69,34	222,32	159,55	42,61	184,30	266,94	202,55	26,77	89,00
SM5	68,57	183,58	155,47	49,41	83,28	224,60	167,73	30,82	170,08	199,52	190,19	9,70	97,00
ZN1	98,23	112,33	108,22	5,93	69,26	182,03	96,48	28,81	97,78	113,31	106,41	5,05	100,00
ZN2	79,15	113,15	102,02	15,46	71,80	115,94	93,17	13,07	76,39	120,34	106,81	13,15	100,00
ZN3	106,4	180,57	127,58	35,41	70,43	114,68	90,47	13,56	99,50	119,55	109,38	7,21	100,00
ZN4	78,56	110,60	94,40	17,14	68,36	113,96	89,60	13,55	101,93	113,57	107,66	4,30	100,00

Min = minimum; Max = maximum; SD = Standard Deviation; C overall (%) = Compliance overall percentage; RX1 = Rouxville Water Treatment Plant; RX2 = Rouxville Municipality; RX3 = NG Kerk Rouxville; RX4 = Rouxville Police Station; RX5 = Roleleathunya Library; SM1 = Smithfield Water Treatment Plant; SM2 =Mohokare Local Municipality; SM3 =

Distrubution Network (Fire Hydrant); SM4 = Thembalethu Clinic; SM5 = Stoffel Coetzee District Hospital; ZN1 = Zastron Water Treatment Works; ZN2 = Mohokare Local Municipality; ZN3 = Distribution Network (Fire Hydrant); ZN4 = Matlakeng Clinic

4.2.2. Fluoride

All fluoride values over the three sampling years complied with the recommended limit (≤ 1.5 mg/L) outlined by the SANS 241 (2015). The highest Fluoride value of 0.65 mg/L was recorded at SM5 in Year 2 (Table 4.2). The values for ZN1 to ZN4 for Year 1 and Year 2 showed zero.

Table 4.2 Fluoride statistical summary (Year 1 – Year 3)

	Year 1 Fluoride (Limit ≤ 1.5 mg/L)				Year 2 Fluoride (Limit ≤ 1.5 mg/L)				Year 3 Fluoride (Limit ≤ 1.5 mg/L)				Compliance
Sample site	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	C Overall (%)
RX1	0,22	0,37	0,30	0,07	0,00	0,47	0,18	0,12	0,00	0,32	0,19	0,09	100
RX2	0,23	0,33	0,28	0,05	0,00	0,33	0,16	0,12	0,00	0,39	0,16	0,13	100
RX3	0,18	0.36	0,28	0,09	0,11	0,33	0,18	0,06	0,06	0,25	0,17	0,07	100
RX4	0,22	0,34	0,26	0,05	0,00	0,29	0,13	0,10	0,00	0,3	0,17	0,09	100
RX5	0,23	0,36	0,29	0,05	0,10	0,29	0,16	0,06	0,00	0,47	0,20	0,13	100
SM1	0,41	0,53	0,48	0,05	0,33	0,57	0,44	0,07	0,39	0,53	0,45	0,06	100
SM2	0,29	0,57	0,45	0,11	0,11	0,55	0,42	0,11	0,21	0,5	0,39	0,10	100
SM3	0,4	0,53	0,44	0,06	0,23	0,55	0,43	0,08	0,29	0,56	0,43	0,11	100

SM4	0,43	0,54	0,47	0,05	0,25	0,58	0,37	0,10	0,37	0,46	0,40	0,03	100
SM5	0,3	0,54	0,44	0,10	0,00	0,65	0,41	0,16	0,24	0,6	0,44	0,11	100
ZN1	0,18	0,33	0,27	0,06	0,00	0,51	0,22	0,12	0,00	0,21	0,14	0,09	100
ZN2	0,2	0,29	0,26	0,04	0,00	0,31	0,17	0,09	0,00	0,23	0,15	0,07	100
ZN3	0,17	0,47	0,29	0,11	0,00	0,31	0,16	0,09	0,00	0,21	0,12	0,08	100
ZN4	0,19	0,36	0,27	0,07	0,00	0,38	0,18	0,11	0,00	0,24	0,09	0,08	100

Min = minimum; Max = maximum; SD = Standard Deviation; C overall (%) = Compliance overall percentage; RX1 = Rouxville Water Treatment Plant; RX2 = Rouxville Municipality; RX3 = NG Kerk Rouxville; RX4 = Rouxville Police Station; RX5 = Roleleathunya Library; SM1 = Smithfield Water Treatment Plant; SM2 =Mohokare Local Municipality; SM3 = Distrubution Network (Fire Hydrant); SM4 = Thembalethu Clinic; SM5 = Stoffel Coetzee District Hospital; ZN1 = Zastron Water Treatment Works; ZN2 = Mohokare Local Municipality; ZN3 = Distribution Network (Fire Hydrant); ZN4 = Matlakeng Clinic

4.2.3. Nitrite

All nitrite values over the three sampling years complied with the recommended limit (≤ 0.9 mg/L) outlined by the SANS 241 (2015). The highest Nitrite value of 0.10 mg/L was recorded at multiple sample sites in Year 2 (Table 4.3).

Table 4.3 Nitrite statistical summary (Year 1 – Year 3)

	Year 1 Nitrite (Limit ≤ 0.9 mg/L)				Year 2 Nitrite (Limit ≤ 0.9 mg/L)				Year 3 Nitrite (Limit ≤ 0.9 mg/L)				Compliance
Sample site	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	C Overall (%)
RX1	0,00	0,10	0,01	0,01	0,01	0,03	0,02	0,01	0,00	0,04	0,02	0,01	100

RX2	0,00	0,02	0,01	0,01	0,01	0,03	0,02	0,01	0,01	0,03	0,02	0,01	100
RX3	0,00	0,02	0,01	0,01	0,00	0,03	0,02	0,01	0,01	0,04	0,02	0,01	100
RX4	0,00	0,02	0,01	0,01	0,01	0,03	0,02	0,01	0,01	0,05	0,03	0,01	100
RX5	0,00	0,03	0,01	0,01	0,01	0,03	0,02	0,01	0,01	0,04	0,02	0,01	100
SM1	0,00	0,02	0,05	0,01	0,01	0,04	0,02	0,01	0,01	0,03	0,02	0,01	100
SM2	0,00	0,10	0,01	0,01	0,01	0,03	0,02	0,01	0,01	0,04	0,02	0,01	100
SM3	0,00	0,10	0,01	0,01	0,01	0,03	0,02	0,01	0,01	0,04	0,02	0,01	100
SM4	0,00	0,10	0,01	0,01	0,00	0,03	0,02	0,01	0,01	0,05	0,02	0,01	100
SM5	0,00	0,10	0,01	0,01	0,00	0,05	0,02	0,01	0,01	0,04	0,02	0,01	100
ZN1	0,00	0,10	0,01	0,01	0,00	0,03	0,02	0,01	0,02	0,05	0,02	0,01	100
ZN2	0,00	0,10	0,01	0,01	0,00	0,03	0,02	0,01	0,00	0,04	0,02	0,01	100
ZN3	0,00	0,10	0,01	0,01	0,00	0,03	0,02	0,01	0,00	0,05	0,02	0,01	100
ZN4	0,00	0,10	0,01	0,01	0,01	0,03	0,02	0,01	0,00	0,04	0,02	0,01	100

