

**Physicochemical and microbio effects of coal mining on the quality
of Naauwpoortspruit river, Mpumalanga, South Africa**

by

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DECLARATION

I, Moses Shimo Seletisha, student No. 43974953, declare that the work titled:

"Physicochemical and microbio effects of coal mining on the quality of Naauwpoortspruit River, Mpumalanga, South Africa" is my genuine academic work. I have acknowledged all reference sources that were used in this study. I further declare that this degree has not been presented to any other institution.

The research proposal for this study was submitted to and accepted by the CAES Health and Research Ethics Committee (2024/CAES_HREC/4624). I declare that I have not violated the UNISA Research Ethics Policy and have collected data in compliance with the criteria of this ethics policy.

I declare that citations, paraphrases, and quotes from specific sources have been properly included in this research's reference section.



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ABSTRACT

Coal mining has been shown to affect both surface water and groundwater quality, primarily because of the presence of acidity in mine drainage, heavy metals, and microbial contaminants. Hence, this study aimed to determine the environmental impacts of coal mining and processing activities on the quality of water of the Naauwpoortspruit River in eMalahleni, Mpumalanga Province. This study used an integrated mixed-methods approach to capture the responses and lived experiences of residents as to how coal mining influences water quality within the Naauwpoortspruit River in eMalahleni, Mpumalanga, South Africa. Qualitative data on perceived water quality and associated health risks were obtained from focus group discussions. Quantitatively, we collected 18 water samples from Masakhane, Coalfield, and Boat Camp during both dry and wet seasons. Qualitative feedback showed that the residents perceived the water as discoloured, foul-smelling, and not safe, with frequent diarrhoea, stomach cramps, and skin irritations. The physicochemical analyses indicated a pH within the range of 7.17-7.35. Iron (Fe) ranged between 0.10-0.30 mg/L, manganese (Mn) within 0.00-0.04 mg/L, while aluminium (Al) ranged from 0.04 to 0.22 mg/L and sulphate (SO_4^{2-}) within 143 to 188 mg/L. Aluminium and iron were found to exceed the permissible limits set by SANS 241:2015 at some sites. Microbiological testing showed significant contamination. Total coliform bacteria ranged from 555 to 920 CFU/100 mL, and faecal coliforms varied between 34 and 766 CFU/100 mL. Of these sampling sites, the Boat Camp site showed the highest level of faecal pollution. The study concluded that coal mining environment and related human activities have degraded the water quality of the Naauwpoortspruit River, presenting notable environmental and public health risks. It emphasized the urgent need for improved mine water management and more effective wastewater control.

Key terms: Coal mining, Naauwpoortspruit, eMalahleni, Masakhane, physicochemical, microbial, water quality, Acid Mine Drainage

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DEDICATION

I dedicate this dissertation to my late father, who passed on while I was quite young. I shall eternally recall him for his true essence.

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ACRONYMS AND ABBREVIATED WORDS

Abbreviation	Meaning
Al	Aluminium
AMD	Acid Mine Drainage
BOD	Biochemical Oxygen Demand
ELM	eMalahleni Local Municipality
FC	Faecal Coliform
Fe	Iron
FGDs	Focus Group Discussions
IDP	Integrated Development Plan
IEA	International Energy Agency
IWMSA	Institute of Waste Management of Southern Africa
MDG	Millennium Development Goals
Mn	Manganese
NWA	National Water Act
NWMS	National Waste Management Strategy
pH	Potential of Hydrogen
SAWS	South African Weather Service
SDG	Sustainable Development Goals
SO ₄ ²⁻	Sulphate
TCB	Total Coliform Bacteria
TDS	Total Dissolved Solids
WHO	World Health Organization
WWTP	Wastewater Treatment Plant

GLOSSARY OF TERMS

Concepts	Definitions
Acid Mine Drainage (AMD)	The oxidation of pyrite in the presence of water and oxygen produces sulphate and acidity, leading to the formation of sulphuric acid (H_2SO_4) (DWS, n.d.).
Air Pollution	The term used to describe the phenomenon wherein undesirable gases, liquids, and particles contaminate the air (Gilpin, 1997). In theory, any material that changes the air's typical composition is considered to be polluting it. In practice, though, this only applies when there are dangerously high concentrations of substances in the air, endangering humans or other forms of life.
Coal Mining	The term is described as the process of coal extraction from the earth. These activities occur in the form of an open-cut surface or underground surface. The coal material is used as a fossil fuel and may be exported internationally or used domestically (particularly by power utilities such as Eskom).
Water Quality	Water quality refers to the physical, chemical, biological, and aesthetic characteristics of water that determine its suitability for various uses and its ability to support healthy aquatic ecosystems. These characteristics are influenced by substances that are either dissolved or suspended in the water (DWAF, 1996). In general, water quality describes variations in water based on its physical, chemical,

	and biological properties, and is often assessed in terms of its fitness for a specific purpose.
Water Pollution	This results from changing the physical, chemical, or biological qualities of a water resource directly or indirectly so that it is less useful for any good use (National Water Act, 1998, p.16).

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CHAPTER 1: INTRODUCTION AND BACKGROUND

1.1 Introduction

The presence of harmful contaminants, such as bacteria, viruses, and chemicals, in water degrades its quality, making it unfit for its intended use, and endanger both humans and the environment (Gilpin, 1997). Such contamination changes the physical, chemical, or biological characteristics of water, either directly or indirectly (National Water Act, 1998). Annually, around one million people are believed to die from diarrhoea due to poor drinking-water quality, inadequate sanitation, and lack of hand hygiene. Despite this, diarrhoea is mostly preventable, and by tackling these issues, the deaths of 395,000 children under five could be prevented each year. In areas where water is scarce, individuals might not prioritize handwashing, which can lead to an increased risk of diarrhoea and other diseases. (WHO, 2023). Several industries in South Africa contribute to water pollution and one of these is the mining industry. This is especially true in regions like Mpumalanga province, South Africa, where coal mining is a way to boost local economies and create jobs in the surrounding communities but is also a major contributor to water contamination.

According to Barnes et al. (2011), energy is the most important factor that contributes to societal and economic growth. Businesses, factories, transportation networks, and service providers all rely on a reliable energy source to run their operations and contribute to the nation's economic growth. The use of fossil fuels such as coal continues to account for 85% of the world's power generation (Zhu et al., 2021). According to the International Energy Association (IEA), anthropogenic activities as well as the increase in global population and urbanisation has increased the demand for fossil fuels such as crude oil and other natural gases, leading to an increase in the world's energy production, which reached 14,421 megatons in 2018 (IEA, 2021). Thus, utilizing fossil fuels including natural gas, coal, and oil climbed by over 370 megatonnes in 2018 alone, which is a significant increase in energy production. Coal is still an important component of many modern energy systems where it accounts for 38.5% of

the world total coal consumption and generates over one-third of the world's electricity (IEA, 2021).

According to the IEA (2021) and Stats SA (2015), coal is still the main source for around 30% of South Africa's liquid fuel production and over 70% of the main source of energy in the nation. In Mpumalanga province, where more than 81% of South Africa's total coal mining occurs, its extraction and processing are among the primary economic activities in several cities. According to the South African Department of Energy, South Africa was the fifth-largest source of steam coal in the world (Stats SA, 2015). Consequently, despite the detrimental effects on the environment caused by coal mining and processing, the country's utilisation of coal is high and is vital for the country as a whole. The demand for coal in generating thermal power is also considerable and contributes to South Africa's current energy crisis (Fraser, 2023). However, the environmental implications of fossil fuels are worsened by the ongoing processing and consumption of energy derived from these sources (Masindi et al., 2022). Coal mining, thermal power plant combustion, coking in the iron and steel industry, and coal washing and sorting are all steps in developing coal resources (Chen et al., 2023). Thus, soil, air, and water contamination are among the many detrimental environmental repercussions of coal resource exploitation.

The mining, washing, and separation of coal processes all generate substantial quantities of gangue, a kind of coal waste material that has no commercial use while thermal power plants also generate substantial quantities of fly ash and desulfurization ash (Amaral Filho et al., 2022). South African coals, in particular, contain a significant concentration of iron pyrite, which typically results in these coal wastes being very large. It is common practice to either let these solid wastes settle to the surface of the earth or to cover the mines with them. However, following exposure to weather and the long-term soaking impact of rain, coal waste materials gradually seep out of these deposits and contaminate surface and groundwater (Nguegang et al., 2022b).

Due to the substantial environmental, socioeconomic, and health implications associated with these various waste products, researchers have long studied the impact of mining on water quality (Seopela et al., 2020; Masindi et al., 2022). This is especially true for coal, as well as gold mines. The most common type of mining waste is acid mine drainage (AMD) and has the most devastating impact on ecosystems and, in particular, water quality. According to Nguegang et al. (2022b) and Masindi et al. (2022), the main problem with AMD is the extremely acidic water that is created by a chain reaction involving the generation of sulphuric acid (H_2SO_4). Sulphide minerals, such as iron sulphide (pyrite), release sulfuric acid when they react with water. This acid lowers the pH of the water, making toxic metals and metalloids more soluble, and so increasing their mobilization into the surrounding water bodies (Masindi et al., 2022).

Since many aquatic creatures cannot live or reproduce in acidic water, this can seriously impact on aquatic ecosystems. A variety of species may become extinct as a result of ecosystems becoming unbalanced due to a subsequent decline in biodiversity. It is also known that the generation of acid mine drainage can be increased by specific bacteria (Lyn, 2017). Gravity drainage was originally intended to minimize excessive water accumulation in mines constructed in the 1800s and earlier, making the problem considerably more severe in older, abandoned mines. Thus, the surrounding ground and surface waterbodies are polluted by water that is contaminated with acid, iron, sulfur, aluminium, and other heavy metals as it flows away from these abandoned mines (Bapwa, 2017; Masindi et al., 2022). Thus, South Africa's limited water resources would unavoidably be impacted by coal mining wastes due to the massive coal extraction and processing operations in the eMalahleni region and the high volumes of water used in the several phases of coal production. Following on from these concerns, this study will primarily focus on the impact of coal mining runoff often acidic water with heavy metals like manganese (Mn), iron (Fe), and aluminium (Al) on the municipally supplied potable water supply as well as the contamination of adjacent rivers, lakes, and aquifers.

1.2 Problem statement

Water quality is significantly impacted by AMD, particularly in the province of Mpumalanga, where there is extensive coal mining. The mining industry is responsible for a great deal of pollution and the loss of land and important resources due to the enormous amounts of waste it produces. The problem is made worse by the presence of harmful heavy metals and metalloids in AMD. Iron, Aluminium, Manganese, and sulphate are metals that are frequently identified in acidic mine drainage. The toxic effects of these metals on aquatic life can hinder development, reproduction, and general well-being. Bioaccumulation and biomagnification occur when these substances build up in living tissue as they move through the food web. The contamination of groundwater sources by AMD has the potential to disrupt drinking water supplies; hence, the effects of AMD on water quality go beyond aquatic ecosystems. Humans are greatly endangered if they drink water polluted with harmful metals and metalloids. Chronic exposure to these pollutants raises the risk of cancer, renal disease, and harm to the neurological system, among other health problems. Water bodies impacted by AMD can undergo both chemical and physical changes, in addition to the obvious impacts on water quality. Water flow might be reduced, and channels can become clogged due to sedimentation caused by the high concentration of metals and metalloids (Masindi et al., 2022).

Several studies have focused on the Naauwpoortspruit River catchment due to the high levels of pollution associated with AMD generated by extensive coal mining activities in the upper Naauwpoortspruit River that eventually flows downstream into the Loskop dam, Kruger National Park, Mozambique, and finally the Limpopo River (Seopela et al., 2020; Masindi et al., 2022). The water's physical and chemical characteristics are changed by the contaminants generated during mining, which frequently causes significant ecological damage. Permanent harm to natural ecosystems can occur when the natural buffering effect of aquatic ecosystems is exceeded, which is a big concern when water pollutants are continuously loaded into major surface water sources. Aquatic ecosystems have an innate tendency to adapt and compensate for changes in water quality. At that time, the water's quality will have dropped to such an extent that

it is no longer usable for irrigation, animal drinking water, and other household purposes (Momba et al., 2016). In response to these concerns, this study aims to study the impacts of mining on the aquatic ecosystem and water quality of the Naauwpoortspruit River and to what extent the water quality in the Witbank dam has deteriorated.

1.3 Motivation

Residents of the eMalahleni local municipality have been increasingly dissatisfied with the city's potable water due to reports of water quality issues, including problems with its colour, smell, and taste (Mhlongo et al., 2018; Goldswain, 2019; Kretzmann & Gilili, 2022). The Witbank dam is the source of eMalahleni's potable water. The Naauwpoortspruit River, which supplies water to the Witbank dam, is widely reported to experience water quality challenges because of extensive coal-mining activities that flows in its upper basin (Seopela et al., 2020; Masindi et al., 2022). There has been an upsurge in complaints lodged with the eMalahleni local municipality by residents of the area, particularly those living in the city. These residents claim that the water supply in the eMalahleni area and the surrounding areas exceeds the National Quality Water Standards, as amended in the National Water Services Act [No. 108 of 1997] (Goldswain, 2019; Kretzmann & Gilili, 2022). Water in this region has been known to discolour, be flavourless, and occasionally smell bad and appeared brownish in colour, according to several communities' reports (CIEL), 2016; Goldswain, 2019; Kretzmann & Gilili, 2022). In addition, Edokpayi et al. (2018), Laisani and Jegede (2019), and Kretzmann and Gilili (2022) reported that the water caused stomach pain and diarrhoea. In response to these concerns, the municipal council of Nkangala District Municipality released a public statement about the availability of potable water and chlorine shortages (Nkuna, 2012). According to the city council, a shortage of chlorine is a problem in many places including eMalahleni, which claims that the discoloration and lack of flavour in the water are caused by this shortfall. As result, most city people now only drink bottled water. Yet, municipal water is consumed by those who are unable to purchase bottled water. Assessing the impacts of mining activities on water

resources is crucial for protecting surface and groundwater freshwater resources from contamination in eMalahleni, Mpumalanga Province, South Africa. The Naauwpoortspruit River is the primary source of water in the area, so understanding how mining has affected it is essential.

1.4 Research aim and objectives

1.4.1 Research aim

The research study aims to evaluate the environmental effects of coal mining and processing activities on the water quality of the Naauwpoortspruit River in eMalahleni, Mpumalanga.

1.4.2 Objectives of the study

To achieve the principal aim of this research study, the subsequent secondary objectives were formulated:

- I. To analyse the perspectives of the communities surrounding the coal mines in eMalahleni regarding the environmental impact on the quality of water by obtaining responses from participants in a focus group followed by thematic analysis of the responses.
- II. To assess the physicochemical characteristics (pH, Fe, Mn, Al & SO₄) of the water from the Naauwpoortspruit River using calibrated meters.
- III. To assess the microbial characteristics (TCB & FC) of the water from Naauwpoortspruit River using the pour plate technique and Membrane filtration.
- IV. To compare measured physicochemical and microbial values against the National Water Quality standards and identify if they exceed regulatory limits.

1.5 Research questions

Physicochemical and microbiological effects of coal mining activities on the quality of Naauwpoortspruit River water have triggered the following set of questions:

- a) What are the levels of chemical pollutants in water from the Naauwpoortspruit River?
- b) What are the physicochemical characteristics (pH, Fe, Mn, Al & SO₄) of the water from the Naauwpoortspruit River?
- c) What are the perceptions of the residents of the communities around the mines in eMalahleni in Mpumalanga on the environmental impacts of coal mining and processing activities on the water quality of the Naauwpoortspruit River?
- d) What are the perceptions of the residents of the communities around the coalfields in eMalahleni, Mpumalanga, on the quality of potable water supplied by the municipality and its effect on their health?

1.6 Significance of the study

The Naauwpoortspruit River system has been adversely impacted by the greater amount of sulphate, metals, and nutrients found in the river. Examples of its effects on aquatic life include the identification of tumours in river fish, measurement of elevated levels of aluminium and iron in fish organs and determining severe liver disease in specific fish species in Loskop Dam (Oberholster et al., 2010, 2022; Bouwman et al., 2014; Seopela et al., 2020). Dabrowski and de Klerk (2022) found that the river's nutrient levels are elevated with average N:P ratios between eutrophic and hypertrophic conditions observed at a number of sample locations. Additionally, the results indicate that sulphate concentrations are still rather high and are rising as one moves downstream, which is likely caused by mining operations.

The enormous potential environmental, ecotoxicological, and socioeconomic consequences of contamination of a key freshwater source is a major reason for concern in a nation with limited water resources such as South Africa. Of the total water that flows into the Limpopo River, roughly 40% originates in the Olifants River (USAID,

2019). As a major water supply for Kruger National Park, it is also vital for a wide range of commercial and industrial uses, including farming, mining, and irrigation dams. Gifford (2022) stated that the second-largest irrigation project in the country is highly endangered due to the acid mine water draining into the Loskop Dam. Another point is that most research has focused on how the Naauwpoortspruit River pollution affects water supplies downstream, but they have paid little attention to how it affects communities and regions upstream.

The concentrations of several major pollutants in the upper river system, which is heavily impacted by coal mining and processing, were defined in this study. Additionally, study results will aid in bringing attention to the issues surrounding coal processing and mining, the impact on the upper Naauwpoortspruit River's water quality, and how these things affect the daily lives of regular South Africans in the local municipality of eMalahleni. Moreover, the study aims to evaluate the level of effort made to address the issues related to coal mining in eMalahleni, such as acid mine drainage and process waste management, for both operational and decommissioned mines. Thus, study results should provide new insights into the existing literature. The study supports tighter regulations and improved management of mining-driven pollution for the benefit of policymakers developing or revising the water quality standards or rehabilitation plans for the Upper Naauwpoortspruit River catchment. The findings call for focused community education programs and joint monitoring efforts that will empower the residents of eMalahleni to safeguard their health and advance demands for cleaner, safer water resources.

1.7 Scope and limitations of the study

This study is limited to the assessment of the environmental impacts of coal mining and processing activities on the water quality of the Naauwpoortspruit River and the potable water of the eMalahleni local municipality. While the Naauwpoortspruit River catchment extends beyond this area, this was not covered in this study. The health impacts of potable water quality are investigated but are limited to feedback from the study questionnaire. The biological and physical properties of collected water samples

were evaluated to determine their compliance with South African National Standards (SANS 241) and World Health Organization (WHO) guidelines for drinking water.