Min = minimum; Max = maximum; SD = Standard Deviation; C overall (%) = Compliance overall percentage; RX1 = Rouxville Water Treatment Plant; RX2 = Rouxville Municipality; RX3 = NG Kerk Rouxville; RX4 = Rouxville Police Station; RX5 = Roleleathunya Library; SM1 = Smithfield Water Treatment Plant; SM2 =Mohokare Local Municipality; SM3 = Distrubution Network (Fire Hydrant); SM4 = Thembalethu Clinic; SM5 = Stoffel Coetzee District Hospital; ZN1 = Zastron Water Treatment Works; ZN2 = Mohokare Local Municipality; ZN3 = Distribution Network (Fire Hydrant); ZN4 = Matlakeng Clinic

4.2.4. Nitrate

All nitrate values over the three sampling years complied with the recommended limit (≤ 11 mg/L) outlined by the SANS 241 (2015). The highest Nitrate value of 4.61 mg/L was recorded at SM3 in Year 2 (Table 4.4). SM1 to SM5 and RX5 recorded the lowest value of zero in Year 2 (Table 4.4).

Table 4.4 Nitrate statistical summary (Year 1 – Year 3)

	Year 1 Nitrate (Limit ≤ 11 mg/L)				Year 2 Nitrate (Limit ≤ 11 mg/L)				Year 3 Nitrate (Limit ≤ 11 mg/L)				Compliance
Sample site	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	C Overall (%)
RX1	0,41	0,51	0,47	0,04	0,19	0,57	0,37	0,13	0,39	0,76	0,53	0,13	100
RX2	0,42	0,54	0,46	0,05	0,20	0,58	0,38	0,13	0,43	0,73	0,56	0,12	100
RX3	0,42	0,51	0,46	0,04	0,19	0,55	0,37	0,12	0,43	0,68	0,52	0,09	100
RX4	0,42	0,5	0,45	0,03	0,18	0,55	0,37	0,13	0,4	0,8	0,54	0,13	100
RX5	0,42	0,5	0,45	0,03	0,00	0,55	0,35	0,16	0,43	0,77	0,58	0,13	100
SM1	0,2	0,34	0,28	0,06	0,00	0,51	0,32	0,17	0,39	0,76	0,53	0,14	100
SM2	0,2	0,33	0,28	0,05	0,00	0,57	0,36	0,15	0,42	0,67	0,52	0,11	100
SM3	0,23	0,31	0,28	0,04	0,00	4,61	0,68	1,19	0,38	0,76	0,51	0,15	100
SM4	0,21	0,3	0,26	0,04	0,00	0,53	0,36	0,14	0,42	0,73	0,58	0,12	100
SM5	0,25	0,46	0,32	0,08	0,00	0,6	0,37	0,16	0,39	0,89	0,57	0,17	100
ZN1	0,43	0,53	0,51	0,04	0,19	0,62	0,37	0,12	0,48	0,58	0,54	0,03	100
ZN2	0,4	0,54	0,49	0,06	0,24	0,59	0,36	0,11	0,00	0,6	0,39	0,23	100
ZN3	0,23	0,54	0,41	0,14	0,22	0,6	0,37	0,10	0,45	0,57	0,52	0,04	100
ZN4	0,42	0,58	0,49	0,07	0,24	0,6	0,37	0,10	0,39	0,66	0,50	0,10	100

Min = minimum; Max = maximum; SD = Standard Deviation; C overall (%) = Compliance overall percentage; RX1 = Rouxville Water Treatment Plant; RX2 = Rouxville Municipality; RX3 = NG Kerk Rouxville; RX4 = Rouxville Police Station; RX5 = Roleleathunya Library; SM1 = Smithfield Water Treatment Plant; SM2 =Mohokare Local Municipality; SM3 = Distrubution Network (Fire Hydrant); SM4 = Thembalethu Clinic; SM5 = Stoffel Coetzee District Hospital; ZN1 = Zastron Water Treatment Works; ZN2 = Mohokare Local Municipality; ZN3 = Distribution Network (Fire Hydrant); ZN4 = Matlakeng Clinic

4.2.5. Sulphate

All sulphate values over the three sampling years were compliant (≤ 500 mg/L limit) when compared to SANS 241 (2015). The highest Sulphate value of 28.07 mg/L was recorded at SM3 in Year 2 (Table 4.5). The lowest value was recorded at ZN4 in Year 3 (Table 4.5).

Table 4.5 Sulphate statistical summary (Year 1 – Year 3)

	Year 1 Sulphate (Limit ≤ 500 mg/L)				Year 2 Sulphate (Limit ≤ 500 mg/L)				Year 3 Sulphate (Limit ≤ 500 mg/L)				Compliance
Sample site	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	C Overall (%)
RX1	9,00	11.88	10,00	1,35	4,00	11,95	7,95	2,46	9,47	12,7	11,04	1,22	100
RX2	8,00	10,50	9,33	0,96	4,00	12,17	7,58	2,46	6,39	18,06	11,39	3,34	100
RX3	9,00	10,67	9,57	0,74	4,00	11,93	7,67	2,53	8,83	12,5	10,82	1,22	100
RX4	9,00	11,00	9,75	0,89	4,00	12,00	7,56	2,44	10,01	15,23	11,60	1,72	100
RX5	9,00	11,00	9,75	0,98	4,00	16,00	8,10	3,44	8,5	18,72	11,85	2,98	100
SM1	10,00	15,76	12,38	2,55	8,00	19,37	12,40	3,97	15,44	21,03	18,26	1,75	100
SM2	10,00	15,74	10,38	2,55	8,00	19,21	12,50	3,77	12,57	19,66	17,62	2,19	100

SM3	10,00	15,56	12,31	2,46	8,00	28,07	15,88	6,56	17,39	20,82	18,51	1,19	100
SM4	10,00	15,55	12,48	2,44	6,08	20,13	12,00	4,16	17,22	21,11	19,04	1,51	100
SM5	10,00	13,81	11,35	1,60	7,00	19,22	12,54	4,00	17,1	20,65	18,63	1,36	100
ZN1	9,00	13,18	10,75	1,78	6,00	20,77	8,80	3,78	7,14	10,61	8,79	1,07	100
ZN2	8,00	13,02	10,52	2,01	6,00	11,50	8,29	1,50	5,78	9,96	8,60	1,55	100
ZN3	9,00	13,40	10,96	1,65	6,00	12,81	8,35	1,54	7,05	10,02	8,57	1,07	100
ZN4	9,00	13,21	10,72	1,78	6,00	12,81	8,35	1,71	3,45	10,16	8,33	2,10	100

Min = minimum; Max = maximum; SD = Standard Deviation; C overall (%) = Compliance overall percentage; RX1 = Rouxville Water Treatment Plant; RX2 = Rouxville Municipality; RX3 = NG Kerk Rouxville; RX4 = Rouxville Police Station; RX5 = Roleleathunya Library; SM1 = Smithfield Water Treatment Plant; SM2 =Mohokare Local Municipality; SM3 = Distrubution Network (Fire Hydrant); SM4 = Thembalethu Clinic; SM5 = Stoffel Coetzee District Hospital; ZN1 = Zastron Water Treatment Works; ZN2 = Mohokare Local Municipality; ZN3 = Distribution Network (Fire Hydrant); ZN4 = Matlakeng Clinic

4.2.6. Aluminium

During the three sampling years, none of the sample sites in SM for Year 2 complied with the recommended limit (≤ 0.3 mg/L) outlined by SANS 241 (2015) (2015), with all measurement values exceeding the recommended limit. The highest recorded value for aluminium was 1.07 mg/L at ZN1 for Year 2 (Table 4.6). Three out of five sample sites in Rouxville (RX) and three out of four sample sites in Zastron (ZN) for year 3 did not comply with the recommended limit outlined by SANS 241 (2015). Poor overall compliance performance at ZN1 was a major concern (Table 4.6).

Table 4.6 Aluminium statistical summary (Year 1 – Year 3)

	Year 1 Aluminium (Limit ≤ 0.3 mg/L)				Year 2 Aluminium (Limit ≤ 0.3 mg/L)				Year 3 Aluminium (Limit ≤ 0.3 mg/L)				Compliance
Sample site	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	C Overall (%)
RX1	0,00	0,03	0,01	0,01	0,00	0,12	0,03	0,04	0,0	0,07	0,04	0,02	100,00
RX2	0,00	0,00	0,00	0,00	0,00	0,15	0,03	0,04	0,02	0,91	0,14	0,31	96,00
RX3	0,00	0,03	0,01	0,01	0,00	0,07	0,02	0,03	0,00	0,08	0,04	0,03	100,00
RX4	0,00	0,00	0,00	0,00	0,00	0,11	0,02	0,04	0,00	0,82	0,12	0,28	96,00
RX5	0,00	0,03	0,01	0,01	0,00	0,08	0,02	0,03	0,00	0,66	0,10	0,22	96,00
SM1	0,00	0,00	0,00	0,00	0,00	0,92	0,12	0,25	0,00	0,11	0,05	0,04	97,00
SM2	0,00	0,00	0,00	0,00	0,00	0,45	0,07	0,12	0,00	0,09	0,04	0,03	97,00
SM3	0,00	0,00	0,00	0,00	0,00	0,70	0,10	0,19	0,00	0,10	0,04	0,04	97,00
SM4	0,00	0,00	0,00	0,00	0,00	0,73	0,10	0,21	0,00	0,08	0,04	0,03	97,00
SM5	0,00	0,03	0,01	0,01	0,00	0,49	0,09	0,14	0,00	0,11	0,04	0,04	97,00
ZN1	0,00	0,00	0,00	0,00	0,00	1,07	0,09	0,29	0,00	0,57	0,09	0,20	93,00
ZN2	0,00	0,00	0,00	0,00	0,00	0,05	0,01	0,02	0,00	0,41	0,07	0,14	96,00
ZN3	0,00	0,00	0,00	0,00	0,00	0,08	0,02	0,03	0,00	0,64	0,10	0,22	96,00
ZN4	0,00	0,00	0,00	0,00	0,00	0,07	0,02	0,03	0,00	0,06	0,02	0,02	100,00

Min = minimum; Max = maximum; SD = Standard Deviation; C overall (%) = Compliance overall percentage; RX1 = Rouxville Water Treatment Plant; RX2 = Rouxville Municipality; RX3 = NG Kerk Rouxville; RX4 = Rouxville Police Station; RX5 = Roleleathunya Library; SM1 = Smithfield Water Treatment Plant; SM2 =Mohokare Local Municipality; SM3 =

Distrubution Network (Fire Hydrant); SM4 = Thembalethu Clinic; SM5 = Stoffel Coetzee District Hospital; ZN1 = Zastron Water Treatment Works; ZN2 = Mohokare Local Municipality; ZN3 = Distribution Network (Fire Hydrant); ZN4 = Matlakeng Clinic

4.2.7. Total Organic Carbon (TOC)

TOC values for Year 1 and Year 3 did not exceed the recommended limit (≤ 10 mg/L) outlined by the SANS 241 (2015). The highest TOC value of 13.94 mg/L was recorded at SM2 in Year 2 (Table 4.7), which exceeded the recommended limit outlined by SANS 241 (2015). The lowest value was recorded at RX2 in Year 3 (Table 4.7).

Table 4.7 TOC statistical summary (Year 1 – Year 3)

	Year 1 TOC (Limit ≤ 10 mg/L)				Year 2 TOC (Limit ≤ 10 mg/L)				Year 3 TOC (Limit ≤ 10 mg/L)				Compliance
Sample site	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	C Overall (%)
RX1	5,91	7,74	5,71	0,84	5,55	9,14	6,82	1,06	6,49	8,66	7,54	0,75	100
RX2	5,57	7,25	6,80	0,71	5,25	8,33	6,60	0,88	2,34	7,93	6,69	1,82	100
RX3	5,81	7,95	6,91	0,84	4,75	8,32	6,41	0,90	6,33	8,58	7,49	0,81	100
RX4	6,4	8,42	7,19	0,89	5,16	8,16	6,55	0,84	6,62	8,01	7,45	0,45	100
RX5	5,49	8,37	6,98	1,02	4,60	8,75	6,43	1,02	5,5	8,38	7,19	0,87	100
SM1	7,13	9,09	8,28	0,78	6,32	9,74	7,95	0,98	7,3	8,94	8,15	0,54	100
SM2	6,92	9,34	7,99	0,92	5,93	13,94	7,78	1,97	6,62	8,11	7,71	0,70	97