1.8 Study Outline

Chapter 1: This chapter focuses on the context of the study and the study background, outlining the significance of water quality together with challenges experienced in the eMalahleni Local Municipality. These include the research problem, research aim, objectives, research questions, and methodology of the study. The chapter further provides an overview of the study area, and key terms are defined throughout the dissertation.

Chapter 2: This chapter presents a literature review to compare various aspects of water quality, pollution sources, and the impact of mining activities on water sources. It outlines theoretical and empirical studies focusing on the water quality standards including environmental legislation and the health implications of contaminated water.

Chapter 3: This chapter addresses the study area, sample strategies, research design, and data gathering methods used to analyse water quality and community perceptions. It further outlines the research tools and instruments used for laboratory analysis, interviews, and questionnaires. This chapter includes ethical considerations, and research reliability and validity.

Chapter 4: This chapter presents the findings of the study, including the physicochemical and microbiological characteristics of water samples. It further presents the perceptions of the community members regarding water quality and health concerns using tables and graphs to illustrate the results.

Chapter 5: The chapter presents and discusses the study results with reference to the literature review and theoretical frameworks. It discusses how mining activities and related factors contribute to water quality deterioration and also conducts assessments on the implications for environmental and public health.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This literature review examines the effects of mining operations on water quality, emphasizing physicochemical as well as microbiological consequences. An increasing South African population requires a potable water supply, but socioeconomic growth impacts the water supply and its quality. Activities such as anthropogenic trends, intensive agriculture, substantial industrial advancements such as mining and electricity generation, and urbanization exert pressure on the quality of the nation's water resources (Luvhimbi et al., 2022). Many of these activities require a rapid expansion of water use and are located upstream of major river catchments, such as the Naauwpoortspruit River catchment, resulting in their effluent discharges and return flows having a significant effect on water resources (Jegede & Shikwambane, 2021). Any deterioration in the water supply profoundly affects aquatic ecosystems, human health, and other water consumers (Pollard & Retief, 2017; Department of Water and Sanitation (DWS), 2022).

In South Africa, factors affecting water quality include acid mine drainage (AMD), harmful organics such as polychlorinated biphenyls, wastewater and sewage discharge, nutrient pollution, organic matter, and sediments resulting from industrial effluents (Pollard & Retief, 2017; DWS, 2022). Furthermore, declining water quality jeopardizes expansion and development of the economy, and this is compounded by inadequate governance, insufficient intergovernmental collaboration, and noncompliance with licensing conditions by certain water users. This literature review examines the global water crisis before focussing in on water quality in South Africa so as to introduce potential water quality difficulties in the current research involving the Naawupoortspruit River, influenced by coal mining activities in eMalahleni, Mpumalanga province.

2.2 The deterioration of water quality

Water quality deterioration is one of the most serious concerns not only in Africa but also in countries all over the world. A rapid population increase, expansion of cities, industrialization processes, and current climatic change force a variety of pollutants into our water supplies. In Africa, countries such as South Africa, Nigeria, Ghana, Kenya, Zambia, and the Democratic Republic of Congo are facing high levels of water pollution following the release of mining, industrial and farming effluents, and this is compounded by the release of untreated sewage that threaten ecosystems such as surface waters and the health of people and animals using or drinking poor-quality water (UN-Water, 2021; Momba et al., 2016). Similar water trends have appeared in India, China, Brazil, and the United States, where industrial waste, agricultural runoff, and wastewater from urban areas damage the quality of surface and groundwater (World Bank, 2020; UNESCO, 2022).

Within South Africa, water quality degradation exhibits pronounced regional variation due to industrial activities, mining operations, and land use. Provinces with high mining activities, including Mpumalanga, Gauteng, Limpopo provinces, and the Northwest, have displayed obvious issues with water quality. More specifically, coal mining in Mpumalanga brings about acid mine drainage and heavy metal contamination of water, while industrial discharge and agricultural runoff raise the levels of nutrient such as nitrogen and phosphorus in river water (Jegede & Shikwambane, 2021; Luvhimbi et al., 2022). Similar pressures are demonstrated by Gauteng's urban and mining zones, exacerbated by wastewater emanating from rapidly growing cities. Gold and platinum mining in Limpopo and the Northwest contribute to increased toxic metal concentrations, which can have implications for aquatic life and downstream users (Lebepe et al., 2017). Because of coal mining in South Africa's Witbank and Highveld coal basins, a change in the chemistry of river water 200 km downstream of these sites was noted (Dabrowski et al., 2015).

The Naauwpoortspruit River in eMalahleni, Mpumalanga province, exemplifies these abovementioned challenges. Mining effluent and upstream industrial activities have significantly altered the river's physicochemical and microbiological quality, including

pH, turbidity, dissolved oxygen, heavy metals, and microbial contamination (Pollard & Retief, 2017; DWS, 2022). This local degradation echoes a broader pattern seen worldwide, where freshwater systems in mining-heavy areas, from the Ganges in India to the Yangtze in China, the Amazon in Brazil, and the Mississippi in the United States, face comparable threats from human activity. It is from the local and national level, to the global level that such influences need to be understood to develop suitable water management plans, enforcement regulations, and mitigation measures.

2.3 Water crisis and an extensive deterioration in water quality

A water crisis occurs when there is an insufficient supply of clean, potable water in a given area to meet its needs. South Africa ranks among the 30 driest nations globally, with approximately 80% of the population dependent on surface water as their primary residential water source. Data from the South African Weather Services (SAWS) indicates that certain regions see greater precipitation than others, with the nation recording the lowest annual rainfall at 450 mm, in contrast to the annual average of 860 mm worldwide (Pitman, 2011; Luvhimbi et al., 2022). This directly affects river flow and the availability of water supply for a growing population and economic activity in South Africa.

A reason for the poor rainfall is that high-pressure systems cover a large area of South Africa (African Women in Agricultural Research and Development (AWARD) & United States Agency for International Development (USAID), 2020; Retief & Pollard, 2020) while South Africa's topography also affects rainfall patterns since the land rises abruptly from the Eastern and Southern escarpments, which constitute the edge of the entire plateau, and then slowly falls to the north and west. Along with these physical and meteorological conditions, a growing number of users exacerbates water shortages. In addition to a high demand for freshwater, water supply levels are decreasing, many major industrial developments are situated far from water courses, resulting in the need for water to be moved across catchment areas on a large scale (Nansubuga et al., 2016; Retief & Pollard, 2020).

Water pollution is mostly caused by urbanization and industrialization, and they have made surface water more polluted (Ubani et al., 2014). An evaluation of river pollution levels and their environmental consequences was carried out in Enugu, Urban Nigeria. This study was prompted because there was insufficient clean drinking water because Enugu's surface water was used for drinking and watering plants. Ude (2011) pointed out that urbanization, fertilized farmland, and waste from slaughterhouses are all sources of pollution in Enugu. In a comparable study conducted in India by (Balwant, 2016), municipal and industrial effluents, together with urbanization, were identified as the primary sources of organic and nutritional pollutants, resulting in elevated concentrations of lead and zinc in water. This emphasizes that different and widespread pollution sources occur depending on the impact of human activities and their effect on the environment - urban activities and agriculture contribute non-point sources of pollution, including nitrogen, phosphorus, and other nutrients into surface water (Du Plessis, 2019).

In addition to agriculture and the use of inorganic chemical fertilizers on agricultural land being a non-point source of water contamination, current and previous mining activities may affect water quality in South Africa and other countries worldwide (DWS, 2020). Pollutants are produced through the weathering of rocks. In addition, heavy metal contamination is probably associated with abandoned mines. In south-eastern Shaanxi Province, China, surface waters now contain higher concentrations of elements such as arsenic (As), iron (Fe), and copper (Cu), long after a local mine had closed (Jiao, 2023).

Elevated levels of these metals in water negatively impact the ecosystem and human health. When water or air breaks down pyrite and other sulphides, it releases metals, sulphate, and acid into the environment, the process of AMD formation (Kefeni et al., 2017; Rambabu et al., 2020). The water becomes very acidic because of AMD, and the chemical composition of water is influenced by elevated concentrations of dissolved metals and salts.

Similar patterns were documented in other mining-affected river systems around the world. Research conducted in India's Damodar Valley, for instance, examined how coal mine water and irrigation from the Damodar River affected soil and maize crops in the coalfield area (Mahato et al., 2017). These authors reported that the Damodar River carried dangerously high concentrations of heavy metals including iron and manganese, along with toxic anions and various organic and biological contaminants. More recently, in 2023, Ceaser Minga and their research team investigated water pollution linked to mining activities in Peru's Parac Subbasin of the Rimac River. Their findings revealed that both surface water and groundwater were heavily contaminated with mine-affected water containing elevated levels of metals such as arsenic, manganese, and iron, as indicated by heavy pollution and contamination indices (Sharma et al., 2020; Ceaser Minga et al., 2023).

One of the most polluted river systems in South Africa is the Naauwpoortspruit River (Heath et al., 2010; Oberholster et al., 2017). Marr et al. (2022) reported increasing levels of sulfate in the Naauwpoortspruit River. Jooste et al. (2015) determined that the median annual sulfate concentrations at Flag Boshielo Dam were approaching the 100 mg/L threshold value for aquatic ecosystem health and were increasing at a rate of 1.32 mg/L annually. In addition, the transformation of carbonates and bicarbonates into carbonic acid has a direct negative effect on the water's buffering capacity (Pollard et al., 2018).

2.4 Acid mine drainage and its impacts on water quality and aquatic ecosystems

The Naauwpoortspruit River stands as one of South Africa's most important waterways, originating in the Highveld region and traveling in a north-north-easterly direction before crossing into Mozambique to eventually join the Limpopo River. This river has earned the somewhat ironic distinction of being one of the country's "hardest working rivers," a testament to the immense pressures placed upon it by human activity (Retief & Pollard, 2020). Over the years, the demands placed on this river system have grown substantially, with water being extracted for industry, mining operations, power generation, agricultural needs, and domestic consumption. These demands have

actually outpaced population growth itself, while simultaneously the river has been receiving an ever-increasing volume of effluents discharged from various sources throughout the catchment (DWS, 2019; Masindi et al., 2019). Adding to these human-induced stresses, the region experiences unpredictable rainfall patterns that bring both prolonged droughts and sudden, devastating floods. The eastern portions of the catchment extending into Mozambique face the additional challenge of tropical cyclones that regularly impact the area (Hara & Backeberg, 2014; Sara et al., 2021).

A combination of these extreme flow variations and the progressive deterioration of water quality have created a cascading water crisis in recent years. Water quality has deteriorated significantly over time, leaving the aquatic ecosystems throughout the catchment increasingly vulnerable while simultaneously threatening the livelihoods of communities that depend on this water source (Ashton & Dabrowski, 2011; Marr et al., 2015). The problem is particularly acute in the upper reaches of the Naauwpoortspruit River, where a complex mixture of treated, partially treated, and completely untreated effluents flows into the system from mines, industrial facilities, and sewage treatment plants. Compounding this issue, AMD seeps from both active and abandoned coal mining operations in these upper areas, introducing harmful nutrients, salts, and metal ions into the water (Netshitungulwana & Yibas, 2012; Shaughnessy et al., 2019). Much of this contamination does not simply flow through the system but instead settles and accumulates in the sediments and water columns of the various storage reservoirs distributed along the river and its tributaries (Ashton & Dabrowski, 2011; Du Plessis, 2019). The monitoring data paint a concerning picture of these reservoirs, showing steadily increasing nutrient concentrations that indicate they are becoming increasingly eutrophic. Aluminium and iron levels frequently exceed the thresholds recommended in national water quality guidelines, raising serious health and ecological concerns (Sharma et al., 2020).

Beyond the mining sector's contributions, the Naauwpoortspruit catchment faces additional water quality challenges from agricultural practices and wastewater treatment facilities. Two particularly troublesome issues have emerged: salinity and eutrophication. Agricultural operations release large volumes of water contaminated

with fertilizers, while in some areas raw sewage is being pumped directly into the river system. The study conducted by (Ramudzuli, 2017) focused on the upper catchment area, identified elevated dissolved oxygen levels and high electrical conductivity, which appeared to originate from intensive livestock operations including piggeries and cattle feedlots, as well as wastewater treatment works and chemical manufacturing plants. While dissolved oxygen is essential for aerobic aquatic life such as fish, plants, and microorganisms, the levels and conditions suggest deeper water quality problems (Ramudzuli, 2017; DWS, 2022).

Lake Loskop has experienced blooms of *Microcystis aeruginosa*, a toxic cyanobacterium believed to be responsible for recent fish deaths in the reservoir, creating serious health risks not only for aquatic life but also for people who use water from this source (Knight & Fitchett, 2019). The severity of the situation is perhaps most clearly illustrated by the recent discovery of over 170 dead crocodiles within the Kruger National Park, a tragedy that captured widespread public attention and brought greater attention to the Naauwpoortspruit River's water quality. The crocodile population in the upper reaches of the catchment have also shown significant decline, serving as a stark indicator of the ecosystem's deteriorating health (Van Vuuren, 2009; Retief & Pollard, 2020).

2.5 Acid Mine drainage and its effects on water quality and the aquatic ecosystem

Mining has historically been a cornerstone of South Africa's economy, with the nation's prosperity built largely on its remarkable abundance of mineral resources. Yet this economic engine has come at a significant environmental cost, particularly to the country's water resources. Given South Africa's naturally limited water availability as discussed previously, the pressures of economic development, expanding land use, and a growing population make the mining industry's impact on water security an increasingly urgent concern. Among the various ways mining affects water resources, AMD has emerged as one of the most persistent and troubling problems, drawing

considerable attention from researchers and policymakers over the years (McCarthy & Humphries, 2013; Dold, 2014).

Acid mine drainage is an unfortunate byproduct of mining operations worldwide, and South Africa is no exceptional case in this regard. The process begins in several ways: natural rainfall can wash through mine dumps, carrying contaminated runoff into nearby water systems; mining companies may discharge water used in their operations; or abandoned mine shafts gradually fill with water until they eventually overflow or flood onto the surface (Kefeni et al., 2017). Regardless of how it originates, water that has passed through mining areas becomes heavily contaminated. This water typically carries elevated concentrations of metals including iron, aluminium, and manganese, along with potentially other heavy metals such as arsenic, which is generally considered the most hazardous. Water draining from both active and especially abandoned mines and mine waste tends to be acidic in nature, creating additional environmental challenges. Within South Africa, acid mine drainage has been documented across multiple provinces, including the Witwatersrand Gold Fields, the coal fields of Mpumalanga and KwaZulu-Natal, and the O'Kiep Copper District in the Northern Cape province (Lebepe et al., 2017). However, many other mining areas throughout the country remain inadequately studied, requiring more comprehensive information gathering, ongoing monitoring, and thorough risk assessments. This need is particularly pressing in vulnerable areas like the Mpumalanga Coal Fields, where mining activities pose a serious threat to the freshwater sources feeding the upper reaches of both the Vaal and Naauwpoortspruit River Systems (Jooste et al., 2014).

The contaminated water from these mining operations inevitably finds its way into local river systems, including the tributaries of the Naauwpoortspruit River. While natural processes gradually neutralize the acidity through dilution and various chemical and biological reactions as the water moves downstream, the resulting water remains highly saline with particularly elevated sulphate concentrations. The Middelburg and Witbank dams provide a stark illustration of this ongoing problem, with monitoring data showing steadily rising salinity and sulphate levels in their waters. The severity of contamination fluctuates with weather patterns, worsening during dry periods when there's less

dilution and improving somewhat when rainfall increases, which explains the variability seen in water quality measurements. However, the underlying trend points unmistakably toward continuously increasing salinity and sulphate contamination. The situation has become so severe that sulphate concentrations in Witbank Dam now regularly exceed 200 mg/L, the maximum level recommended for domestic water use. The local water quality has deteriorated to such an extent that Eskom, the national electricity supply company, has been forced to import water from the eastern escarpment to supply its power stations in the Witbank-Middelburg area rather than using the heavily polluted local sources (Maya et al., 2015). Looking ahead, the problem will only resolve itself once the pyrite present in the rocks throughout these mining areas becomes fully oxidized, at which point acid mine drainage will finally cease. Unfortunately, there is no reliable estimate for when this natural remediation might occur, but experts believe the problem will likely persist for centuries rather than mere decades, representing a long-term environmental legacy of the region's mining activities (Rambabu et al., 2020; Seopela et al., 2020; DWS, 2020)

2.6 Water demand and water supply

The Naauwpoortspruit River catchment faces a complex water management challenge characterised by both high demand and uneven distribution of available water resources across the region (DWS, 2017; Retief & Pollard, 2020). The industrial and agricultural sectors place enormous pressure on the system, with power generation, industry, mining, and particularly formal irrigation agriculture collectively consuming more than three-quarters of all water used in the catchment (Van Vuuren, 2009; Sara et al., 2021). This heavy extraction is compounded by significant evaporation losses from the catchment's numerous small dams and larger water supply reservoirs, leaving the lower reaches of the Naauwpoortspruit River with typically meager flows for much of the year (Netshitungulwana & Yibas, 2012). Occasionally, these low flows receive a dramatic boost when unusually heavy rainfall occurs or when tropical cyclones make landfall in the region, such as the devastating cyclone that struck in 2000, flooding extensive coastal areas of Mozambique and sending surge flows downstream (Knight

& Fitchett, 2019). However, these episodic high-flow events cannot be relied upon to address the fundamental water scarcity challenges facing the catchment.

Climate change adds another layer of complexity and concern to the already strained water situation in the Naauwpoortspruit River catchment. Research indicates that shifts in South Africa's climate will bring significant changes to rainfall patterns, with both floods and droughts becoming more intense, hydrological cycles being disrupted, and agricultural production facing new challenges (Mantel, 2015; Serdeczny et al., 2017). These climate-driven changes are particularly concerning when combined with the province's growing population and expanding economic activities, which will inevitably place even greater demands on the catchment's water supplies. Without careful management, this convergence of factors could lead to severe water scarcity problems that threaten both human communities and ecosystems (Marr et al., 2015; Knight & Fitchett, 2019). The uncertainty surrounding future water availability represents a fundamental threat to both water security and food security in the region, making it essential to develop and implement appropriate, sustainable adaptation measures that can both mitigate climate change impacts and enhance the catchment's capacity to meet future water demands.