SM3	6,67	9,25	8,12	1,03	6,40	8,95	7,93	0,75	6,49	9,2	8,19	0,78	100
SM4	7,18	9,35	8,29	0,91	6,12	8,95	7,78	0,94	5,88	9,65	7,94	1,23	100
SM5	6,02	9,05	7,80	1,23	6,37	9,17	7,79	0,83	7,04	8,56	7,82	1,24	100
ZN1	4,69	7,14	5,76	1,07	4,62	8,94	6,15	1,14	4,64	6,27	5,43	0,52	100
ZN2	4,84	7,57	6,09	1,27	4,30	8,12	5,86	1,10	2,74	7,8	5,33	1,58	100
ZN3	4,75	9,51	6,50	1,96	4,59	7,77	5,88	1,02	4,3	6,09	4,99	0,69	100
ZN4	4,91	7,93	6,33	1,18	4,50	7,65	5,82	0,94	4,25	8,38	1,28	1,28	100

Min = minimum; Max = maximum; SD = Standard Deviation; C overall (%) = Compliance overall percentage; RX1 = Rouxville Water Treatment Plant; RX2 = Rouxville Municipality; RX3 = NG Kerk Rouxville; RX4 = Rouxville Police Station; RX5 = Roleleathunya Library; SM1 = Smithfield Water Treatment Plant; SM2 =Mohokare Local Municipality; SM3 = Distrubution Network (Fire Hydrant); SM4 = Thembalethu Clinic; SM5 = Stoffel Coetzee District Hospital; ZN1 = Zastron Water Treatment Works; ZN2 = Mohokare Local Municipality; ZN3 = Distribution Network (Fire Hydrant); ZN4 = Matlakeng Clinic

4.3. Microbiological drinking water quality

The microbiological parameters that were analysed included Total Coliform (TC) and *E. coli*. These parameters were compared to the SANS 241 (2015) standards. To summarise and analyse the data, descriptive statistics were calculated over the three sampling years.

4.3.1. Total coliform

During the three sampling years, certain values exceeded the recommended SANS 241 (2015) limit (≤ 10 CFU) in each year. No single year achieved full compliance with the recommended TC limit. The highest recorded value of 201 CFU was observed at multiple sample sites. However, SM2-SM5 exhibited a consistent recording of 201 CFU for both Year 2 and Year 3 (Table 4.8). Poor overall compliance performance of SM4 was a major concern. The overall compliance for all the sample sites was also a compliance issue.

Table 4.8 Total coliform statistical summary (Year 1 – Year 3)

	Year 1 Total coliform (Limit ≤ 10 CFU)				Year 2 Total coliform (Limit ≤ 10 CFU)				Year 3 Total coliform (Limit ≤ 10 CFU)				Compliance
Sample site	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	C Overall (%)
RX1	0,00	1,00	0,20	0,45	0,00	25,00	2,00	6,92	0,00	201,00	32,88	70,64	89,00
RX2	0,00	6,00	1,40	2,61	0,00	19,00	2,38	5,22	0,00	59,00	14,25	21,21	89,00
RX3	0,00	3,00	1,00	1,41	0,00	62,00	6,00	16,97	0,00	83,00	21,63	27,77	77,00
RX4	0,00	2,00	0,40	0,89	0,00	38,00	3,77	10,43	0,00	145,00	26,25	50,65	85,00
RX5	0,00	0,00	0,00	0,00	0,00	11,00	2,85	4,69	0,00	83,00	22,13	29,24	76,00
SM1	0,00	12,00	2,40	5,37	0,00	34,00	4,95	9,40	0,00	48,00	6,13	16,92	87,00
SM2	0,00	201,00	41,40	89,26	0,00	201,00	32,85	74,73	0,00	201,00	34,00	69,28	73,00
SM3	0,00	36,00	7,40	15,99	0,00	201,00	31,31	75,32	0,00	201,00	25,25	71,01	84,00
SM4	0,00	34,00	6,80	15,21	0,00	201,00	46,31	81,92	0,00	201,00	72,00	83,45	58,00
SM5	0,00	201,00	40,20	89,89	0,00	201,00	39,31	75,70	0,00	201,00	33,50	69,57	73,00
ZN1	0,00	4,00	1,20	1,79	0,00	201,00	15,62	55,70	0,00	1,00	0,13	0,35	97,00
ZN2	0,00	5,00	1,60	2,30	0,00	1,00	0,23	0,44	0,00	12,00	2,88	5,06	96,00

ZN3	0,00	3,00	1,20	1,64	0,00	1,00	0,23	0,44	0,00	201,00	27,38	70,37	92,00
ZN4	0,00	12,00	2,40	5,37	0,00	70,00	5,62	19,36	0,00	101,00	20,13	35,11	82,00

Min = minimum; Max = maximum; SD = Standard Deviation; C overall (%) = Compliance overall percentage; RX1 = Rouxville Water Treatment Plant; RX2 = Rouxville Municipality; RX3 = NG Kerk Rouxville; RX4 = Rouxville Police Station; RX5 = Roleleathunya Library; SM1 = Smithfield Water Treatment Plant; SM2 =Mohokare Local Municipality; SM3 = Distrubution Network (Fire Hydrant); SM4 = Thembalethu Clinic; SM5 = Stoffel Coetzee District Hospital; ZN1 = Zastron Water Treatment Works; ZN2 = Mohokare Local Municipality; ZN3 = Distribution Network (Fire Hydrant); ZN4 = Matlakeng Clinic

4.3.2. *E. coli*

During the three sampling years, only four sampling sites achieved 100% compliance when compared to SANS 241 (2015). The highest number of *E. coli* non-compliances occurred in the third year of monitoring, with Rouxville (n=4) contributing the most, followed by Zastron (n=2) (Table 4.9). The highest value of 165 CFU was recorded at ZN3 in Year 3 (Table 4.9), which exceeded the recommended limit (0 CFU) outlined by SANS 241 (2015). The poor overall compliance performance of four out of five sample sites in RX was a key compliance issue.

Table 4.9 E. coli statistical summary (Year 1 – Year 3)

	Year 1 *E. coli* (Limit = 0 CFU)				Year 2 *E. coli* (Limit = 0 CFU)				Year 3 *E. coli* (Limit = 0 CFU)				Compliance
Sample site	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	C Overall (%)
RX1	0,00	1,00	0,20	0,45	0,00	0,00	0,00	0,00	0,00	9,00	1,38	3,11	81,00
RX2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00

RX3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	0,63	0,92	87,00
RX4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	11,00	1,75	3,77	83,00
RX5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,13	0,35	96,00
SM1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00
SM2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00
SM3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,00	0,13	0,35	96,00
SM4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00
SM5	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00
ZN1	0,00	0,00	0,00	0,00	0,00	1,00	0,08	0,28	0,00	0,00	0,00	0,00	97,00
ZN2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	100,00
ZN3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	165,0	20,63	58,34	96,00
ZN4	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,00	0,25	0,71	96,00

Min = minimum; Max = maximum; SD = Standard Deviation; C overall (%) = Compliance overall percentage; RX1 = Rouxville Water Treatment Plant; RX2 = Rouxville Municipality; RX3 = NG Kerk Rouxville; RX4 = Rouxville Police Station; RX5 = Roleleathunya Library; SM1 = Smithfield Water Treatment Plant; SM2 =Mohokare Local Municipality; SM3 = Distrubution Network (Fire Hydrant); SM4 = Thembalethu Clinic; SM5 = Stoffel Coetzee District Hospital; ZN1 = Zastron Water Treatment Works; ZN2 = Mohokare Local Municipality; ZN3 = Distribution Network (Fire Hydrant); ZN4 = Matlakeng Clinic

4.4. Physical drinking water quality

The physical parameter that was analysed was colour. This parameter was compared to the SANS 241 (2015) standards. To summarise and analyse the data, descriptive statistics were calculated over the three sampling years.

4.4.1. Colour

During the three sampling years, all sampling sites in Year 2 recorded non-compliance values, with multiple values in Year 1 and Year 3 exceeding the recommended SANS 241 (2015). No single year achieved full compliance with the recommended colour limit (≤15 Pt-Co mg/L). The highest recorded value of 143 mg/L Pt-Co was recorded at ZN2 in Year 2 (Table 4.10). Poor overall compliance performance of all the sample sites except for ZN1 was a key compliance issue.

Table 4.10 Colour statistical summary (Year 1 – Year 3)

	Year 1 Colour (Limit ≤ 15 Pt-Co mg/L)				Year 2 Colour (Limit ≤15 Pt-Co mg/L)				Year 3 Colour (Limit ≤ 15 Pt-Co mg/L)				Compliance
Sample site	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	C Overall (%)
RX1	2,00	21,00	10,40	7,67	4,00	25,00	13,23	6,88	4,00	22,00	11,50	5,50	79,00
RX2	6,00	26,00	12,80	7,98	7,00	133,00	30,08	35,23	3,00	29,00	12,13	7,75	71,00
RX3	6,00	19,00	9,60	5,41	3,00	90,00	21,77	23,43	4,00	23,00	11,00	6,05	79,00
RX4	6,00	22,00	12,80	6,06	7,00	106,00	28,46	27,91	6,00	28,00	13,38	6,80	64,00
RX5	5,00	20,00	8,33	6,95	3,00	59,00	20,62	18,11	5,00	26,00	12,38	6,44	74,00
SM1	6,00	19,00	12,00	4,74	5,00	22,00	13,00	4,83	4,00	32,00	12,71	9,02	75,00
SM2	6,00	13,00	8,80	3,42	4,00	22,00	8,77	4,60	4,00	21,00	9,88	6,96	89,00
SM3	5,00	10,00	8,60	2,30	6,00	42,00	17,77	10,97	4,00	33,00	18,13	10,55	72,00
SM4	7,00	12,00	9,40	1,95	5,00	62,00	19,08	15,85	6,00	65,00	19,88	19,42	72,00

SM5	6,00	19,00	11,40	4,93	7,00	27,00	12,54	6,59	4,00	23,00	12,38	6,25	71,00
ZN1	1,00	5,00	3,40	1,67	2,00	18,00	7,92	4,55	1,00	12,00	4,38	3,50	97,00
ZN2	3,00	10,00	6,60	2,70	2,00	143,00	18,77	37,73	3,00	28,00	12,00	10,24	80,00
ZN3	3,00	11,00	7,60	3,13	2,00	35,00	12,85	8,73	0,00	11,00	4,75	3,58	90,00
ZN4	4,00	10,00	6,20	2,28	4,00	20,00	10,00	4,85	2,00	17,00	10,75	5,65	87,00

Min = minimum; Max = maximum; SD = Standard Deviation; C overall (%) = Compliance overall percentage; RX1 = Rouxville Water Treatment Plant; RX2 = Rouxville Municipality; RX3 = NG Kerk Rouxville; RX4 = Rouxville Police Station; RX5 = Roleleathunya Library; SM1 = Smithfield Water Treatment Plant; SM2 =Mohokare Local Municipality; SM3 = Distrubution Network (Fire Hydrant); SM4 = Thembalethu Clinic; SM5 = Stoffel Coetzee District Hospital; ZN1 = Zastron Water Treatment Works; ZN2 = Mohokare Local Municipality; ZN3 = Distribution Network (Fire Hydrant); ZN4 = Matlakeng Clinic

4.5. Comparison of drinking water quality measurements over the three years

ANOVA test was conducted to determine whether there were significant differences in water quality across multiple sample sites over three years. The study included five sample sites from RX and SM and 4 sample sites from ZN that were analysed collectively as RX, SM, and ZN, respectively, and classified as sampling site groups. If ANOVA revealed significant differences among the years, a Tukey HSD Post Hoc test was performed to identify which years significantly differed from each other. The significance level was set at $\alpha = 0.05$.

The ANOVA test revealed no significant differences for Colour, and it was therefore not reported on separately. ANOVA test was also not performed on the *E. coli* because of the presence of multiple zero values.

4.5.1. Total alkalinity

ANOVA test revealed that sample sites in Rouxville and Smithfield indicated significant differences, while no significant differences were observed in Zastron. Further analysis using Tukey HSD Post Hoc test revealed that the differences were recorded between Year 1 and Year 3 and between Year 2 and Year 3 (Table 4.11).

Table 4.11 Statistical comparison of Total alkalinity (Year 1 – Year 3)

	SS	Df	MS	F	P-value	F crit	Significant years
Rouxville	5696,276	2	2848,138	38,52912	7,83E-05	4,45897	Y1-Y3, Y2-Y3
Smithfield	1541,617	2	770,8085	10,65027	0,005557	4,45897	Y1-Y3, Y2-Y3
Zastron	631,1477	2	315,5738	4,638472	0,060582	5,143253	NS

SS = sum of squares; df = degrees of freedom; MS = mean square; Y1 = Year 1; Y2 = Year 2; Y3 = Year 3

4.5.2. Fluoride

ANOVA test revealed that sample sites in Rouxville, Smithfield and Zastron indicated significant differences in their Fluoride levels. Further analysis using Tukey HSD Post Hoc test revealed that the differences were recorded between Year 1 and Year 2 and between Year 1 and Year 3 at three of the sampling site groups (Table 4.12).