Recognising these challenges, researchers have conducted several studies examining how climate change might affect the Naauwpoortspruit River catchment, though most of this work has focused narrowly on hydrological responses rather than broader adaptation strategies. Singh et al. (2014) investigated the hydrological impacts of climate change at both gauged and ungauged monitoring stations throughout the catchment, finding evidence that rising temperatures and declining precipitation would likely lead to decreased runoff. Similarly, Cullis et al. (2011) assessed how projected climate changes might affect water resource planning in the region. Wagener et al. (2011) took a different approach by evaluating whether existing hydrologic models were sufficiently robust to capture the full scope of climate change impacts in the Naauwpoortspruit River catchment. Their findings revealed a significant limitation: due to the scarcity of stream flow gauges throughout the catchment, these models

frequently fail to capture the complete extent of hydrological changes occurring in the system (Wagener et al., 2010).

To provide a context for water quality management, South Africa has established national drinking water standards under SANS241:2015, which regulate surface water quality parameters. Some of these standards are indicated in Table 1. However, despite this regulatory framework and the growing body of research on hydrological responses to climate change, there remains a critical gap in the literature. Very little research has been conducted on practical adaptation strategies that could be implemented to mitigate the effects of climate change on the catchment's water resources, leaving water managers with limited guidance on how to prepare for and respond to the challenges ahead.

Table 1: Comparison of study results with reference to the South African National Water Drinking standard of SANS241:2015 (Nthunya et al., 2017; Wanda et al., 2016).

Parameter	National Standard (SANS 241:2015)	Observed Range (Study Results)	Exceeds Standard	Comments / Interpretation
pH	5.0 – 9.7 (acceptable range)	7.17 – 7.35	Within limit	All sites show neutral pH; no acidity threat.
Iron (Fe)	≤ 0.1 mg/L	0.10 – 0.30 mg/L	Overexceedence	Highest at Masakhane; indicates mining-related discharge or corrosion.
Manganese (Mn)	≤ 0.05 mg/L	0.00 – 0.04 mg/L	Within limit	Within acceptable limits but elevated near Masakhane (0.03–0.04 mg/L).
Aluminium (Al)	≤ 0.03 mg/L	0.04 – 0.22 mg/L	Overexceedence	Significantly high Al across seasons, especially wet season at Masakhane (0.22 mg/L).
Sulphates (SO₄²⁻)	≤ 250 mg/L	143 – 188 mg/L	Within limit	Close to threshold; increasing during the dry season at Masakhane and Coalfield.

Total Coliform Bacteria (TCB)	0 CFU/100 mL (no coliforms permitted)	555 – 920 CFU/100 mL	Overexceedence	Extremely unsafe for drinking; indicates faecal/organic contamination.
Faecal Coliform (FC)	0 CFU/100 mL	34 – 766 CFU/100 mL	Overexceedence	High levels, particularly at Boat Camp (766 CFU), indicate sewage contamination.

2.7 Physicochemical and microbiological parameters

The physicochemical and microbiological parameters we present in Table 1 have been chosen because they are appropriate indicators of drinking water safety, anthropogenic pollution, and ecological health, especially in mining-impacted and human-settled catchments. The pH is a basic characteristic of water that indicates if water is acidic or basic and can be defined as a measure of hydrogen ion activity in water (Hobbs & Cobbing, 2007). It represents the balance between hydrogen and hydroxide ions in water. The pH is a crucial water quality parameter since many heavy metal ions and chemical species depend on pH as a controlling factor in their solubility and bioavailability (Tutu et al., 2008). pH can directly influence aquatic organisms or indirectly by controlling the chemical form of certain pollutants (Naicker et al. 2003).

Iron was also added because it is one of the most common contaminants found in mining-impacted settings, arising from acid mine drainage, geological weathering, or the corrosion of pipes and other infrastructure (Masindi et al., 2022). High levels of iron can lead to aesthetic problems, such as water discoloration, a metallic taste, and staining, and can be an early warning sign of pollution from industrial or mining sources (McCarthy and Pretorius, 2009). This makes iron an important tracer of geochemical disturbance. Manganese (Mn) is often found together with iron in groundwater and surface water contaminated by mining under low-redox conditions (Seopela et al., 2020). While manganese is a biologically required trace element, overexposure can cause serious health effects to the nervous system (Masindi et al., 2018). Manganese monitoring can be used to evaluate redox conditions and early mobilisation of metals in aquatic systems.

Aluminium (Al) is highly pH-sensitive; it is often mobilized under acidic or disturbed environmental conditions (Durand, 2012). Elevated aluminium concentrations stem from mining activities, soil erosion, and runoff. Elevated levels of aluminium may affect aquatic ecosystems and reduce the efficacy of drinking water treatment (Tutu et al., 2008). Therefore, it is an important indicator of catchment disturbance and seasonal

variations in water quality. Sulphates (SO_4^{2-}) were chosen because they are among the most important indicators of mining and mineral oxidation by sulphide-bearing rocks. Mining and industrial activities can lead to acid mine drainage and industrial discharge, with high sulphate concentrations often present (Bell et al., 2001). High levels of sulphates may affect the taste of water and cause gastrointestinal effects in humans (Ochieng et al., 2010).

Total coliform bacteria are a group of related bacteria that are (with few exceptions) not harmful to humans, but are found in human feces (Samie et al., 2012). Thus, the total coliform count is a good indicator of other pathogens (some of which are harmful) in the water and of possible contamination of the water supply. The presence of faecal coliforms in a water supply indicates that microbial contamination of human or animal origin has occurred. Such contamination may enter drinking water supplies from direct discharges or via runoff (Mema 2010). The presence of faecal coliforms or *Escherichia coli* (*E. coli*) is the most important water-quality indicator of drinking-water deterioration in developing countries. In these countries, the primary exposure pathway is likely to be ingestion of untreated drinking water, although some data suggest that transmission by other routes may occur (Dlamini et al., 2019).

2.8 Health hazards linked to physicochemical characteristics and microbials

Even though coal mining companies in eMalahleni generally indicate that they follow environmental rules, mining areas are naturally highly vulnerable to environmental pollution. Environmental experts working in the mining industry face the ongoing challenge of managing stormwater and groundwater, a task that requires constant attention and adaptation. However, this does not mean that acid mine drainage (AMD) cannot enter public watercourses. Heavy rain, in particular, can move pollutants from mining sites into streams and dams nearby, such as tributaries of the Naauwpoortspruit River. Because of this, downstream communities are still susceptible to the combined effects of AMD, heavy metals, and microbiological contamination of the water.

The health of people living in the eMalahleni Local Municipality is seriously threatened by their exposure to contaminated water, whether through drinking or everyday household use. Naauwpoortspruit River contains heavy metals and microbiological contaminants that of significant concern. For example, high levels of faecal coliforms in the water indicate that sewage pollution, and this is linked to gastrointestinal problems such as abdominal pain, diarrhoea, and gastric infections. Furthermore, Khan et al. (2016) reported that excessive aluminium exposure in Pakistan has been linked to impairment of neurological function, renal failure, and skeletal fragility conditions that present significant hazards to vulnerable populations, including children, the elderly, and those with preexisting health issues. In addition, high amounts of sulphate, even if they are still within the national limit, might irritate the stomach and induce dehydration, especially in people who are sensitive (Marr et al., 2022).

The health hazards, together with people's reports of dirty, smelly, and low-quality water, illustrate the imperative for enhanced water resource management, control mine drainage, and preserve public water supplies. The results of this study show that mining and human activities are still causing physicochemical and microbiological pollution that compromises both ecosystems and people in the area.

2.9. Empirical review of previous studies

Kumar et al. (2026) investigated the influence of coal mining on surface and groundwater quality in the Jharia Coalfield, India, by analysing water samples collected from active mines, coal washery units, overburden dumps, and the Damodar River. Their findings demonstrated that coal mining substantially degraded water quality, with elevated concentrations of TDS, hardness, BOD, aluminium, cadmium, chromium, and nickel. The authors attributed this deterioration primarily to acid mine drainage and coal washery effluent, highlighting the cumulative effects of mining activities on surrounding water resources.

These findings corroborate those of the present study, which similarly identified elevated concentrations of mining-related contaminants, particularly iron and

aluminium, in the Naauwpoortspruit River. The consistency between the two studies suggests that mining-induced deterioration of water quality is not site-specific but represents a common environmental consequence of coal mining across different geographical regions. Nevertheless, Kumar et al. (2026) focused primarily on physicochemical and heavy metal contamination, whereas the present study adopted a broader mixed-methods approach by integrating microbiological water quality assessment with community perceptions of water pollution and associated health risks. By combining environmental measurements with social perspectives, the present study provides a more comprehensive understanding of how coal mining affects both freshwater resources and the wellbeing of communities that rely on them.

Although previous international, African, and South African studies have consistently demonstrated that coal mining deteriorates water quality through acid mine drainage and heavy metal contamination, several important knowledge gaps remain. First, most South African studies have concentrated on downstream impacts while giving limited attention to upstream communities exposed to mining activities. Second, many investigations have focused exclusively on physicochemical characteristics, with comparatively few incorporating microbiological water quality indicators. Third, limited research has integrated scientific water-quality assessment with community perceptions and associated public health risks. Addressing these gaps, the present study adopts an integrated mixed-methods approach that combines physicochemical and microbiological analyses with community perceptions to provide a comprehensive assessment of the environmental and health impacts of coal mining on the Naauwpoortspruit River. This approach contributes new evidence to support improved water resource management and policy development in South Africa.

2.10. Analytical framework as a guiding tool

Figure 2.10 illustrates the analytical framework that directed this research. The framework delineates the process by which coal mining operations were assessed concerning water quality degradation, environmental and public health hazards, and the comprehensive analysis of the results.

The framework initiates with coal extraction operations, which constitute the primary emphasis of the research. These actions produce possible pollution sources, such as acid mine drainage (AMD), mining refuse, and surface runoff, which could negatively impact adjacent water resources.

The second element of the framework consists of the water quality metrics employed to assess the degree of pollution. The quantitative evaluation encompassed physicochemical factors (pH, iron, manganese, aluminium, and sulphate) as well as microbiological metrics (Total Coliform Bacteria and Faecal Coliforms). Laboratory examinations were performed to ascertain the levels of these indicators, while focus group dialogues were employed to gather qualitative insights on community views of water quality and related health hazards.

The analytical methodology combines quantitative laboratory results with qualitative community insights to deliver a thorough evaluation of water quality. The amalgamation of these two datasets allowed for a comparison between quantified water quality and the experiences of the impacted populations, thus enhancing the analysis of the results.

Ultimately, the comprehensive evaluation was employed to examine the possible environmental and public health hazards linked to the declining water quality in the Naauwpoortspruit River. The framework consequently directed the gathering, examination, and interpretation of the data, guaranteeing that both empirical evidence and community experiences informed the study's findings.

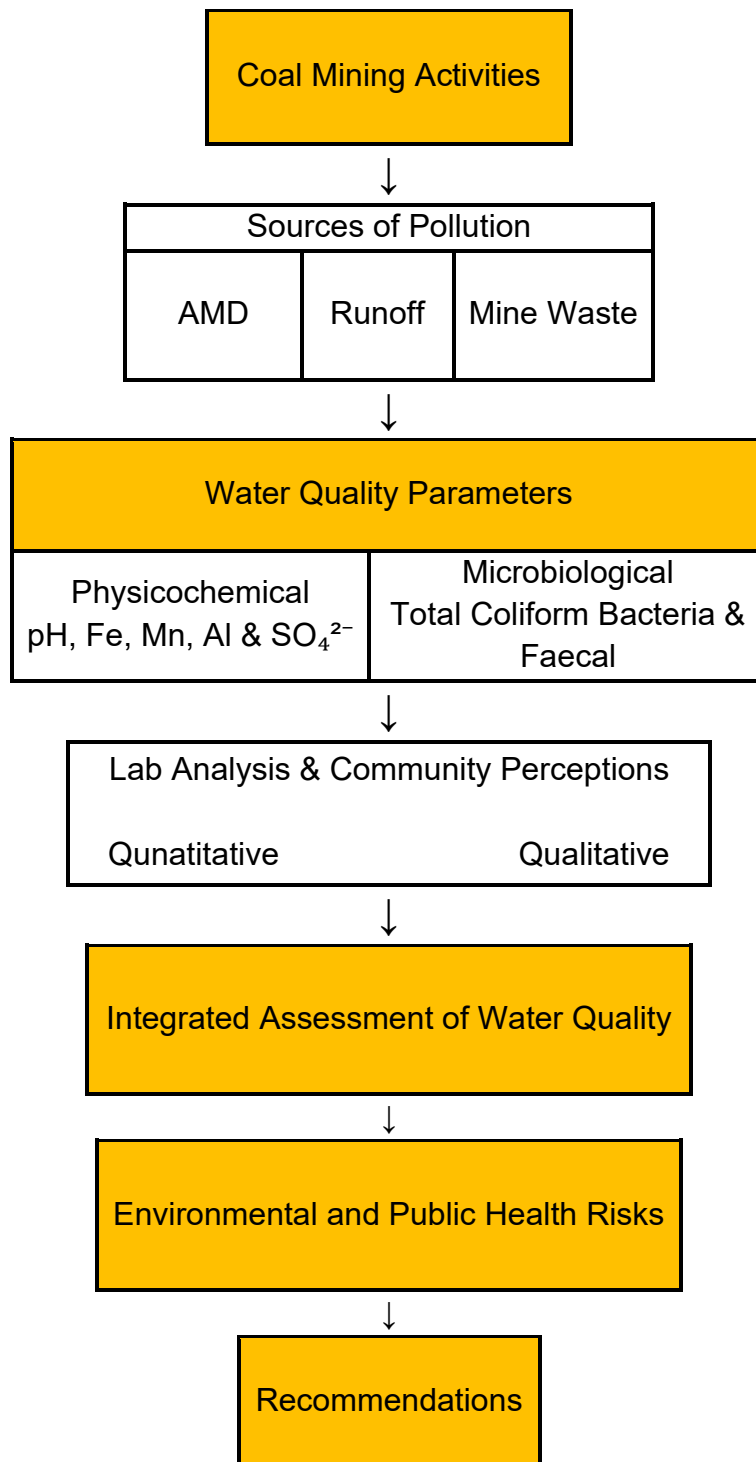


Figure 1a. Conceptual analytical framework for the assessment of water quality in coal mining environments.

CHAPTER 3: RESEARCH METHODS AND DESIGN

3.1. Introduction

The methodological approach for this study gives the research a structure. It decides how the data for a certain study will be gathered. Creswell and Creswell (2018) suggested that a research design provides the framework that bridges the gap between the research questions and the practical implementation of the study. It gives a clear plan that shows how the different methodologies are used in a research process to get valid and correct responses to the research questions (Kumar, 2014).

3.2. Research design

The research applied a mixed-methods design that blended qualitative and quantitative techniques. Water samples were collected from three sites along the Naauwpoortspruit River in eMalahleni, Mpumalanga province, South Africa, and their physicochemical and microbiological quality were analyzed as part of this study's quantitative and qualitative methodologies. The population residing in the Masakhane area was also engaged in focus group discussion. To gain insight into the effects of coal mining operations on the quality of the Naauwpoortspruit River and possible impacts on human health, the collected data were analyzed, discussed, and compared with South African regulatory bodies' guidelines standards. These bodies included the Department of Water and Sanitation (DWS), the Department of Fisheries, Forestry and Environment (DFFE), and the World Health Organization (WHO).

3.3. Study area

This research was conducted in the eMalahleni Local Municipality (ELM) (Figure), a location renowned for its significant role as South Africa's foremost coal-producing area, which, along with the Highveld, contributes to around 75% of the nation's coal output (Department of Energy, n.d.). The mining town, previously known as Witbank, was renamed eMalahleni in 2006, a Nguni term meaning 'site of coal.' eMalahleni is

situated in the Nkangala District Municipality (25.8728° S, 29.2553° E) within a water-scarce area of the northeastern part of Mpumalanga province in South Africa as shown in Figure .

The ELM covers the following areas: eMalahleni, Ga-Nala, Kwa-Guqa and Ogies. The eMalahleni municipal area contains approximately 20 coal mines, characterized predominantly by underground and opencast operations. The area has more power stations than anywhere else in South Africa, including Kendal, Ga-Nala, Duvha, and Matla. The Kusile power station, one of the newest facilities, is located a few kilometres east of Phola. In 2022, the local municipality's population was approximately 434, 522 individuals. Water samples for the investigation were obtained from the Naaupoortspruit River and the Witbank Dam around the area (Figure 1).