Table 4.12 Statistical comparison of Fluoride (Year 1 – Year 3)

	SS	df	MS	F	P-value	F crit	Significant Years
Rouxville	0,043704	2	0,021852	187,9081	1,89E-07	4,45897	Y1-Y2, Y1-Y3
Smithfield	0,00488	2	0,00244	5,836504	0,027345	4,45897	Y1-Y2, Y1-Y3
Zastron	0,044902	2	0,022451	46,90024	0,000217	5,143253	Y1-Y2, Y1-Y3, Y2-Y3

SS = sum of squares; df = degrees of freedom; MS = mean square; Y1 = Year 1; Y2 = Year 2; Y3 = Year 3

4.5.3. Nitrite

ANOVA test revealed that sample sites in Rouxville, Smithfield and Zastron indicated significant differences with regards to their nitrite levels. Further analysis using Tukey HSD Post Hoc test revealed that the differences were recorded between Year 1 and Year 2 and Year 1 and Year 3 (Table 4.13).

Table 4.13 Statistical comparison of Nitrite (Year 1 – Year 3)

	SS	df	MS	F	P-value	F crit	Significant years
Rouxville	0,000489	2	0,000245	87,46513	3,66E-06	4,45897	Y1-Y2, Y1-Y3
Smithfield	0,000109	2	5,47E-05	0,404837	0,680019	4,45897	Y1-Y2, Y1-Y3
Zastron	0,00045	2	0,000225	406,0973	3,94E-07	5,143253	Y1-Y2, Y1-Y3

SS = sum of squares; df = degrees of freedom; MS = mean square; Y1 = Year 1; Y2 = Year 2; Y3 = Year 3

4.5.4. Nitrate

ANOVA test revealed that sample sites in Rouxville and Smithfield indicated significant differences with regards to their nitrate levels, and no significant differences were observed in Zastron. Further analysis using Tukey HSD Post Hoc test revealed that the differences were recorded between Year 1 and Year 2, Year 2 and Year 3 and Year 1 and Year 3 (Table 4.14).

Table 4.14 Statistical comparison of nitrate (Year 1 – Year 3)

	SS	*df*	*MS*	*F*	*P-value*	*F crit*	*Significant years*
Rouxville	0,079912	2	0,039956	120,5755	1,06E-06	4,45897	Y1-Y2, Y2-Y3
Smithfield	0,162695	2	0,081348	9,172094	0,008504	4,45897	Y1-Y3
Zastron	0,033459	2	0,016729	7,525993	0,023151	5,143253	NS

SS = sum of squares; df = degrees of freedom; MS = mean square; Y1 = Year 1; Y2 = Year 2; Y3 = Year 3

4.5.5. Sulphate

ANOVA test revealed that sample sites in Rouxville, Smithfield and Zastron indicated significant differences for Sulphate. Further analysis using Tukey HSD Post Hoc test revealed that the differences were recorded for sulphate mainly between Year 1 and Year 3 at three of the sampling site groups (Table 4.15).

Table 4.15 Statistical comparison of sulphate (Year 1 – Year 3)

	SS	df	MS	F	P-value	F crit	Signficant years
Rouxville	31,89628	2	15,94814	206,7659	1,3E-07	4,45897	Y1-Y2, Y1-Y3, Y2-Y3
Smithfield	123,7508	2	61,87539	63,77362	1,21E-05	4,45897	Y1-Y3, Y2-Y3
Zastron	13,2256	2	6,612798	233,2915	2,05E-06	5,143253	Y1-Y2, Y1-Y3

SS = sum of squares; df = degrees of freedom; MS = mean square; Y1 = Year 1; Y2 = Year 2; Y3 = Year 3

4.5.6. Aluminium

ANOVA test revealed that sample sites in Rouxville, Smithfield and Zastron indicated significant differences. Further analysis using Tukey HSD Post Hoc test revealed that the differences were recorded between Year 1 and Year 3 at three of the sampling site groups.

Table 4.16 Statistical comparison of aluminium (Year 1 – Year 3)

	SS	df	MS	F	P-value	F crit	Significant years
Rouxville	0,020067	2	0,010034	10,83568	0,005285	4,45897	Y1-Y3, Y2-Y3
Smithfield	0,022157	2	0,011079	119,6253	1,1E-06	4,45897	Y1-Y2, Y1-Y3, Y2-Y3
Zastron	0,00926	2	0,00463	5,820231	0,039348	5,143253	Y1-Y3

SS = sum of squares; df = degrees of freedom; MS = mean square; Y1 = Year 1; Y2 = Year 2; Y3 = Year 3

4.5.7. Total organic carbon (TOC)

ANOVA test revealed that sample sites in Rouxville indicated significant differences, and no significant differences were observed in Smithfield and Zastron. Further analysis using Tukey HSD Post Hoc test revealed that the differences were recorded only between Year 2 and Year 3 (Table 4.17).

Table 4.17 Statistical comparison of TOC (Year 1 – Year 3)

	SS	*df*	*MS*	*F*	*P-value*	*F crit*	*Significant years*
Rouxville	1,375791	2	0,687896	3,330569	0,088652	4,45897	Y2-Y3
Smithfield	0,158782	2	0,079391	5,636227	0,02969	4,45897	NS
Zastron	8,706203	2	4,353102	3,069948	0,120728	5,143253	NS

SS = sum of squares; df = degrees of freedom; MS = mean square; Y1 = Year 1; Y2 = Year 2; Y3 = Year 3

4.5.8. Total coliform (TC)

For the TC, ANOVA test revealed that sample sites in Rouxville indicated significant differences, and no significant differences were observed in Smithfield and Zastron. Further analysis using Tukey HSD Post Hoc test revealed that the differences were recorded between Year 1 and Year 3 and between Year 2 and Year 3 (Table 4.18).

Table 4.18 Statistical comparison of TC (Year 1 – Year 3)

	SS	*Df*	*MS*	*F*	*P-value*	*F crit*	*Significant years*
Rouxville	1549,702	2	774,851	43,17572	5,17E-05	4,45897	Y1-Y3, Y2-Y3
Smithfield	582,456	2	291,228	1,188292	0,353299	4,45897	NS
Zastron	250,7123	2	125,3562	1,355048	0,326877	5,143253	NS

SS = sum of squares; df = degrees of freedom; MS = mean square; Y1 = Year 1; Y2 = Year 2; Y3 = Year 3

4.6. Water Quality Index (WQI)

The Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) was used to assess the drinking water quality at various sample sites in Mohokare Local Municipality. To demonstrate data used for calculations of CCME-WQI values, the example below (Table 4.19) consists of measurements from nine parameters, all collected at a single sampling site to calculate CCME-WQI values.

Table 4.19 Example used to demonstrate CCME-WQI calculations

Parameters	Colour	TA	Fluoride	Nitrite	Nitrate	Sulphate	Aluminium	TOC	TC
SL (mg/L)	15	200	1.5	0.9	11	500	0.3	10	10
Y1	21	151.48	0.36	0.01	0.51	12.00	0.025	7.74	1
Y2	25	165.90	0.47	0.03	0.57	11.95	0.120	9.14	25
Y3	22	112.00	0.32	0.04	0.76	12.70	0.070	8.66	201

Number of failed parameters: 2

Total number of parameters: 9

Number of failed measurements: 5

Total number of measurements: 27

F1= 22.22

F2= 18.52

Parameters	Colour	TA	Fluoride	Nitrite	Nitrate	Sulphate	Aluminium	TOC	TC
Excursion									
Y1	0.40	0	0	0	0	0	0	0	0.00
Y2	0.67	0	0	0	0	0	0	0	1.50
Y3	0.47	0	0	0	0	0	0	0	19.10

Sum Excursion = 22.14

nse= 0.82

F3= 45.05

CCME-WQI= 69.09

SL = standard limit; TA = total alkalinity; TOC = total organic carbon; TC = total coliforms; Y1= Year 1; Y2 = Year 2; Y3 = Year 3; F1 = scope; F2 = frequency; F3 = amplitude

4.6.1. CCME-WQI analysis of drinking water quality

The CCME-WQI was calculated to analyse the drinking water quality of 14 sample sites in Mohokare Local Municipality. Out of 14 sample sites, three were water treatment plants (RX1, SM1 and ZN1) and the rest were end-user points. The CCME-WQI values revealed that none of the drinking water treatment plants were above 70% (good and excellent). All were below 70%, indicating poor performance. Furthermore, it revealed that none of the end-user points were good or excellent. The Zastron (ZN) sample sites were all in a fair range and Smithfield (SM) sample sites recorded the poorest score with all in the Marginal category (45-64). The highest CCME-WQI value of 74 was recorded at ZN2 and the lowest CCME-WQI value of 50 was recorded at SM5 (Table 4.20).

Table 4.20 CCME-WQI values and WQI ranking

Sample Site	CCME-WQI	WQI Ranking
RX1	69.09	Fair
RX2	67.71	Fair
RX3	71.27	Fair
RX4	59.10	Marginal
RX5	64.88	Marginal
SM1	64.00	Marginal
SM2	50.47	Marginal
SM3	52.52	Marginal
SM4	51.69	Marginal
SM5	50.00	Marginal
ZN1	66.26	Fair
ZN2	74.00	Fair
ZN3	67.29	Fair
ZN4	73.00	Fair

Note: WQI categories, Excellent (95-100), Good (80-94), Fair (65-79), Marginal (45-64), and Poor (0-44).

Chapter 5

Discussion and conclusion

5.1. Introduction

This study was conducted to profile the water quality of Zastron (ZN), Rouxville (RX), and Smithfield (SM) in Mohokare Local Municipality in the Free State. During this study, the drinking water quality of the three towns was assessed in terms of chemical, physical, and microbiological parameters. The drinking water quality measurements were obtained from 5 sampling sites in RX, 5 sampling sites in SM, and 4 sampling sites in ZN. In this study the identified water treatment plants (WTPs) were Rouxville water treatment plant (RX1), Smithfield water treatment plant (SM1) and Zastron water treatment works (ZN1). The drinking water quality measurements were compared to permissible limits specified by the South African National Standards (SANS) (SANS 241, 2015), followed by statistical analysis and analysis using the CCME-WQI.

Access to safe drinking water is a basic human right and it is important to human health (Hodgson and Manus, 2006; Nehaluddin and Lilienthal, 2020; Higgs, Hill and Meissner, 2025). Nevertheless, South African Category B local municipalities, as defined in the Municipal Systems Act (Act No. 32 of 2000), are often unable to sustainably deliver safe water (Bazaanah and Mothapo, 2023). Mohokare Local Municipality, a Category B municipalty under Xhariep District Municipality, functions as both WSA and WSP In the Free State, 14 out of 19 municipalities have been classified as poor in terms of the microbiological and chemical pollution of drinking water (Jankielsohn, 2024).

5.2. Interpretation of findings

5.2.1. Chemical properties

The chemical parameters mostly revealed compliant values, with only three parameters that were of concern. The chemical parameters of concern were alkalinity, aluminium and total organic carbon (TOC) when compared to the SANS 241 (2015). Various values of alkalinity were high, and the lowest recorded value was at RX2 as presented in chapter 4. Three aluminium values complied with the recommended limit outlined by the SANS 241 (2015), while only one TOC value did not comply with the recommended limit outlined by the SANS 241 (2015) (Table 4.7).

Alkalinity refers to the ability to neutralize water acids (Naseem et al., 2022). In this study, the alkalinity values for sample sites SM2, SM3, SM4 and RX5 were very high (Table 4.1). This may be due soil-ion exchange reactions and atmospheric dust (Islam and Majumder, 2020). RX2 had the lowest value of alkalinity and water with low alkalinity is more likely to be corrosive, which could cause deterioration of plumbing (Vaidya and Gadhia, 2012) (Table 4.1). The health risks of consuming high alkalinity water include lowering of natural stomach acidity that kills bacteria and expels other unwanted pathogens from entering the bloodstream and causing gastrointestinal issues and skin irritations (Mills, 2019).

In this study, aluminium values exceeded the recommended limit outlined by the SANS 241 (2015) on multiple occasions during the second and the third year of the sampling periods. Aluminium salts are commonly used in water treatment as coagulants to reduce organic matter, colour, turbidity, and microorganism levels. The use of aluminium salts as coagulants in water treatment increases the concentration of aluminium in drinking water (Krupińska, 2020). Other sources include natural processes and industrial discharge (Alasfar and Isaifan, 2021). Epidemiological research has identified a correlation between aluminium concentration in the brain and Alzheimer's disease in people consuming tap water(García-Ávila et al., 2025). Additional health risks of being exposed to aluminium in drinking water include adverse health effects to those with chronic kidney disease and an increase in hip fractures (Weisner et al., 2023).

Total organic carbon (TOC) is a parameter that estimates the amount of organic content in a water sample (Shetty and Goyal, 2022). In this study, TOC value at sample site SM2 during year 2 was the only observed value that did not comply with the recommended limit outlined by the SANS 241 (2015) (Table 4.7). Sources contributing to an increase in TOC include sewage, industrial particulates, soil organic matter and living phytoplankton (Pandey, Satpute and Neehad'souza, 2021). The risks of organic carbon content in drinking water include microbial growth and formation of harmful disinfection by-products (DBPs), which can cause bladder cancer (Huang et al., 2020)2020. Regrowth in the water can lead to a decline in water quality, and increased microbial activity, resulting in higher Coliform and *E. coli* counts.