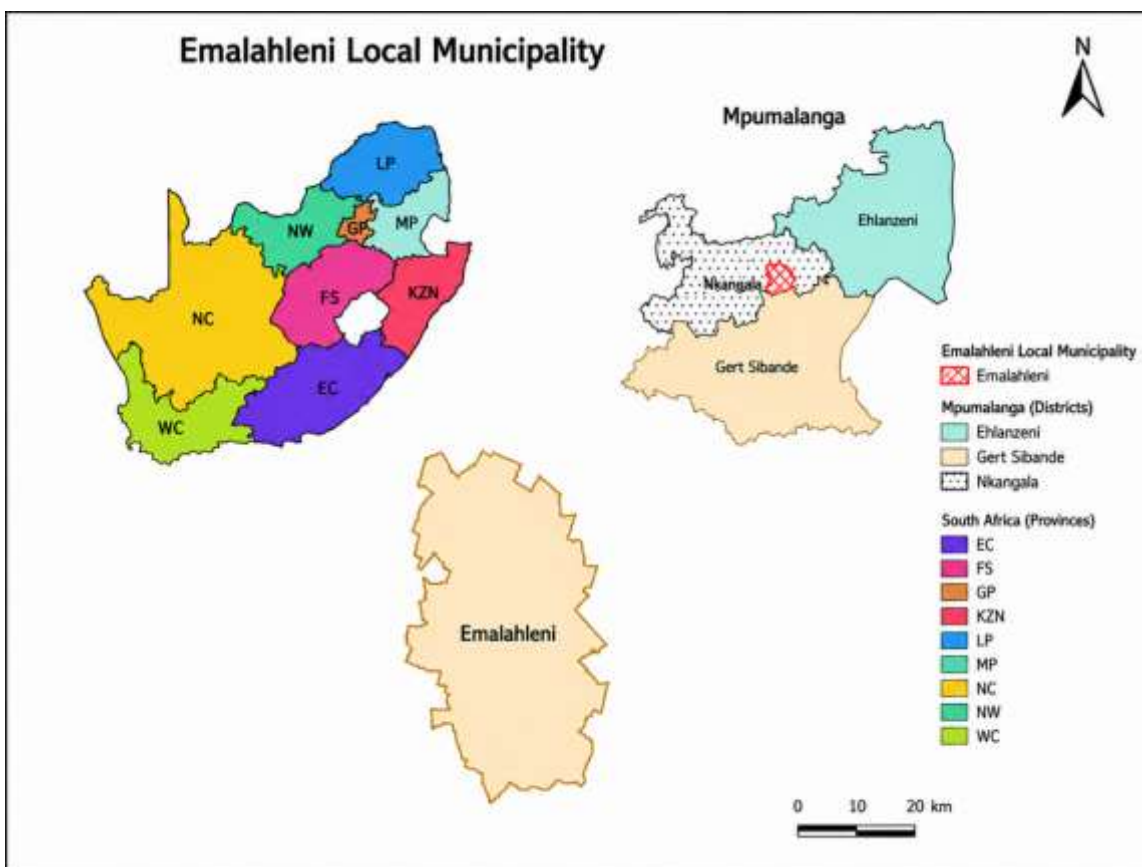


Figure 1: Map of South Africa indicating Mpumalanga Province. eMalahleni Local Municipality is situated within the Nkangala District Municipality

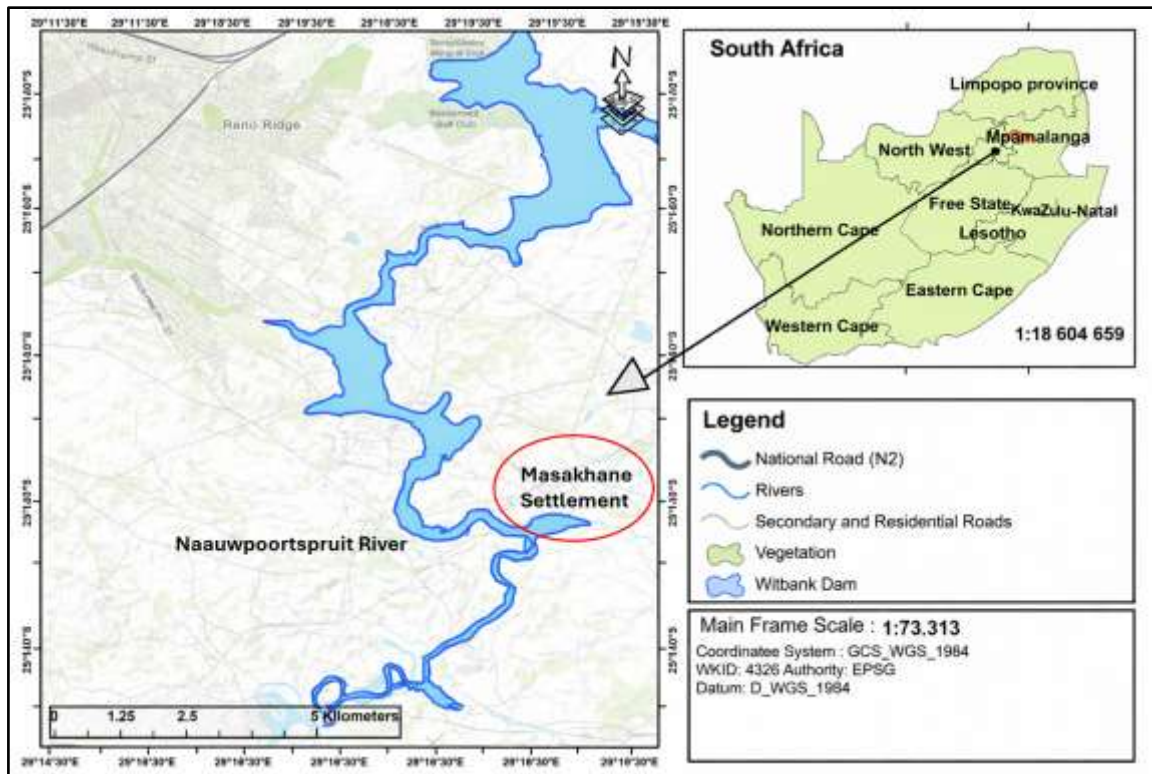


Figure 1: Overview of study area - Naauwpoortspruit River at Masakhane Settlement.

3.4. Qualitative research method

A qualitative research design was utilized for exploring the experiences, perceptions, and attitudes held by members within the community of Masakhane about the impact created by coal mines on the Naauwpoortspruit River water quality. A qualitative research design is applicable for this study as the method allows for the exploration and understanding of human experiences and realities as they exist within natural settings (Creswell, 2014). A qualitative approach was applied for obtaining community perceptions and experiences that cannot be readily gathered. Qualitative research encompasses a wide array of methodologies. Qualitative studies seek to elucidate participants' experiences and their interpretations and emotions regarding these experiences within a particular context (Brink 1996).

3.4.1. Study population, recruitment and sampling technique

The target population was adult residents (18 years and above) living within the Masakhane and other surrounding communities and aged at least five years within the area. This was to ensure that the participants were well-versed and knowledgeable about the dynamic water quality within the area. The participants were recruited through the community councillor's network and his ability to organise members of the community at their convenience. Purposive sampling was used with the intention of involving well-versed participants with regard to local water sources and the effects of mining activities (Etikan et al., 2016). A total of 60 participants were selected and composed into 12 groups with each having a total of five participants. The researcher obtained a permission letter (Appendix A) from the eMalahleni Local Municipality Council to conduct a Focus Group Discussion (FGD) with the Masakhane community regarding their water quality conditions.

3.4.2. Data collection

The study employed Focus Group Discussions (FGDs), which proved effective for exploring experiences and perceptions shared by participants (Krueger and Casey, 2015). A semi-structured discussion guide was used for FGDs to facilitate discussions while giving participants the freedom to share their opinions. These FGDs were held at a community hall and moderated by the researcher, aided by a community leader. The FGDs were held in English and local languages (Xitsonga, Sepedi, isiZulu, and Setswana). The researcher successfully introduced the theme of the day and facilitated a comfortable atmosphere for the participants in answering the following developed research questions:

1. How would you describe the current state of water quality in the Masakhane area from your own experience or observations?
2. Explain how the condition of the water in this area makes you feel?
3. Do you ever run out of potable/drinking water for days? if yes, what is your alternative source of potable water?

4. Do you drink water from the tap, or do you prefer to buy bottled water from the shop? yes or no, please explain. Why?
5. In your view, what are some of the major human (anthropogenic) activities contributing to water pollution in this area? Can you give specific examples?
6. Among the possible pollution sources like mining, transport, agriculture, or others, which do you believe are the most harmful locally, and why?
7. What would you propose to the mining industry to protect water resources and water quality management?

A duration of 45-60 minutes was taken for each FGDs. Recording was done with participants' consent and field notes were taken to observe behaviours and non-verbal cues.

3.4.2.1. Implementation of the Focus Group Discussions

The investigation conducted 12 semi-structured focus group discussions (FGDs), with 5 participants in each, culminating in a total of 60 interviewees. The selection of these semi-structured focus groups was based on their ability to strike a balance between consistent conversations guided by preset questions and the opportunity for members to share their experiences and perceptions regarding water quality and health implications. This strategy was fitting since the study sought to examine collective experiences in the community while also facilitating the spontaneous emergence of new themes in conversation.

Subjects were deliberately picked from Masakhane and nearby areas because to their awareness of local water sources and their presence in the study region. The assemblies featured male and female adults (18 years and older) with differing educational experiences and job roles to provide a broad range of insights regarding water quality and the ramifications of coal mining. Each group's structure represented the heterogeneity of the surrounding community rather than conforming to defined demographic standards.

Subjects were deliberately picked from Masakhane and surrounding areas based on their understanding of local water resources and their presence within the study region. The assemblies included adult participants (18 years and older) of both sexes with varying educational experiences and jobs, to garner a spectrum of insights regarding water quality and the ramifications of coal mining. Each organization was formed to embody the diversity of the local community instead than fulfilling particular demographic requirements.

The researcher functioned as the moderator for all conversations, with a community leader providing support in coordinating participants and interpreting languages as needed. A semi-structured dialogue guide was utilized to uphold uniformity among groups while enabling the investigation of matters that need more clarity. Open-ended inquiries facilitated discussions among participants on their experiences with water quality, perceived pollution origins, health-related concerns, and proposals for better water management. Additional queries were utilized to garner extra elucidation if needed.

Each conversation spanned about 45 to 60 minutes and was recorded audibly with the participants' approval. In conjunction with audio recordings, field notes were created to record non-verbal cues, group interactions, and contextual observations that could facilitate data interpretation.

3.4.3. Data Management

The audio recordings were all transcribed word for word. Where conversations were carried out in local languages, they were translated into English. The transcript was then checked for any inconsistencies with the audio recordings. All the data were anonymized by assigning participants with codes.

3.4.4. Data analysis

3.4.5. Application of Braun and Clarke's six-step thematic analysis

Thematic analysis was employed to analyze the data. The researcher provided clarification and answers to the posed questions. A process of thematic analysis was

used on the qualitative findings consistent with the six-step process outlined by Braun and Clarke (2006):

3.4.5.1. Familiarization with the data

The researcher became familiar with the qualitative data by reading and re-reading the focus group discussion transcripts several times. This process enabled a thorough understanding of participants' perceptions and experiences regarding the impacts of coal mining on the water quality of the Naauwpoortspruit River.

3.4.5.2. Generation of initial codes

The transcripts were systematically examined, and meaningful segments of text relevant to the research objectives were assigned initial codes. The coding process focused on recurring ideas relating to perceived water quality, health concerns, water insecurity, pollution sources, and suggested interventions.

3.4.5.3. Searching for patterns and emergent themes

The initial codes were compared and grouped according to similarities and relationships. This process allowed broader patterns to emerge, leading to the development of preliminary themes that reflected the participants' shared experiences and perceptions.

3.4.5.4. Reviewing and refining themes

The preliminary themes were reviewed against the coded extracts and the complete dataset to ensure they accurately represented the participants' responses. Themes were refined by merging overlapping concepts, removing irrelevant information, and ensuring internal consistency.

3.4.5.5. Defining and naming themes

Each theme was clearly defined and appropriately named to reflect its central meaning. Four overarching themes were identified: Perceived Water Quality and Health Risks, Water Insecurity, Sources of Water Pollution, and Solutions and Recommendations. These themes

captured the key issues raised by participants during the focus group discussions.

3.4.5.6. Producing the final report

The final report presented the themes in a logical and coherent manner, supported by direct quotations from participants to illustrate the findings. The qualitative results were interpreted alongside the quantitative water quality analyses to provide a comprehensive understanding of the environmental and public health impacts of coal mining on the Naauwpoortspruit River. This method allowed for the important themes tied to perceived water quality, health effects, water insecurity, pollution sources, and suggested solutions from the community to be readily identified.

3.5. Quantitative data

3.5.1. Sample sites

The sample sites were independent from each other since upstream (Coalfield), midstream (Boat Caravan Club), and downstream (Masakhane Settlement), as shown in Figure 2 and Figure 3. Samples were collected near the riverbank for convenience of sample collection as well as because pollutants are pushed back to the riverbank during the water flow. Water samples were collected at 25-30 cm below the surface using a clean container that was immersed in the water. In addition, samples were collected during normal operating hours. During collection, personal protective equipment (PPE) was worn by the researcher.

Three pre-established sampling locations: Point 1, Point 2, and Point 3 locations are detailed in Table 2.

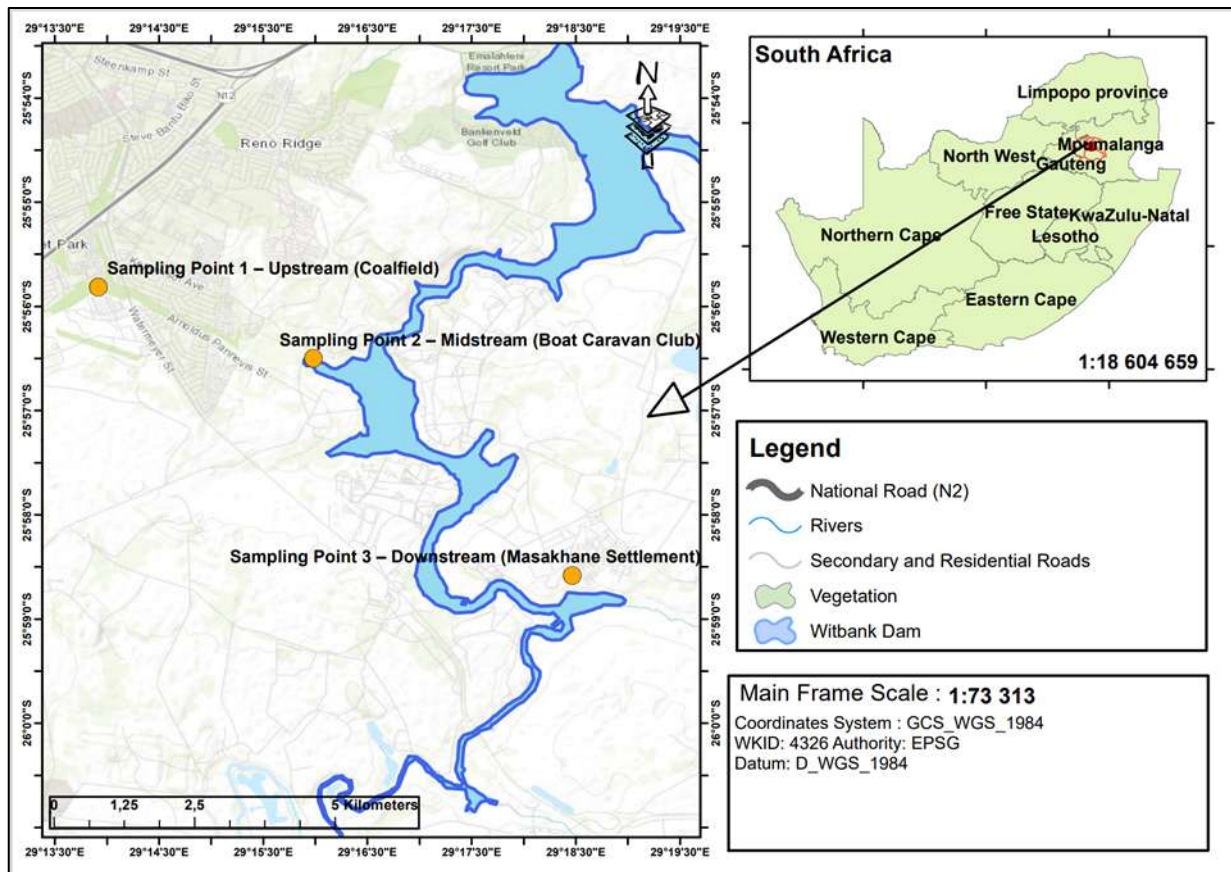


Figure 2: Map showing the location of the sampling points.

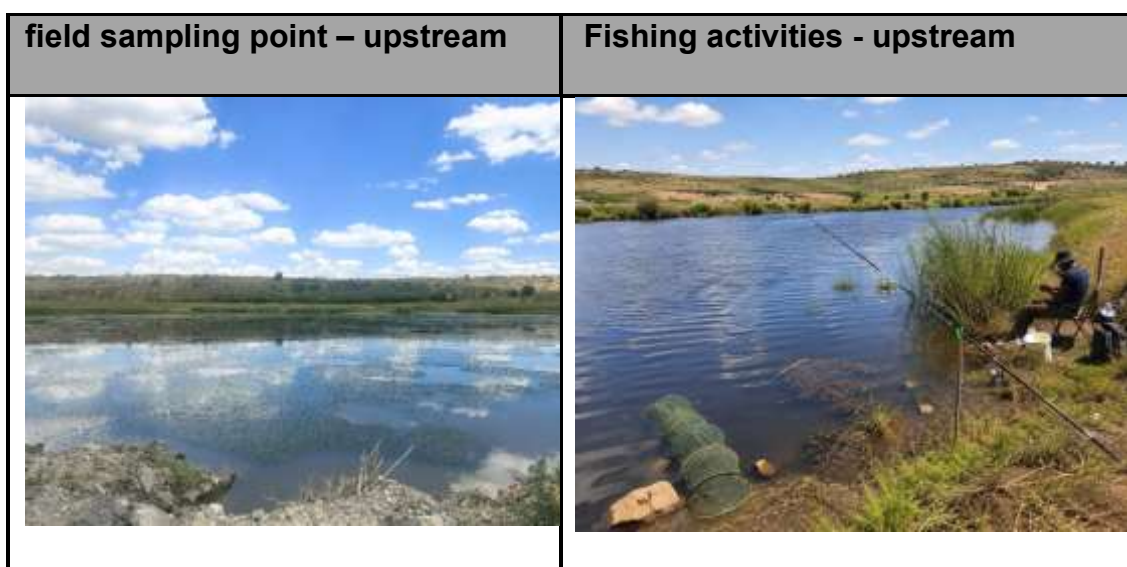


Figure 3: Photographs showing overview of the sample sites

Characteristics	Description	Location	Related pollution activities
Upstream Sampling Point 1	Coalfield	25°55'48.7"S 29°13'55.1"E	Run-off from an array of local coal mining fields.
Midstream Sampling Point 2	Boat Caravan Club	25°56'30"S 29°15'59"E	Receiving exhaust fumes and car wash inorganic detritus, and also the discharging point of the municipal wastewater treatment plant.
Downstream Sampling Point 3	Masakhane Settlement	25°58'35"S 29°18'28"E	Residential Area where fishing and boating activities are taking place timeously, and toxic littering is observed.

Table 2: Detailed description of the sample sites.

3.5.2. Sampling technique

The Grab method was employed for sampling the water. Prior to sampling, all containers were thoroughly cleaned and sterilized through autoclaving to eliminate potential microbial contaminants. Water samples were collected in triplicate at each site using sterilized 500 ml Schott bottles. After collection, the samples were placed in a cooler box containing ice packs to maintain appropriate storage temperatures during transport to the Regen Waters Laboratory in eMalahleni for subsequent analysis.

3.5.3. Physicochemical parameters analysis

To assess water quality in the Naauwpoortspruit River, samples were analyzed for several physicochemical parameters: pH, iron (Fe), manganese (Mn), aluminum (Al), and sulphate (SO_4). Standard analytical methods for water quality assessment were employed throughout the study. Before beginning fieldwork, all instruments (multiparameter instrument (HANNA Instruments, Thermofisher, Johannesburg, South Africa) were carefully calibrated in the laboratory following manufacturer recommendations and instructions established in the Standard Methods for the Examination of Water and Wastewater (APHA, 2017).

3.5.3.1. Determination of Potential Hydrogen (pH)

pH serves as an indicator of water's acidity or alkalinity through the measurement of hydrogen ion concentration (U.S. EPA, 2012). A multiparameter instrument (HANNA-HI 9829 Instruments, Johannesburg, South Africa) was used to measure pH in the field.

3.5.3.2. Metal Detection (Fe, Mn, Al)

The concentrations of Fe, Mn, and Al were measured using a calibrated multimeter water quality analyser equipped with ion-specific probes. Prior measurements, this instrument was calibrated according to the manufacture instructions. Water samples

were taken into precleaned polyethylene bottles and filtered through 0.45 µm membranes filter paper immediately on return to the laboratory to minimize oxidation for further microbial analysis.

3.5.3.3. Sulphate Analysis

The SO₄ concentrations were measured using an ISE meter (Orion model 93-07). The electrode of the meter was rinsed with deionised water before determining the level of SO₄ concentrations of any subsequent sample, to prevent inter-sample contamination.

3.5.4. Microbiological analyses

3.5.4.1. Heterotrophic plate counts

Heterotrophs are microorganisms, including bacteria, Molds, and yeasts, that utilize organic carbon sources for growth (Lyn, 2017). Total coliform bacteria represent the aggregate of viable aerobic bacteria in each sample, without differentiation. This signifies that the culturable species identified may constitute merely 1% of the entire bacterial population (Lyn, 2017). Total bacterial counts were determined using the pour plate technique with plate count agar (APHA, 2017). Each water sample underwent tenfold serial dilution, and 1 ml of the 10⁻³ dilution was aseptically pipetted into a sterile petri dish. Standard plate count agar (20 ml) was then added and gently mixed with the sample. The plates were left undisturbed until the agar solidified, then inverted and incubated at 37°C for approximately seven days to allow for any delayed bacterial growth. After incubation, colonies were counted on all plates containing between 30 and 300 colonies. Final bacterial counts were calculated by averaging duplicate counts and dividing by the volume of the original sample plated, with results expressed as colony-forming units per millilitre (CFU/mL).

3.5.4.2. Total coliforms and faecal coliforms

The membrane filtration method was used to quantify total coliform and faecal coliform bacteria in water samples. Approximately, 100 ml of water samples were filtered through 0.45 µm membrane filter paper. Each filter was then transferred to a petri dish

containing m-Endo agar. Within 30 minutes of filtration, plates were incubated for 24 hours at 35°C for total coliform enumeration and at 44.5°C for faecal coliform enumeration. After incubation, total coliform colonies displaying a characteristic golden-green colour with metallic sheen were counted and recorded. Similarly, faecal coliform bacteria appearing as blue colonies were enumerated. Bacterial concentrations were calculated using the following formula:

$$TC \text{ or } \frac{TF}{100} = \frac{\text{Number of colonies}}{\text{Volume of samples filtered}} \times 100$$

3.6. Reliability and validity of the research study

In the case of reliability, the sampling of water was collected under strict guidance and standardized procedures from Regen Waters Laboratory, which is an accredited water analysis laboratory based in eMalahleni. Moreover, the interviews and questionnaires enhanced validity by means of cross-verifying findings.

3.7. Ethical consideration

3.7.1. Obtaining permission

Ethical considerations were appropriately acknowledged and integrated into the research process in compliance with the regulations of the University of South Africa (UNISA). The UNISA College of Agriculture and Environmental Sciences (CAES) Health Research Ethics Committee received the research proposal for ethical approval (Appendix B). After reviewing the low-risk application on February 12, 2024, it was determined that it complied with both the Standard Operating Procedure on Research Ethics Risk Assessment and the UNISA Policy on Research Ethics. The UNISA CAES Health Research Ethics Committee then issued ethical clearance, with reference number REC: 2024/CAES_HREC/4624. Additionally, the eMalahleni Local Municipality granted authorization to examine and utilize water quality monitoring data.

3.7.2. Gathering Consent

Prior to beginning the focus group discussion, the researcher introduced himself to the participants before explaining and clarifying the study's purpose to the participants, tailoring the explanation to their comprehension level. The research topic and study

objectives were meticulously analysed. All participants were assured that there were no correct or incorrect answers in accordance with the principles of the focus group discussion and that they could leave the study at any time. Participants were provided ample time to review and sign the consent forms (Appendix C). The researcher assisted all individuals requiring clarification and support in completing the consent form. Each point was explained to ensure that participants understood the contents of the consent forms before signing. The consent forms were non-binding if participants choose to withdraw from the research study.

3.8. The limitations and assumptions of the study

The research study in terms of quantitative data was impacted by the secondary data provided by the ELM. Moreover, two sampling points were outside the sampling points of eMalahleni Local Municipality, wherein the researcher had to frequently (twice a month) visit the sampling points as per the requirement. There were livestock activities and restrictions of access especially at Masakhane Settlement sampling point. Such activity led to a continued contamination of water at the sampling point. At times, the researcher had to return home without taking samples of which led to time-to-time rescheduling tendencies.

3.9. Statistical analysis

Minitab 19 statistical software was used for data analysis. The General Linear Model (GLM) procedures within Minitab version 19 were applied to conduct an analysis of variance (ANOVA) using a 2×3 factorial design (Minitab, 2019). This factorial design was appropriate because water samples were collected across two seasons (wet and dry) and from three sampling sites (Masakhane, Boat Camp, and Coalfield). Tukey's post hoc test was then employed to compare treatment means. Statistical significance was set at $P < 0.05$.

CHAPTER 4: DATA ANALYSIS AND INTERPRETATION OF RESULTS

Part 1 - Qualitative

4.1 Qualitative data analysis

In the coal-mining region of South Africa, specifically eMalahleni, Mpumalanga, it has long been evident that mine and coal processing activities over several decades have led to severe pollution of the water resources, including the Naauwpoortspruit River, because mine acid concentrations are high, and due to metallic, and suspended particulate waste in the water (Bell et al., 2018; Durand, 2012). Hence, the current study assessed community perceptions on the environmental impacts associated with coal mining, processing and affecting the water quality of the Naauwpoortspruit River (Table 3). A qualitative research design and approach were used to assess lived experiences and perceptions on water quality by community members in the Masakhane village, which is part of the eMalahleni municipality.

A total of 60 participants were purposively sampled and grouped into twelve focus groups comprising five members each, and were stratified by age (18-30, 31-45, 46-64, and 65+ years; three set for each group), to generate intergenerational perceptions on water quality and health impacts. Every stratum represented by the twelve focus groups offered greater representation and validity on the health impacts associated with water quality. Inclusion of equal numbers of males and females provided balanced perceptions on domestic water and health risk considerations (Table 4).

Qualitative objectives
1. To analyze the perspectives of the communities surrounding the coal mines in eMalahleni regarding the environmental impact of coal mining and processing waste.

Table 3: Showing a qualitative objective.

Groups	Age group (Years)	Gender ratio (M: F)
Group 1	18-30	2:3
Group 2	18-30	2:3
Group 3	18-30	3:2
Group 4	31-45	2:3
Group 5	31-45	2:3
Group 6	31-45	2:3
Group 7	46-64	2:3
Group 8	46-64	3:2
Group 9	46-64	3:2
Group 10	65+	3:2
Group 11	65+	2:3
Group 12	65+	3:2

Table 4: Biographical information of the groups of participants

4.2 Thematic analysis and interpretation of the findings

Four broad themes were revealed by the thematic analysis, each consisting of two sub-themes (Table 5) These are encapsulations of the intricate interplay between exposure, reliability, perception, and governance, which are often evident in similar studies carried out elsewhere across the globe, particularly in mining-dependent eco-systems (Kemp et al., 2016, Oliveira et al., 2020).

Themes	Sub-themes
Perception of water quality and health risks	1.1. Poor water conditions
	1.2. Perceived health and emotional effects
Water insecurity	1.3. Water shortage
	1.4. Avoidance of tap water
Sources of water pollution	1.5. Mining activities
	1.6. Other anthropogenic activities
Solutions and recommendations	1.7. Infrastructures
	1.8. Governance and collaborations

Table 5: Presentation of themes and sub-themes

4.2.1 Theme 1: Perceived water quality and health risks

This theme clearly reflects that people generally recognise the water quality of Masakhane to be unsafe and deteriorating. In various age groups, most people indicated their domestic water to be:

‘poor, ‘dirty, ‘brown, ‘smelly, and/or ‘toxic’

which is supported by the noted impacts of mine and industrial pollution on water clarity and health (Ochieng et al., 2010; Matshusa & Odiyo, 2018). Two sub-themes emerged from this sub-theme as described below.

Sub-theme 1.1: Poor water conditions

Participants characterized water as:

"brown, muddy, and smelly with suspended particulate matter"

These sensory factors, including colour, odour, and turbidity, are universally accepted hazard indicators, and the perception of water risk is activated, even if technical information is not adequate (Doria, 2010). In areas surrounding mining areas, such visible pollution can hardly be separated from the presence of Acid Mine Drainage

(AMD), which adds iron oxides, manganese, sulphates, and suspended sediment to the surface and groundwaters (McCarthy & Pretorius, 2009; Durand, 2012). The brownish-red water, so often reported by residents, matches the ferric hydroxide precipitates found in AMD-impacted stream systems. In addition to dissatisfaction with aesthetic appearances, the participants' attention to dirt and discoloration exhibits a failure of trust regarding the treatment carried out by the towns. Participants indicated:

Group 1 noted that: "Water smells bad and is always dirty."

Group 8 stated that: "...water is not purified, it is brown and muddy."

Group 3 said that: "The water is brown and sometimes smells like metal.
We're scared to use it."

This distrust is normally associated with past exposure to either unprocessed or improperly treated water, often evident in minority groups who historically face long periods of pollution (Harvey & Reed, 2007). Residents' observations are also a significant source of environmental knowledge, which is relevant to hydrochemical and ecological changes associated with coal mining.

Sub-theme 1.2: Perceived health and emotional effects

The participants associated poor water quality with health conditions such as diarrhoea, gastrointestinal problems, and dermatitis. These health problems are scientifically supported by the presence of pathogenic bacteria, suspended materials, heavy metals, and sulphates, which are found in mine water and are known to cause diarrhoea, dehydration, and organ toxicity (Karabulut et al., 2019; Nkosi & Wichmann, 2015). Furthermore, people most affected by such health problems include infants, the elderly, and immunocompromised people. Participant also said that:

Group 2 noted that: "We might end up sick because of this dirty water."

Group 10 observed that: "Once consumed, chances are you might experience diarrhoea."

Group 6 commented that: "You can see dirt in the water, and after drinking it, we get stomach problems."

Group 9 indicated that: "The water causes skin rashes, especially for kids."

Emotions such as fear, anxiety, and frustration were also exhibited, which resonate with the global literature regarding the feeling of hopelessness, powerlessness, and environmental stress associated with pollution (Brisbois, 2019). The intergenerational trauma of emotions apparent in Masakhane implies that the issue of water is not just a technical breakdown but a psychosocial burden. Hence, the health risk perceptions of the community are the result of exposure, assessment, and experience, which are elements well known to influence health risk perceptions.

4.2.2 Theme 2: Water insecurity

Water insecurity emerged as a theme from the participants' responses to questions 3 and 4. This theme highlights the struggles of the community members with access to potable water and their lack of confidence in the quality of available sources of water. The majority of participants report frequent shortages of potable water, relying on alternative sources such as municipal tankers, boreholes, employers, or commercial suppliers. This is therefore unpacked into the following two sub-themes: shortage of water and avoidance of tap water. The residents' experience is not just about poor water quality but also about the uncertainty of water access, which falls under the definition of water insecurity by the UN, including accessibility (UN Water, 2021).

Subtheme 2.1. Shortage of water

Respondents cited regular and unpredictable instances of unavailability of potable water. These unavailability instances are common among the affected municipalities because of mining. This is due to, among other factors, the high demand and the effects of pollution on water treatment (Tempelhoff et al., 2018). Relying on water trucked into the community, boreholes, and bottles is a common practice among water-insecure people worldwide (UN-Water, 2021). Although the above methods are important, considerable costs are incurred, especially by low-income households. To most people, water scarcity creates a need to ration, fetch water from far away, and buy water in bottles, which reinforces social inequalities. Groups 2, 4, 5, 6, and 10 reported

frequent reliance on purchased water. Group 12 described dependence on municipal tanker deliveries.

Group 5 reported that: “We buy bottled water from the shop.”

Group 2 reported that: “Sometimes we go two or three days without water.”

Group 7 said that: “When there is no tap water, we fetch from the river.”

Group 10 warned that: “We stockpile water because we don’t trust it will always be available.”

As reported by Schlosberg (2013), literature on environmental justice has long established the inequitable transfer of costs associated with environmental deterioration to poorer societies. The volatility of the reported shortage by certain groups reflects the instabilities associated with urban water infrastructure, which often has interruptions and patchwork phases of repair. In general, this sub-theme points to water insecurity as a failure, technical and socio-economic stress.

Sub-theme 2.2. Avoidance of tap water

Tap water avoidance stood out as a notable behavioural adaptation. In the global perspective, the distrust of piped water is closely associated with past experience with pollution, mixed messages and information generated by the municipality regarding water, and observable changes in the water quality (Doria, 2010). In Masakhane, it is driven by sensory dissatisfaction (“dirty water”), past illnesses, and perceptions of piped water as “unsafe.” The community’s turn to alternative sources, such as boiling, bottling water, and borehole drilling, is a risk mitigation practice.

Group 1 noted that: “If we don’t have money, we drink the tank water because we don’t have taps.”

Group 6 reported that: “No, we prefer bottled water from the shop.”

These measures are indicative of resilience but also demonstrate governance failure. Regaining community confidence to consume piped water involves long-term commitment to reliable water quality and governance accountability (Harvey & Reed, 2007). Even the fact that Masakhane leans on bottled water raises several environmental and financial considerations, which clearly suggests a practice of unsustainable consumer behaviour. As a sub-theme, it highlights the ways and means by which water insecurity is constituted into everyday life.

4.2.3 Theme 3: Sources of water pollution

The sources of water pollution were mainly identified by participants to result from human activities such as coal mining, which verified scientific observations of the eMalahleni region to be among the most polluted mining areas within South Africa (McCarthy & Pretorius, 2009; Bell et al., 2018). The majority of the participants perceive primarily human activities as the biggest contributing factors to local water contamination, particularly industrial operations and poor environmental practices. Mining activities and other anthropogenic activities emerged as the two main sub-themes under this theme.

Sub-theme 3.1. Mining activities

The participants mainly pointed to coal mining as the source of water pollution. This is supported by scientific literature, which suggests eMalahleni mine is characterized by AMD, heavy metals, oils, hydrocarbons, and suspended solids, which are released into the surrounding rivers (Bell et al. 2018; Maree 2020). The inclusion of "oil spills," "dirty water from mines," and "dust" is a sign of community understanding of both point source and non-point source pollution as elaborated by participants:

Group 1 suggested that: "The mines dump dirty water, and it goes straight into the river."

Group 4 pointed out that: "...there is always issue of oil spills and dirty water from mines..."

Groups 11 and 12 said that: “....a lot of dust, dirty water and chemicals come from mines...”

The description of dust suggests atmospheric deposition as another source of pollution. In mining districts, dust is known to carry metal particles, sulphates, and carbon residues, which consequently fall on soil, roofs, and water (Ochieng, 2010). This indicates a community conscious of pollution as having various dimensions. The priority on mining reflects a strong causal attribution, which is supported by global literature identifying communities surrounding extractive industries as having high levels of awareness regarding industrial hazards (Kemp et al., 2016). This is supported by South African literature verifying Naauwpoortspruit River Basin is under severe pollution due to mining waste, stormwater runoff, and treatment failures (McCarthy, 2011). Consequently, the under-themed finding declares that community perceptions demonstrate defined regional hydrochemical influences.

Sub-theme 3.2. Other anthropogenic activities

The participants were also able to identify other sources of pollution, which include transportation industries, commercial factories, illegal dumping, and littering. The comprehension of the origins of pollution reflects a rich understanding of the concept of cumulative pollution, which is referred to as the interaction of several sources of pollution affecting an ecosystem (Ning & Liu, 2021). Trucks and vehicle workshops are also sources of leakages of oil, fuel, and lubricants, which drain into water sources when it rains.

Group 5 reported that: "The sewage plant also makes the river dirty."

Group 6 responded that: "People dump rubbish and wash cars near the river."

Other sources of pollution include illegal dumping of plastic, biological, and chemical materials into drains. In addition, industries emit industrial waste and pollution. Although such sources were considered secondary to mining, their frequent occurrence suggests; awareness of complex pollution paths, understanding of the

interconnections between human activities and water quality, understanding the role of mining as part of a greater landscape of industrial disturbances. This is true to the finding that communities along industrial corridors worldwide recognize pollution to be of a cumulative, multi-source nature (Oliveira et al., 2020).

4.2.4 Theme 4: Solutions and recommendations

In spite of the frustrations expressed by the participants relating to water quality in the Masakhane area, they proposed realistic and constructive solutions and recommendations. This theme highlights the community's willingness to participate in change, emphasizing their desire for inclusive governance, stronger partnerships, and systems that respect and incorporate local voices. At the same time, community members demand active engagement and environmental responsibility from both the government and mining industries. The two sub-themes that emerged under this theme include infrastructure and governance, and collaborations, as outlined below.

Sub-theme 4.1: Infrastructures

This sub-theme emphasises the solutions and recommendations necessary for alleviating problems at hand. The majority of the participants reported on physical interventions and technical infrastructure to minimize environmental harm.