5.2.2. Microbiological properties

The microbiological parameters mostly revealed non-compliant values. Total coliform and *E. coli* were the only microbiological parameters assessed in this study and both were of concern. Various values of total coliform were high, and the highest recorded value of 201 mg/L was observed at multiple sample sites. The highest recorded value of *E. coli* was observed at ZN3 as presented in chapter 4 (Table 4.9).

Total coliform is an indicator of the presence of pathogens in drinking water (Kothari et al., 2021). Total coliforms are a group of bacteria that are commonly found in the aquatic environment in soil and vegetation, and in the intestines of mammals, including humans (Maheux et al., 2014). The presence of coliform in drinking water indicates the presence of pathogens in the water system. Health symptoms associated with polluted drinking water range from no ill effects to gastrointestinal distress (Bai et al., 2022).

E. coli are regarded as indicators of recent faecal contamination as they are found exclusively in the gastrointestinal tract of humans and animals (Petculescu et al., 2022). The primary sources of *E. coli* include open field defecation, animal wastes, economic activities such as agricultural, and wastes from residential areas (Luvhimbi et al., 2022). *E. coli* in drinking water can put consumers at risk of health hazards such as diarrheal diseases and problems of antibiotic resistance, since *E. coli* is known to be resistant to a variety of antibiotics (Soares et al., 2023). In this study, Rouxville water treatment plant (RX1), exhibited the lowest overall compliance for *E. coli*. This indicates that Rouxville community as at risk to develop diarrheal diseases.

5.2.3. Physical properties

The physical parameter assessed in this study revealed multiple non-compliant values. Colour was the only physical parameter assessed in this study, and it exhibited values outside the norm. The highest recorded value of 143 mg/L was recorded at ZN2 during year 2 (Table 4.10).

The colour of the water is a function of water appearance and it is primarily caused by dissolved substances (Stephen, James and Ahmad, 2023). Although the colour of water may be affected due to the corrosion of iron pipes and standpipes in the distribution system (Addisie, 2022), the results in this study suggest that the colour issue is more likely linked to water treatment plants (WTPs) running beyond their design capacity that does not allow sufficient time for the flocculate to interact with the water due to fast flowing/movement of the water through the system. Suspended material in water bodies may be a result of natural causes and human activity. Suspended material in water may contain various pollutants and pathogens that are harmful to human health (Shah et al., 2023).

The colour of raw water is improved during the water treatment process. The settling of solids following the coagulation and flocculation process as well as the sand filtration process improve turbidity and the colour of the water, making it more aesthetic and pleasing to consume (WRC, 2008). The effective coagulant dosage during the water treatment process improves the colour of the water (Collave et al., 2024). The elevated aluminium levels could be attributed to irregular dosing at the treatment plant as part of the flocculant and coagulant dosing and highlights the link to elevated colour levels observed (WRC, 2006).

5.2.4. The Canadian Council of Ministers of the Environmental Water Quality Index (CCME-WQI)

CCME-WQI revealed that the drinking water quality of water treatment plant RX1 and ZN1 were classified as fair, while SM1 was classified as marginal (Table 4.20). This implies that SM1 drinking water quality is frequently threatened or impaired and conditions often depart from natural or desirable levels (Azuamah, Appiah-Effah and Akodwaa-Boadi, 2023). The findings indicate that the identified water treatment plants are not consistently effective in removing all contaminants and this might pose a health risk for the people of Mohokare Local Municipality, Free State. The CCME-WQI furthermore revealed that the quality of drinking water at the end-user points was not good or excellent (Table 3.2).

5.3. Limitations

This study was limited by the use of secondary data obtained from the Mohokare Local Municipality. As such, the accuracy and completeness of the data depended on the quality of the record keeping by the municipality. Furthermore, the scope of the evaluation of water quality was limited to the available data provided by the municipality. In addition, the study assessed only a limited number of water quality parameters, which may not fully represent all possible contaminants influencing drinking water safety.

5.4. Conclusion

In accordance with the WQI, the study indicates that over half of the assessed water quality parameters did not meet the required standards outlined by the SANS 241 (2015). This indicates the poor state of the drinking water quality in Mohokare Local Municipality, Free State. In support of this, the CCME-WQI confirmed that none of the sample sites recorded values in the good or excellent categories. The poor water quality indicates challenges in the municipality's overall water quality management, which is in agreement with the 2023 Free State’s Blue Drop findings. This further indicates that the people of Mohokare Local Municipality are exposed to potentially contracting waterborne diseases, which is contravening the bill of rights and the obligation of municipalities in terms of section 152 of the constitution to ensure a safe and healthy environment to its citizens.

Mohokare Local Municipality’s Blue Drop scores have consistently declined over the years, with the worst recorded performance in 2023. The observed non-compliant values when compared to SANS 241 (2015), therefore contributes to understanding the low Blue Drop score achieved by the Municipality. The ANOVA further indicated that Year 3 (2023), showed significant differences in multiple water quality parameters, with poor compliance compared to Year 1 (2021) and Year 2 (2022). This indicates that the overall water treatment is not consistent. The irregular treatment compliance could be an indication of a deeper management issue. The effectiveness of water treatment facilities in rural and semi-urban regions is significantly influenced by the type of technology implemented, the competency of operational staff, and is often compromised by poorly maintained equipment and a shortage of skilled personnel (Aoyi et al., 2016; Fanteso and Yessoufou, 2022; Adom and Simatele, 2024).

Drinking water containing unsafe levels of contaminants can affect health. It is therefore important to improve water supply and sanitation and manage the water resources better to prevent adverse health-related issues associated with poor water quality. Addressing drinking water quality issues requires strategies to prevent, treat and remediate water pollution (Ngcongo, 2020).

5.5. Recommendations

Based on the findings in Chapter 4 and Chapter 5, the following recommendations are proposed:

- Ensuring regular maintenance of the water treatment plants (WTPs) and providing training for the WTPs operators;
- Infrastructure maintenance of the distribution network;
- Reporting leaks or damaged water pipes to curb contamination of treated water supplies; and
- Ensuring continuous microbial monitoring and implementation of a stricter disinfection protocol to address persistent non-compliant total coliform values;
- Educating the community about safe water practices and the potential health risks of consuming polluted water;
- Conducting a review of the current water safety plan of the municipality, updating the current risk assessment to address the challenges identified in the Blue drop report, and incorporating the findings and recommendations of this study, ensuring implementation of a monthly microbial monitoring programme and weekly chlorine monitoring programme.

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