Groups 1 and 2 suggested the need to:

“Construct water treatment plants” and

“Proper stormwater management”, respectively.

While focus group 4 suggested the:

“Rehabilitation of mining sites and shutdown of illegal mines.”

These recommendations are supported by global best practice regarding AMD management and principles of water resource management (Younger, 2021; Ashton

et al., 2001). The awareness achieved shows that residents are not passive but rather are active observers, who are able to provide scientifically applicable recommendations. In addition, the call to rehabilitate illegal and abandoned mines is relevant to debates surrounding environmental governance in South Africa, where so-called 'ownerless' mines are known to significantly pollute the environment (Department of Mineral Resources, 2017). This sub-theme suggests the presence of practical knowledge within the community, which can then be meshed into more formal planning and water management.

Sub-theme 4.2. Governance and collaborations

The residents called for community participation, increased government surveillance, enforcement of mining laws, and financial support to enable community-led initiatives to monitor mining. These requests resonate with the global shift towards co-governance, which assumes community involvement to improve environmental governance and curb conflict (Lange et al. 2017). Community-based water monitoring, to name an example, has been found to improve transparency, detection of pollution events, trust-building between government, industry, and community, empowerment of marginalized communities, and environmental democracy (Brisbois et al., 2019). The demand of the participants to "follow regulations" and "not contaminate water" is an indication of concern about the environment and the upholding of constitutional rights to a safe and clean environment (Section 24 of the South African Constitution). Hence, it is evident that the under-identified issue of inclusiveness regards the desire to have involvement of the community not only informed but also engaged.

Group 9 stated that: "...government must involve community members to ensure sustainable water supply...."

Group 8 suggested: "...subsidise/fund municipality for water quality monitoring..."

4.3 Overall thematic analysis

Overall, the analysis paints a picture of a community nobly bearing the fingerprints of mining's environmental toll. Participants showed an understanding from lived experience and local context how mining ties into polluted household water and the health risks that follow. Their distrust of tap water, the turn to alternative sources, and worries handed down through generations all point to long-term exposure to environmental harm. The community, however, appeared to remain optimistic despite these challenges. They had very realistic suggestions for how things could be improved, including better infrastructure, increased rule enforcement, and governance based on collaboration. This resilience is more than just hopeful rhetoric; it provides real direction for policy makers, city officials, and mining companies desiring to improve water quality and rebuild residents' trust.

Part 2- Quantitative

4.4 Quantitative data analysis

The results of physicochemical and microbiological evaluation of the water quality provided in this section were derived from water samples obtained from the Masakhane Settlement, Boat Caravan Club, and the Coalfield sampling locations during the wet and dry periods. Table 6 showed the objectives for quantitative results. The study focused on important factors such as the pH levels, Iron (Fe) content, Manganese (Mn) levels, Aluminium (Al) values, Sulphate levels (SO_4) present, and Total Coliform Bacteria (TCB), Faecal Coliform (FC) presence, to understand the variations and similarities between the sampling stations based on the South African water quality standards during the wet and dry periods. These factors helped to understand the effects exerted on the river system, thus affecting the status of water quality.

Quantitative objectives	
i.	To assess the physicochemical characteristics (pH, Fe, Mn, Al & SO ₄) of the Water from the Naauwpoortspruit River.
ii.	To assess the microbial characteristics (TCB & FC) of the water from Naauwpoortspruit River.
iii.	To estimate the water quality of the potable water supplied to the residents in eMalahleni by comparing it with the national water quality standards.

Table 6: Showing objectives for quantitative results as interpreted.

4.5 Physicochemical and microbial analyses of river water

4.5.1 pH values by location and season

The pH levels recorded for the three study areas (Coalfield, Boat Caravan Club, and Masakhane) were constant during the wet and dry periods, fluctuating slightly between pH 7.1 and pH 7.4 (Figure 4). This indicates that there are no acidic inputs, such as acid mine drainage, contributing to the acidity levels. In addition, the values for the dry period appeared slightly higher, an effect perhaps due to evaporation. Neutral to slightly basic pH ranges were also observed at several mine areas within Southern Africa, including the Naauwpoortspruit River and Upper Witbank Coalfields (Hobbs & Cobbing, 2007; Tutu et al., 2008; Naicker et al. 2003), where high carbonate contents and mine water treatments are known to hinder associated pH depression, thereby counteracting acidity associated with AMD (sulphates, Fe, Mn, and Al) on water quality (Bell et al. 2001; McCarthy, 2011). Most importantly, the recorded values were well within the range recommended by the SANS 241 standard (5.0 to 9.7). The small standard errors for the recorded pH levels indicate that the pH levels are constant and that the catchment area's buffering capacity remains high. In addition, the values for the wet period are slightly affected, a factor linked to the runoff effect.

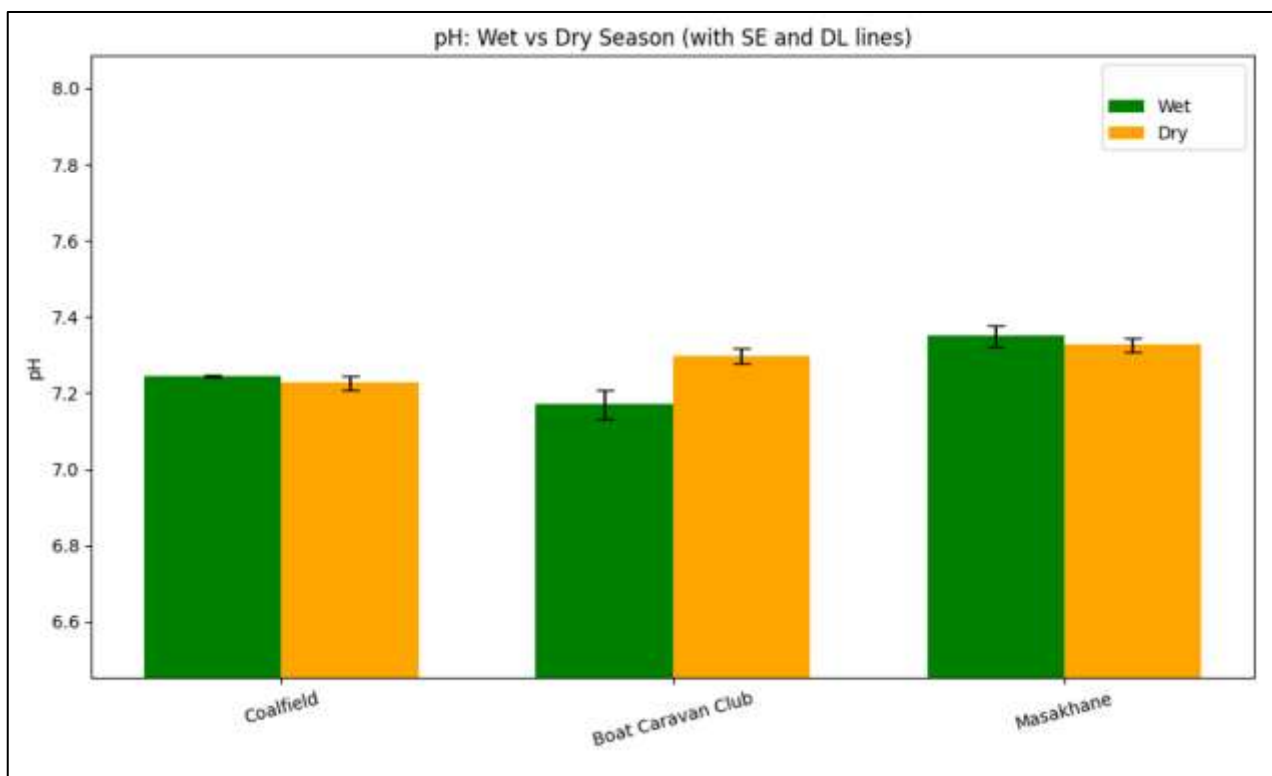


Figure 4: Bar plots representing the distribution of the pH levels during the wet and dry seasons for the sampling points (Masakhane Settlement, Boat Caravan Club, and Coalfield).

4.5.2 Variability of Iron (Fe) Concentration and Compliance

Iron concentrations varied, with higher averages compared to the dry season during the rainy season, reflecting soil and sediment runoff during rain (Figure 5). During the wet season, Fe levels were between 0.08 and 0.25 mg/L during the dry season and between 0.11 and 0.33 mg/L. This also happens to be part of the wider AMD process, which has been well-documented to discharge iron on a constant basis into receiving water sources, such as tailing dams, waste rock dumps, and underground mine-seals (Masindi et al., 2022). Iron has also been widely noted by various authors, such as McCarthy and Pretorius (2009), to contaminate AMD-affected river systems, such as near the Witbank Coalfield, on a permanent basis, due to high mobility.

Although none of the iron concentrations during sampling surpassed the maximum allowable charge of 0.3 mg/L, indicated by SANS 241, it is apparent that the concentration at Masakhane during the wet season approximated this value, which is more susceptible to sedimentation and upstream pollution. This is due to the

hydrological effect of rainfall, which, when it rains, stormwater runoff increases, soil erosion and Fe-bearing sediments and particulate matter is transported into the river system. Such observations were explained by other authors during the wet season in mine-affected river systems, which are more susceptible to Fe-bearing particulate matter and dissolved Fe during the wet season (Oberholster et al., 2010, Seopela et al., 2020).

As water moves along the mining areas from upstream towards the downstream towns, suspended and dissolved materials are often deposited, becoming more concentrated in the latter areas. These are supported by observations made by other studies conducted on the Olifants River, which found downstream towns to contain higher metal concentrations compared with upstream areas (Oberholster et al., 2012). The moderately high standard errors depicted, particularly at points such as Boat Caravan Club, also indicate the dynamic nature associated with midstream areas, which often have wastewater discharge and changing water flow.

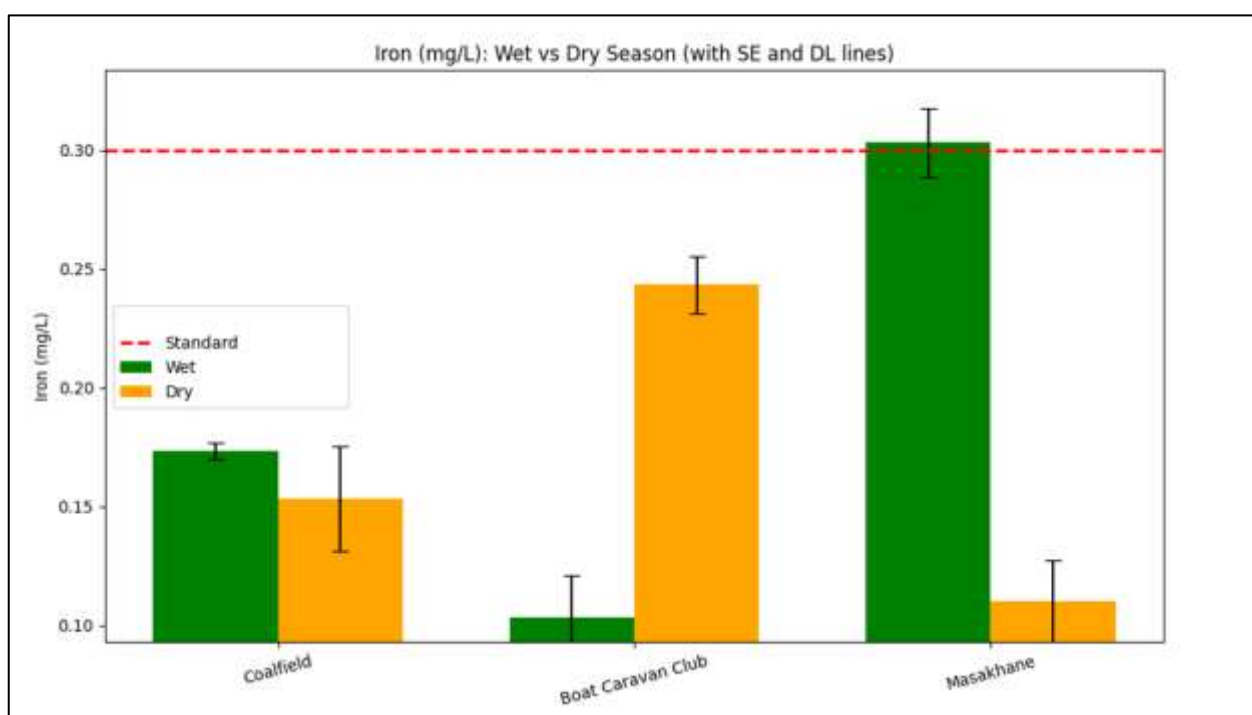


Figure 5: Average Iron (Fe) concentrations for the wet and dry periods at each sampling point,

expressed as mean values with standard error bars and the operational limit of SANS 241 (0.01 mg/L) marked by the red dotted detection/limit line.

4.5.3 Manganese (Mn) Trends and Seasonal Influence

Manganese levels varied seasonally, and the means during the wet season were higher, showing greater mobilisation as a result of soil saturation and runoff. During the wet season, the dry season values were slightly lower, ranging from 0.00 to 0.03 mg/L, while the averages fluctuated between 0.01 and 0.05 mg/L. The increase in manganese during the wet season aligns with what we already know about how Mn behaves geochemically due to shifting moisture and oxygen levels. When soils are saturated and oxygen is low, Mn oxides in sediments tend to dissolve into the water, boosting Mn²⁺ in the water column. In coalmining regions of Mpumalanga and Limpopo, studies have reported this same wet-season bump, linking it explicitly to rainfall-driven reductive dissolution and stirring of sediments (Masindi et al., 2018; Seopela et al., 2020). The highest levels of Mn were detected at the Masakhane site, which suggests the cumulative impact of upstream human activity when considering the spatial pattern. Downstream of the source in mine-impacted rivers, metals are deposited and then later remobilized. Studies undertaken in mining catchments within Olifants, Vukani, and Bojanala found elevated Mn and other metals downstream due to longer interaction with contaminated sediments and the convergence of multiple sources of pollution (Oberholster et al., 2010; Tutu et al., 2008).

Moderate variability was evidenced by the data for the Boat Caravan Club with their error bar suggesting fluctuating Mn inputs, likely from mixed land use such as recreational areas, small-scale farming, and stormwater runoff. Although Mn concentrations were still far less than the South African drinking-water limit of 0.05 mg/L, as illustrated in Figure 6, the increasing trend through the wet season serves as an early warning of possible contamination if mining and land disturbance continue. International experience has demonstrated that gradual rises in Mn, even within guideline values, perhaps indicate active AMD processes and reduced catchment resilience (Younger, 2001). The Mn signature in this river thus represents both

seasonal hydrological variations and long-term effects of coal mining in the region of eMalahleni.

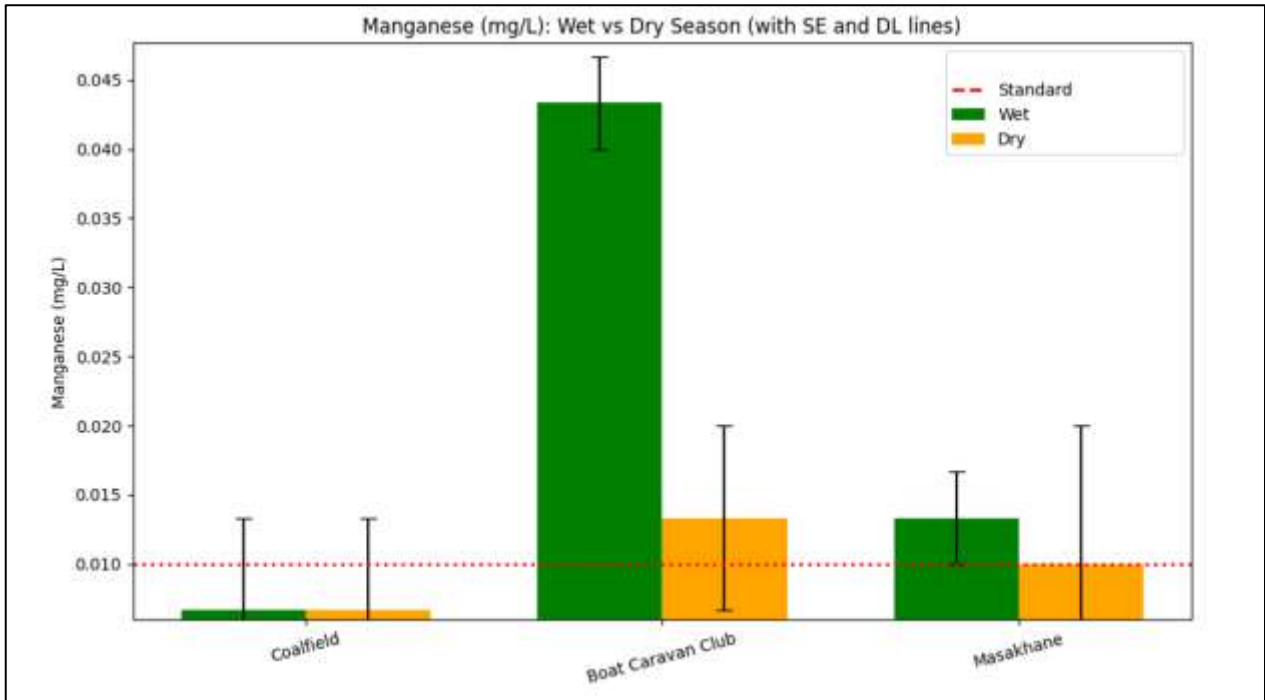


Figure 6: Average Manganese (Mn) levels for wet and dry periods for the three sampling stations, including standard error and the limit for SANS 241 (0.010 mg/L) as the dotted lines.

4.5.4 Al Concentrations and Spatial Differences

Aluminium reveals regular seasonal fluctuations compared to the other metals. During the wet season, Al levels were considerably raised, averaging 0.20–0.24 mg/L, especially at Masakhane, and during the dry season, the averages were significantly lower, ranging from 0.02–0.06 mg/L as illustrated in (Figure 7). This trend, especially during the wet season, reflects the usual high levels of sediment resuspension, soil erosion, and particulate matter in the water. This is in agreement with general trends that coal mining increases soil acidity and enhances Al solubility, particularly where rainfall brings about acidic surface runoff that can dissolve Al-bearing minerals (Durand, 2012; Tutu et al., 2008). Although the levels were higher during the wet

season, they were not much above the operational limit for SANS 241 of 0.3 mg/L. Nevertheless, the close proximity to the limit indicates the potential for elevated levels, especially if the land use and rainfall increase. The standard errors were larger compared to Fe and Mn. All values were above detectable levels, ensuring that the quantification was valid.

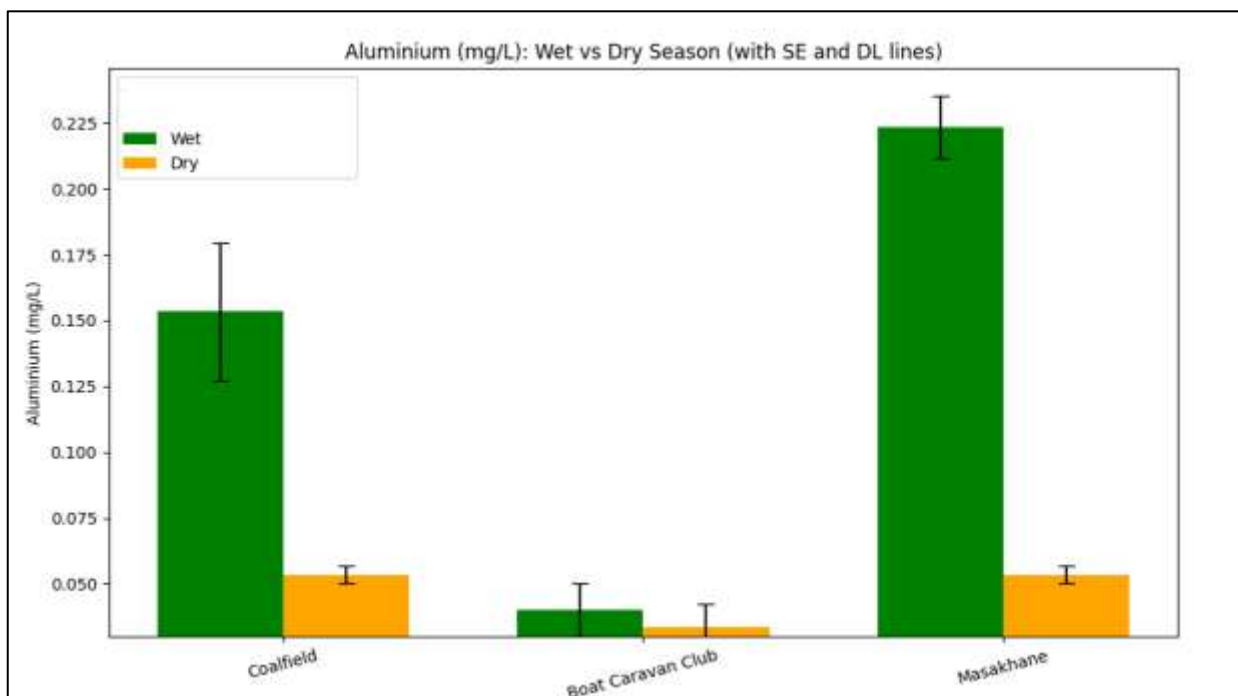


Figure 7: Average aluminium (Al) content during the wet and dry periods for Masakhane, Boat Caravan Club, and Coalfield, depicted with standard error bars and the SANS 241 aesthetic limit (0.30mg/L).

4.5.5 Sulphate (SO_4^{2-}) concentration

The levels of sulphate were relatively constant during the two seasons and at the three locations, having the least variability among the various physicochemical factors considered. The mean values for sulphate were recorded to range from 140 to 197 mg/L during the wet and dry periods (Figure 8). Sulphate contrasts to the metals in that dry-season waters carry markedly more sulphate than in the wet season across all sites. This fits with mining-area dynamics, where SO_4^{2-} tends to build up in surface water during dry periods due to evaporation and continuous drainage from underground workings (Ochieng et al., 2010; Bell et al., 2001). Rainy periods dilute

these inputs from mine drains, lowering overall concentrations, a pattern seen in many AMD-impacted Mpumalanga rivers. Masakhane again recorded the highest sulphate, pointing to the merging of multiple sulphate sources downstream. These concentrations are well below the 500 mg/L as required by the South African National Standards 241 Health, thus posing no threats regarding taste, corrosion, and health.

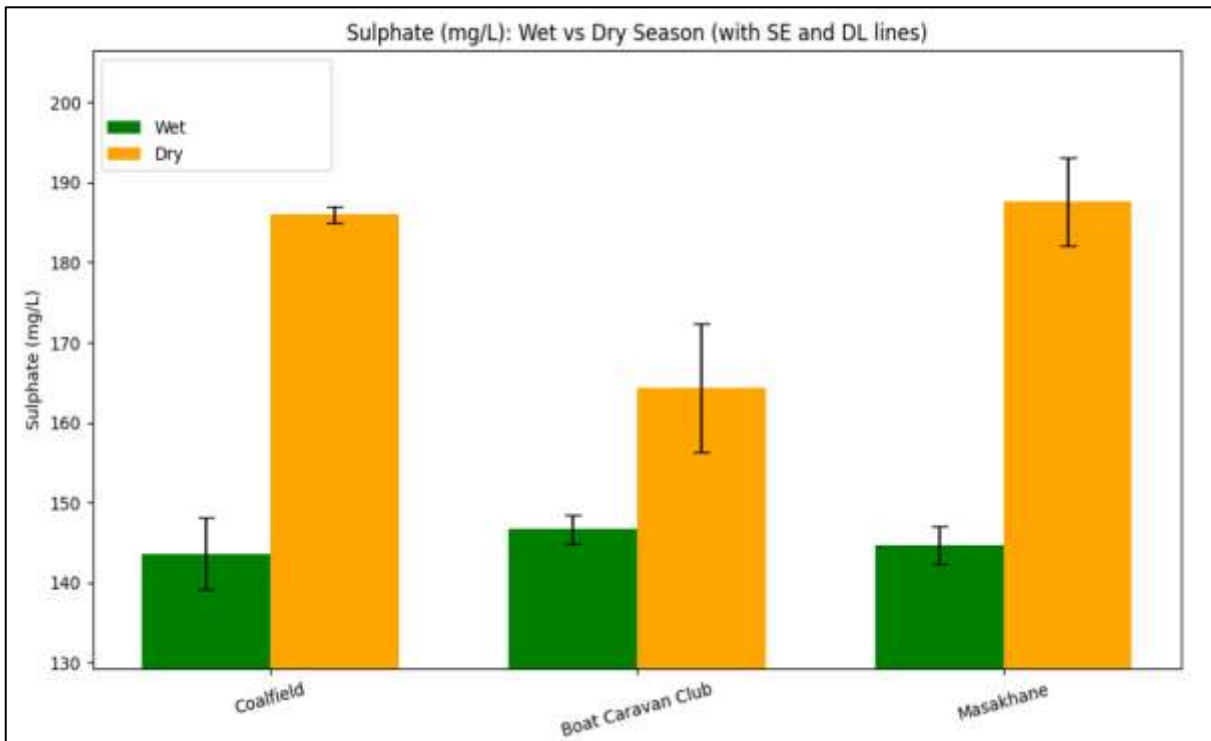


Figure 8: Average sulphate (SO_4) content for the sampling locations and periods, with standard error bars and the SANS 241 regulatory limit for sulphates of 500 mg/L.

4.6 Microbiological analysis

4.6.1 Total Coliform Bacteria contamination analysis at all sites

Figure 9 indicated that TCB levels remain relatively high throughout the wet and dry seasons in Masakhane Settlement, Boat Caravan Club, and Coalfield. On average, TCB remains at about 1000 CFU/100 mL, especially during the wet season, which suggests intense microbial contamination from stormwater runoff, informal settlement discharge, and probable sewage infiltration. For example, the Boat Caravan Club and Coalfield have the highest variability, yet both sites remain above the safe limit at all times, indicating multiple and diffuse sources of pollution in the catchment. Reduced

titres did occur during the dry season in a few places, such as Coalfield (250 CFU/100 mL), but values remain well above South African guidelines, suggesting the microbial load is persistent even under low-flow conditions. The upstream Coalfield showed a lower titre during the dry season due to low river discharge and little surface runoff carrying pollutants into the river. On the whole, these patterns suggest chronic river contamination supported by poor sanitation, leaking wastewater infrastructure, and uncontrolled points of discharge. The consistently high counts insinuate that the river does not naturally recover seasonally; instead, there is continuous and ongoing pollution pressure rather than spot pollution incidents.

Notably, TCB spikes during the rainy season except for Masakhane which in which has the lowest concentration (180 CFU/100mL). Surface runoff carries faecal material, soil bacteria, decaying vegetation, and waste from informal settlements and farms into the river. Wet-season TCB may surge to nearly a thousand CFU/100 mL, indicating contamination from diffuse sources such as leaking pit latrines, sewer overflows, poorly managed grazing areas, and illegal dumping-reported throughout South African rural and peri-urban catchments (DWAF, 1999; Mema 2010; Samie et al., 2012). During the dry season, it decreases significantly because of reduced runoff and lethal effects of sunlight. Amongst the sites, the midstream Boat Caravan Club site displays the highest loads, likely due to recreational activities, nearby settlements, or wastewater leaks. This seasonal trend agrees with those in the Vaal, Olifants, and uMngeni Rivers, where the wet-season microbial deterioration is very closely linked with stormwater runoff.

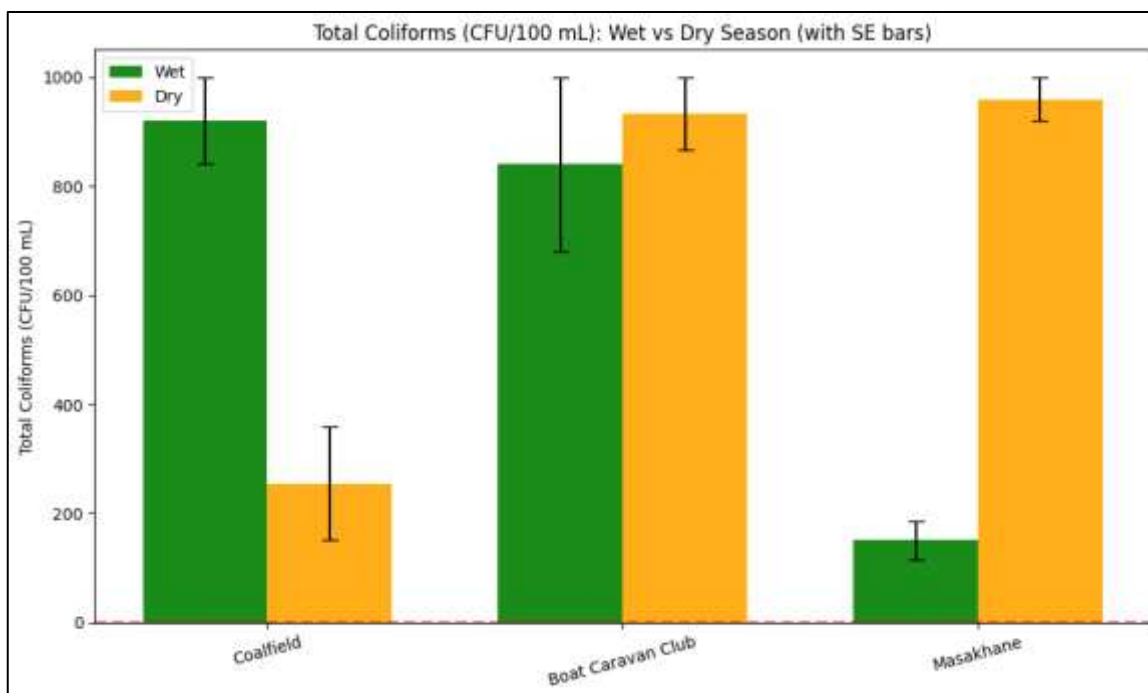


Figure 9: Average Total Coliform Bacteria (TCB) values for the wet and dry periods for each sampling point, and standard errors, with the South African Microbiological Water Guideline of less than 0 CFU/100 mL shown as the dotted red line.

4.6.2 Detection of faecal coliforms (FC) across all sites

The FC levels more clearly signal direct faecal contamination. These levels often reach 750 CFU/100 mL in the wet season (Figure 10). They remain above those levels throughout the dry season. Coalfield and Boat Caravan Club consistently show high FC counts in wet season. This indicates failing or absent sanitation facilities, direct releases of wastewater, or surface runoff from densely populated areas. Wet-season peaks arise from strengthened surface runoff that conveys human and animal waste into the river. Coalfield also shows substantial FC contamination, though with greater variability. This is likely due to intermittent pollution events or localised inputs from agriculture. In the dry season, FC values remain correspondingly low. They reach up to approximately 350 CFU/100 mL. This suggests the contamination is mostly rain-driven as low concentration of faecal coliform was observed in dry season. These FC levels significantly exceed South African guideline limits (0 CFU/100 mL) for domestic

uses, recreational uses, and certain agricultural uses. They indicate a real risk of waterborne diseases. The persistence of FC points to continuing faecal inputs and a lack of adequate containment of wastewater across all sites in the catchment.

Levels of faecal coliform significantly increase during the wet season, peaking at midstream with approximately 760 CFU/100 mL-the highest across the studied sites. These levels are above South African recreational-water guidelines of 0-130 CFU/100 mL, hence posing a serious public-health risk.

The significant wet-season jump coincides with the rainfall-induced movement of faecal pollution from informal settlements, nonperforming sewage systems, grazing areas, and landfills-four general sources that have been reported to contaminate most South African rivers (DWAF, 2005; Dlamini et al., 2019). The FC counts in Masakhane are lower than those of BCC, which may be as a result of superior dilution, wider channel, or reduced upstream activities of man. The mean FCs drop to about 30-50 CFU/100 mL in the dry season, indicating rainfall and stormwater as major drivers of contamination. Variations of FC along the pronounced wet-dry seasonal cycle agree with similar observations along the Crocodile, Nkomati, and Klip Rivers, where microbial water quality drops significantly with storm events.

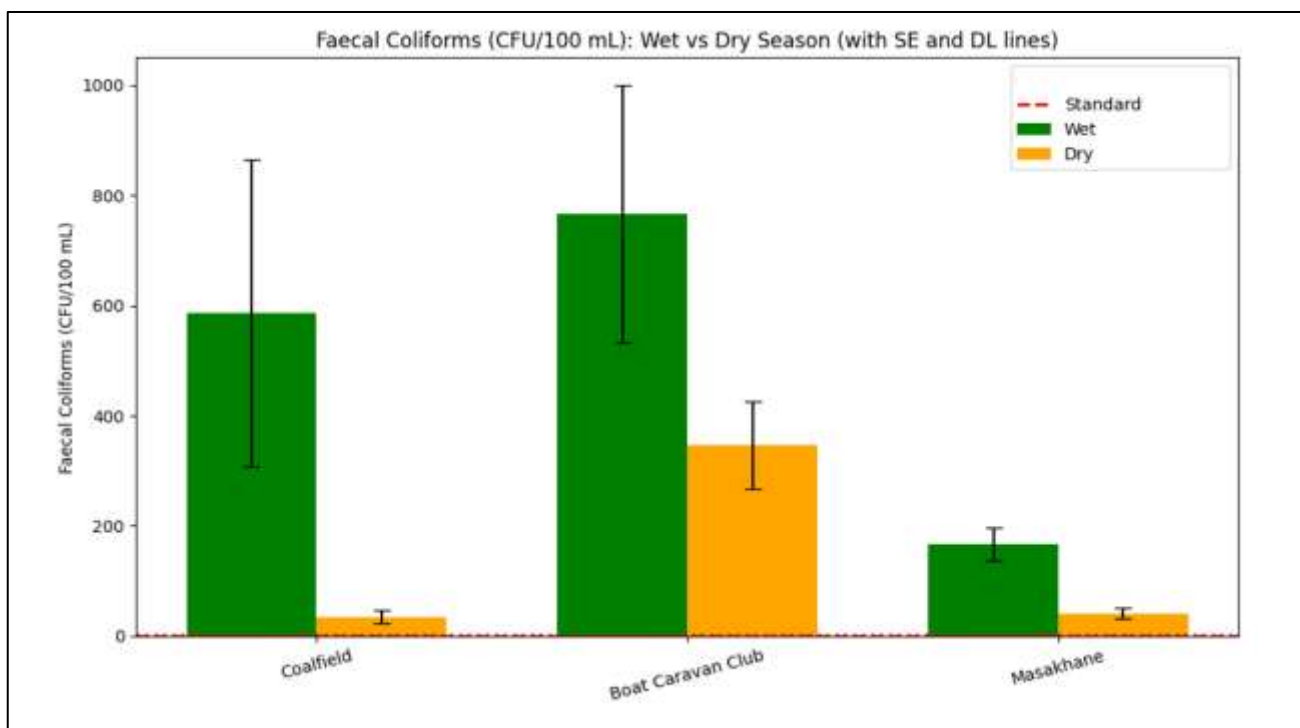


Figure 10: Average Faecal Coliform (FC) values for Masakhane, Boat Caravan Club, and Coalfield during the wet and dry periods, with standard error bars and the South African standard for faecal coliform levels (<0–100CFU/100mL, depending on use) marked as the dotted red line.

4.7 Overall chemical and microbial characteristics of the water from the Naauwpoortspruit River and the Witbank Dam.

The physicochemical and microbiological properties of the water from the Witbank Dam and the Naauwpoortspruit River were determined in this study. Both wet and dry seasons were used to gather the water samples, and from three different sampling sites, namely Masakhane, Boat camp, and Coalfield. According to the statistical analysis of this study, there was no significant difference ($P > 0.05$) in the pH, Fe, Mn, and TCB/CFU observed from seasons. However, the mean values (0.14 and 179.33 CFU/100mL) respectively observed for Al and SO₄ from wet season were significantly ($P < 0.01$) higher than those (0.05 and 145.00) observed from dry season. Nonetheless, the FC mean (506.44 CFU/100mL) values observed from wet season was also noticeably greater ($P < 0.05$) than the mean value (140.78) observed from dry season.

These results are in agreement with those from other South African river studies, which indicate that heavy-metal and microbial contamination is usually heavier in the wet season due to rainfall that washes soils and sediments into the watercourses. For example, Dlamini et al. (2023) recorded higher concentrations of aluminium and iron in the Kaap River during rainfall due to catchment runoff and mining activities. In addition, rain enhances the surface runoff and mobilizes the leaching of oxidized mineral residues from coal mine dumps, tailings, and exposed rock faces. This pattern is a characteristic feature of acid mine drainage, which involves the oxidation of pyrite and other sulphate minerals with a resulting release of sulphates and metals. High sulphate levels (179.33 mg/L) thus reflect increased AMD generation and mobilization during heavy storms.

The analysed data shows that there was no significant difference ($P > 0.05$) for SO_4 observed across the sampling sites. However, pH, Fe, Mn, Al, TCB/CFU, and FC mean values significantly differed across sampling sites. We observed a higher pH value (7.34) from the water sample collected at Masakhane, which was significantly higher ($P < 0.05$) than the pH means values (7.34 and 7.24) from the water samples collected from Boat camp and Coalfield respectively. Nonetheless, the higher Fe and Mn mean values (0.21 and 0.03) observed respectively from water samples collected from Masakhane was similar to the Fe and Mn mean values (0.17 and 0.01) observed from Boat camp but differed from those (0.16 and 0.00) collected from Coalfield. However, the two Fe mean values (0.17 and 0.16) and Mn mean values (0.01 and 0.00) from samples collected from Boat camp and Coalfield, respectively, did not differ significantly. The water samples collected from Masakhane showed a higher Al mean value (0.14) compared to the mean values observed from the water samples collected from Boat camp and coalfield. However, the Al mean value (0.10) observed from Caol mine was also significantly higher ($P < 0.01$) than that observed from Boat camp (0.04). The water samples collected from Boat camp had a higher (886.67) TCB mean value which differed significantly ($P < 0.01$) from the similar TCB/CFU mean values (555.50 and 587.67) observed from water samples collected from Masakhane and Coalfield respectively. The water samples collected from Boat camp had a higher FC mean value

(556.67) which was higher than the mean value (103.83) observed from the water samples collected from Masakhane, but similar to the mean value (310.33) observed from water samples collected from Coalfield. Nonetheless, the two FC mean values observed from the water samples collected from Masakhane and Coalfield did not differ significantly ($P>0.05$). Mgobozi, Moyo, and Khumalo (2022) also reported a greater abundance of faecal indicator bacteria in the Apies River during rainfall, resulting from surface runoff from informal settlements and agricultural land.

Seasons and sampling locations did not appear to have a significant impact on Mn or any of the microbiological parameters (TCB/CFU and FC). Nonetheless, we observed a high significant effect ($P<0.01$) of the interaction between seasons and sampling sites for chemical parameters (pH, Fe, and Al). From the samples collected during wet season, we observed a higher pH and Fe mean values (7.35 and 0.30) respectively which were found to be similar to the pH and Fe mean values (7.24 and 0.17 mg/L), respectively, observed from the water samples collected from Coalfield, however significantly higher than the mean values (7.17 and 0.10), respectively, observed from water samples collected from Boat camp.

For the community, the wet seasons showed a higher FC and TCB level, which could result in an increased risk of waterborne illness when people depend on untreated surface water for drinking, washing, or recreation. Regular seasonal checks and targeted water treatment are necessary in order to protect public health (Mgobozi et al., 2022).

The clear seasonal and geographical shifts in metal and microbial contamination point toward inputs from mining, farming, and wastewater. Industries should be engaged regarding effective runoff control, proper wastewater treatment, and strong environmental protections. The findings highlight how crucial it is to monitor during several seasons and sites to capture both temporal and spatial variation. Researchers should expand and include analysis on more chemical parameters, sediment analysis, pathogen-specific microbial analyses, and multivariate approaches to identify the main drivers of water quality, as noted by Sithole and Zulu (2020).

The water samples collected from both Boat camp and Coalfield did not differ significantly ($P>0.05$). On the other hand, water samples collected during dry seasons showed an insignificant ($P>0.05$) pH mean value (7.29) at the average across all sampling sites. Study results showed a higher Fe mean value (0.24) from the water samples taken during the dry season at the boat camp and the lower Fe mean values (0.11 and 0.15) were obtained from water samples collected from Masakhane and Coalfield, respectively. That spike indicates that Boat Camp bears a bigger load from contamination sources, resulting from upstream mining, leaking infrastructure, or a river which isn't flushing as effectively when flow is reduced during the dry season. With less dilution to spread and dilute the metals, the water tends to carry more dissolved iron, pointing to heavier pollutant input or weaker natural cleansing there compared with the other sites.

Water samples collected during the wet season from Masakhane showed a higher Al mean value (0.24 mg/L) which differed significantly from the lower Al mean values (0.4 and 0.15), respectively observed from water samples collected from Boat camp and Coalfield. However, the Al mean value observed from the water samples collected from Coalfield was found to be significantly higher than the one observed from Boat camp. However, the average Al mean value (0.04) from water samples taken from all sampling locations during the dry season did not differ significantly ($P>0.05$). During wet season, water samples collected from Masakhane, Boat camp, and Coalfield showed an insignificant ($P>0.05$) difference in the SO₄ with the average mean value of 145.00. However, water collected from Masakhane and Coalfield during the dry season showed a higher SO₄ mean values (187.67 and 186.00) respectively which differed significantly ($P>0.05$) from the lower SO₄ mean value (164.33) observed from the water samples collected from Boat camp. What does this imply? These conditions indicate that land use, water movement, and human activities within the locality determine the quality of the water, a condition that is in agreement with results from studies conducted at the Luvuvhu River and Lower Vaal River catchments (Mthembu & Dlamini, 2021; Sithole & Zulu, 2020). They, thus, show the importance of considering

both spatial aspects of water quality during management action planning and monitoring.

CHAPTER 5: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Introduction

This chapter concentrates on the study's findings in relation to the research objectives described in Chapter One. The main goal of the study was to analyse and understand the physicochemical and microbial quality of water from the Naauwpoortspruit River, and Witbank Dam, especially in the Masakhane Settlement community. The study also aimed to understand how local communities feel about the effects of coal mining and the safety of their water supply. The importance of these results was evaluated in relation to current research, national water quality requirements, and the wider consequences for public health, environmental sustainability, and water resource management.

5.2 Summary

The study examined how coal mining operations affect water quality including its chemical makeup and bacterial content in the local river, dam, and drinking water supplied to Masakhane residents.

The first objective was to analyse the perspectives of communities surrounding the coal mines in eMalahleni regarding the environmental impact on water quality by obtaining responses from participants in a focus group, followed by thematic analysis of those responses. The qualitative study findings revealed that residents perceive their domestic water quality as severely deteriorated, describing it as brown, smelly, dirty, and unsafe, a perception strongly linked to visible pollution and recurrent health effects such as diarrhoea, gastrointestinal illness, and skin irritation. These perceptions are grounded in lived experiences and supported by quantitative evidence. Water insecurity emerged as a significant challenge, with frequent shortages and widespread avoidance of tap water leading many residents to rely on costly bottled water. These results indicate that community perceptions are rooted in what can be seen to be happening in the environment and experienced in terms of health, rather than in presumed impacts. The qualitative results correspond with the quantitative findings to

a high degree, thereby underlining the importance of local knowledge as a complement to scientific monitoring of environmental change.

The second objective was to assess the physicochemical characteristics (pH, Fe, Mn, Al & SO₄) of the water from the Naauwpoortspruit River using calibrated meters. The findings indicated that, although the pH of the water samples was alkaline, the study showed that mining activities, particularly acid mine drainage (AMD), were the major contributors to water pollution, amplifying levels of heavy metals such as aluminium, iron, manganese, and sulphates beyond acceptable limits set by SANS 241 and WHO standards. These results indicate that river chemistry is significantly influenced by coal mining through the oxidation of minerals and the mobilisation of metals. Metal levels were elevated even when pH was seemingly within an acceptable range, indicating degradation of water quality that could not be determined solely by pH.

The third objective was to assess the microbial characteristics (TCB & FC) of the water from Naauwpoortspruit River using the pour plate technique and Membrane filtration. The results indicated that both Total Coliform Bacteria and Faecal Coliforms were present in all water samples at levels above safe levels for domestic use. High levels of microbes are a strong indicator that wastewater, surface water, and leaking sewage from nearby communities, along with inadequate sanitation infrastructure, are seeping into the river regularly. Hence, people who depend on the river for drinking water and other water needs are in substantial danger due to the high levels of microbial pollution. The findings also show that mining operations and poor sanitation in communities near mines are closely linked to environmental degradation.

The last objective was to compare measured physicochemical and microbial values against the National Water Quality standards and to determine whether they exceed regulatory limits. By comparison, several factors, including aluminium, iron, Total Coliform Bacteria, and Faecal Coliforms, exceeded the permissible limits set by SANS 241 and the WHO drinking water quality criteria. Though pH and manganese showed values within the specified limits. However, the presence of microbial contamination and elevated heavy metal concentrations justified violations of the guidelines at many

sampling sites. The results of this study clearly indicated the heightened vulnerability of water sources to pollution and the potential risks to public health. The concordance between local worry and laboratory data was thus objectively substantiated.

Despite these challenges, community members demonstrated strong awareness of pollution sources and proposed practical solutions, including improved infrastructure, stricter enforcement, better collaboration, and community-inclusive governance. Overall, the study paints a picture of a deeply affected yet resilient community, actively participating in identifying solutions for sustainable water quality management.

5.3 General Conclusions

The study concludes that coal mining and related industrial activities have a significant negative impact on the water quality of the Naauwpoortspruit River and the potable supply delivered to the Masakhane community. The pH levels recorded in the river fell within the acceptable SANS 241 range, confirming the presence of alkaline conditions even when there is AMD. Heavy metals specifically iron, aluminium, and manganese, as well as sulphates, were detected at concentrations exceeding domestic water quality standards, posing both ecological and human health risks. Microbial analysis further confirmed contamination from faecal matter, reinforcing residents' health complaints and documenting the potential for gastrointestinal diseases.

The community's low trust in municipal water supply reflects years of exposure to visibly polluted water, unreliable treatment systems, and failing infrastructure. The results obtained align with national and global research, which shows that mining-intensive regions often suffer from chronic water quality deterioration, weak governance, and minimal enforcement of environmental regulations. The findings also demonstrate that the upper Naauwpoortspruit River catchment experiences severe ecological stress, with implications for biodiversity, public health, and long-term sustainability. Overall, the research confirms that without urgent and coordinated interventions, water pollution in eMalahleni will continue to escalate, deepening environmental, social, and health-related vulnerabilities.

5.4 Recommendations

The study recommends urgent implementation of integrated water management strategies to address the deteriorating water quality affecting Masakhane and the broader Naauwpoortspruit River system by eMalahleni Local Municipality.

First, improved water treatment infrastructure is essential, including the construction of modern water treatment plants, proper stormwater management systems, and the rehabilitation of abandoned and illegal mines that continue to contribute untreated AMD to the river. The municipality should upgrade its potable water treatment capacity to better handle both chemical and microbial contaminants.

Second, enforcement of environmental regulations must be strengthened. Mining companies should be compelled to comply with water discharge standards, and regular government-led inspections must be reinstated. Community-based monitoring initiatives should be funded and institutionalised to increase transparency, strengthen trust, and involve residents in environmental governance.

Third, public health interventions such as emergency potable water provision, health risk communication, and household-level filtration technologies are recommended to protect vulnerable groups.

Finally, long-term sustainable planning should prioritize multi-stakeholder collaboration involving government, communities, researchers, and industry to ensure accountability and co-governance in water resource management. These recommendations reflect both global best practices and the practical insights offered by the community, demonstrating that inclusive governance is crucial for restoring water quality and safeguarding public health.

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Appendix A: Permission Letter



APPENDIX 5

RESEARCH PERMISSION LETTER

Request for permission to conduct research at Masakhane Settlement Communities in Emalahleni, Mpumalanga)

"Effects of coal mine activities on physicochemical and microbiological quality of
Naaupoortspruit river following coal mine activities, Emalahleni, Mpumalanga,
South africa."

15 May 2025

To, Masakhane Community Council.

Dear Cllr. Tshepo Gulube.

My name is Moses Shimo Seletisha and I wish to conduct a research on water quality at Emalahleni Local Municipality. I am supervised by Esther Kibuka-Sebitosi (a Full Professor at the University of South Africa).

We are inviting you the community of Masakhane and Benicon Settlement to participate in the focus group interview of the research study.

The study is entitled "*Physicochemical and microbiological quality Naaupoortspruit River following coal mine activities, Emalahleni, Mpumalanga Province.*"

The aim of the study is to assess the environmental impacts of the coal mining and processing activities on the ***physicochemical and microbiological quality of Naaupoortspruit river following coal mine activities in Emalahleni, Mpumalanga Province.***

Your community has been selected because it is within my research area of interest/focus.

The benefits of this study are expansion of knowledge and understanding of the quality of water in the research area.



University of South Africa
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Feedback procedure will entail a submission of a final copy of the research paper for the reference of the community.

We shall be most grateful for your help.

Yours sincerely



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Appendix B: Ethical approval



College of Agriculture and Environmental Sciences_Health REC

Date: 12/02/2025

Dear: Mr Moses Seletisha

NHREC Registration # : REC-170616-051
Ref # : 2024/CAES_HREC/4624
Name: Mr Moses Seletisha
Student # : 43974953

**Decision: Ethics Approval from
12/02/2025 to 31/01/2028**

Researcher: Mr Moses Seletisha
43974953@MYLIFE.UNISA.AC.ZA +27796930053

Supervisor: Professor Esther Kibuka-Sebitosi consortiumafrica@yahoo.com

Effects of coal mine activities on physicochemical and microbiological quality of Naauppoortspruit River, Emalahleni, Mpumalanga, South Africa

Qualification: MSc Environmental Management

Thank you for the application for research ethics clearance by the College of Agriculture and Environmental Sciences_Health REC for the above mentioned research study. Ethics approval is granted for three years, **subject to submission of yearly progress reports. Failure to submit the progress report will lead to withdrawal of the ethics clearance until the report is submitted.**

Due date for progress report: 31 January 2026

The **low risk application** was **reviewed** by College of Agriculture and Environmental Sciences_Health REC on 11 February 2025 in compliance with the Unisa Policy on Research Ethics and the Standard Operating Procedure on Research Ethics Risk Assessment.

The proposed research may now commence with the provisions that:

1. The researcher(s) will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study should be communicated in writing to the College of Agriculture and Environmental Sciences_Health REC.
3. The researcher(s) will conduct the study according to the methods and procedures set out in the approved application.
4. Any changes that can affect the study-related risks for the research participants, particularly in terms of assurances made with regards to the protection of participants' privacy and the confidentiality of the data, should be reported to the Committee in writing, accompanied by a progress report.
5. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study. Adherence to the following South African legislation is important, if applicable: Protection of Personal Information Act, no 4 of 2013; Children's act no 38 of 2005 and the National Health Act, no 61 of 2003.
6. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data requires additional ethics clearance.

7. No field work activities may continue after the expiry date (31 January 2026). Submission of a completed research ethics progress report will constitute an application for renewal, for Ethics Research Committee approval.

Additional Conditions

1. Disclosure of data to third parties is prohibited without explicit consent from Unisa.
2. De-identified data must be safely stored on password protected PCs.
3. Care should be taken by the researcher when publishing the results to protect the confidentiality and privacy of the university.
4. Adherence to the National Statement on Ethical Research and Publication practices, principle 7 referring to Social awareness, must be ensured: "Researchers and institutions must be sensitive to the potential impact of their research on society, marginal groups or individuals, and must consider these when weighing the benefits of the research against any harmful effects, with a view to minimising or avoiding the latter where possible." Unisa will not be liable for any failure to comply with this principle.

Note

The reference number 2024/CAES_HREC/4624 should be clearly indicated on all forms of communication with the intended research participants, as well as with the Committee.

Kind regards,



Dr MD Matlala
Chair of College of Agriculture and Environmental Sciences_Health REC
E-mail: matlamd1@unisa.ac.za



Prof NO Mapholi
Executive Dean / By delegation from the Executive Dean of College of Agriculture and Environmental Sciences_Health REC
E-mail: maphon@unisa.ac.za

Appendix C: Consent form



APPENDIX 1

CONSENT FORM AND QUESTIONNAIRES

TITLE OF RESEARCH PROJECT:

EFFECTS ON COAL MINE ACTIVITIES ON PHYSICOCHEMICAL AND MICROBIOLOGICAL QUALITY OF WATER OF NAAUWPOORTSPRUIT RIVER, EMALAHLENI, MPUMALANGA, SOUTH AFRICA.

Dear

Prof/Dr/Mr/Mrs/Mme/Miss.....Date...../...../2024.

Nature and purpose of the study.

I am Moses Shimo Seletisha, a Master student at the University of South Africa (UNISA), at the College of Agriculture and Environmental Sciences (CAES), Department of Environmental Sciences, conducting a research project with the purpose to measure the perceptions of the community members on the effects of coal mine activities on the Naauppoortspruit river, Emalahleni, Mpumalanga Province, South Africa. In this study, I will use questionnaire to get information about the physical quality of water and possible effects on human health. This will be done through questionnaires administration to selected inhabitants.

CONFIDENTIALITY

Please note that information regarding your identity and your profession and your location are strictly confidential, and only members of the research team will have access to the information. No data published in dissertations and journals will contain any information through which the respondent may be identified. In that regard, your anonymity is therefore ensured. If you have any questions concerning this research project, you can contact the supervisor Professor Esther Kibuka-Sebitosi at the Department of Environmental Sciences, UNISA, Tel + 27798994761.



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CONSENT.

I the undersigned..... (Full name) have read the above information relating to the project and have also heard verbal version from the researcher and declare that I understand it. I have been afforded the opportunity to discuss relevant aspects of the project with the researcher and hereby declare that I agree voluntary to participate to the project and indemnity the university and any employee or student of UNISA against any liability that I may incur during the course of the project.

I further undertake to make no claim against UNISA and the researcher in respect of damages to my personality that may be incurred as result of the project or through the fault of other participants, unless resulting from negligence on the part of UNISA, its employees or students.

Residential address.....

Name of the researcher.....

Signature.....at.....on...../.....2025.

Name of the respondent.....

Profession of the respondent.....

Signatureat.....on...../.....2025