

**AN EVALUATION OF THE IMPACTS OF URBANISATION ON KLIP
RIVER WETLAND DEGRADATION, JOHANNESBURG SOUTH**

by

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DISSERTATION

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DEDICATION

This work is dedicated to the memory of my late co-supervisor, Prof. JM Letsoalo, whose guidance and constant encouragement greatly influenced my academic career and personal development. The dissertation is evidence of her lasting influence, and I appreciate her mentoring.

Additionally, this work is dedicated to my late uncle, Mr. Baloyi Dankie, whose wisdom, love, and support have inspired me throughout my life. Even though he is no longer with us, his unwavering optimism and faith in my abilities inspire me every day.

With sincere gratitude for your beneficial influence, I dedicate this dissertation to you all. I hope your precious souls continue to rest in eternal peace.

DECLARATION

I declare that the dissertation titled, "An evaluation of the impacts of urbanisation on Klip River Wetland degradation, Johannesburg South," which I have submitted to the University of Limpopo for the Degree of Master of Science in Geography is my work and that all the sources that I have used or quoted have been indicated and acknowledged using complete references and that this work has not been submitted before for any other degree at any other institution.



KL Mabale

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18/11/2024

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ABSTRACT

Wetlands are among the most productive and vulnerable ecosystems in the world, serving fundamental ecological functions such as water purification and water supply. They are however deteriorating due to urbanisation-induced factors. Urbanisation which is increasing as people are consistently moving from rural to urban areas for better economic opportunities, has been linked with high rates of anthropogenic activities in urban areas, which interact with natural ecosystems, thus putting pressure on wetlands. This study, therefore, evaluated the impacts of urbanisation on Klip River Wetland (KRW), by linking water quality in the wetland and the socioeconomic dynamics within two communities in the city of Johannesburg municipality, i.e. Protea Glen (PG) and Lenasia (LENZ). Water samples were collected seasonally, during wet and dry seasons, at four monitoring sites, to assess the spatial and temporal dynamics in the wetland's physicochemical and biological characteristics. This was done by, employing Multi-parameter, Spectrophotometer, Ion Chromatography (IC), Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES), and Colilert-18, for assessing the physical, chemical, and biological constituents of the water. The water quality assessment was augmented with community perceptions and attitudes on how urbanisation impact local communities (via closed and open-ended questions), as well as evaluating water degradation factors through field observations and key factors from the open-ended responses. Findings indicated that water degradation is occurring during both wet and dry seasons in the KRW and that there are spatial variations in water quality in the monitored areas of the wetland. Ranking in quality from marginal to poor water quality ($S3 > S1 > S2 > S4$), with sampling site S4 ranking lowest. Results confirms that KRW quality is influenced by parameters such as pH, turbidity, dissolved oxygen (DO), chemical oxygen demand (COD), nitrate (NO_3^-), magnesium (Mg^{2+}), calcium (Ca^{2+}), manganese (Mn^{2+}), *Escherichia coli* (*E. coli*) and total coliforms, which recorded values that did not comply with the South African Water Quality Guidelines (SAWQGs) and the Klip River Catchment's (KRCs) In-stream Water Quality Guidelines (ISWQGs). The close-ended sociodemographic characteristics of the surveyed community revealed that there were more males (52%) than females (48%), and that there is a relationship between gender and other sociodemographic characteristics such as age, education background, and economic

status. According to the respondents, the most significant influences of urbanisation on KRW include infrastructure (25%), environment degradation (22%), economic activities (19%), and waste disposal (17%), within the communities. These results, together with field observations, linked factors related to urbanisation within the communities that interact with water quality such as traffic congestion, drainage and sewage issues, construction activities, wildfires, mining and industrial activities, and waste. The convergence of these socioeconomic findings, with the water quality assessment, substantiates water quality degradation within the KRW, linked to urbanisation. These findings underscore the urgent need for integrated urban planning, water resource management and conservation strategies to mitigate the adverse effects of urbanisation on KRW.

Keywords: Urbanisation, Klip River Wetland, socioeconomic dynamics, water quality

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LIST OF ACRONYMS

AMD	Acid Mine Drainage
CDM	Capricorn District Municipality
COD	Chemical Oxygen Demand
DWAF	Department of Water Affairs and Forestry
DWS	Department Water Sanitation
EC	Electrical Conductivity
EWSETA	Energy and Water Sector Education and Training Authority
IC	Ion Chromatography
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
GHG	Greenhouse Gas
KRC	Klip River Catchment
KRW	Klip River Wetland
LENZ	Lenasia
LULC	Land Use and Land Changes
MPN	Most Probable Number
PAHs	Polycyclic Aromatic Hydrocarbons
PCA	Principal Component Analysis
PG	Protea Glen
QGIS	Quantum Geographical Information Systems
RQIS	Resource Quality Information System
SAWQGs	South African Water Quality Guidelines
SDGs	Sustainable Development Goals
SOM	Soil Organic Matter

TREC	Turfloop Research Ethics Committee
TWQR	Target Water Quality Range
UV	Ultraviolet
WHO	World Health Organisation
WMA	Water Management Area
WQI	Water Quality Index

ELEMENTS

C	Carbon
Cl ⁻	Chloride
CO ₂	Carbon Dioxide
Cr	Chromium
Cu	Copper
E. coli	<i>Escherichia Coli</i>
F ⁻	Fluoride
Fe	Iron
FeS ₂	Pyrite
Mn ²⁺	Manganese
Na ⁺	Sodium
NH ₃ -N	Ammonia Nitrogen
NH ₄ ⁺	Ammonia
NO ₃ ⁻	Nitrate
pH	Potential of Hydrogen
SO ₄ ²⁻	Sulphate
Zn	Zinc

UNITS OF MEASURE

CFU	Colony Forming Unit
CM	Centimetre
M	Metres
ML	Millilitres
Mg/L	Milligrams Per Litre
MPN	Most Probable Number
NTU	Nephelometric Turbidity Limit
Km ²	Square Kilometre
°C	Degrees Celsius
µS/cm	Micro siemens

CHAPTER 1: INTRODUCTION

1.1. Background

Water is at the core of attaining the Sustainable Development Goals (SDGs) (Peydayesh *et al.*, 2024). Of all available natural resources, water is deemed to be most essential for maintaining environmental diversity, social and economic growth (Marara and Palamuleni, 2020). However, urbanisation, which induces socioeconomic development, has reached a point where it is adversely affecting wetlands, which are known as the transitional areas between terrestrial and aquatic environments (Seretlo, 2019; Zhao *et al.*, 2023). There is a necessity to constantly assess the influence of a range of factors which are linked to urbanisation, such as agriculture, industrial, and mining activities that negatively impact wetlands water quality (Marara and Palamuleni, 2020). Wetlands offer important ecological services in the ecosystem such as, serving as habitat for aquatic life and species, remediation of pollutants, water supply and sequestration of carbon (Nayak and Bhushan, 2022; Pedersen *et al.*, 2019).

As stated by McDonald *et al.*, (2014), urbanisation is a significant trend of the 21st century that has an impact on various aspects of human well-being, including natural resource utilisation, global economic development, and human habitat. According to Duncan *et al.*, (2023), urbanisation has been identified as the main cause of wetland exploitation, especially in coastal wetland areas, as it places significant pressure on the wetland's sedimentation and hydrological regimes. In addition, Duncan *et al.*, (2023) stated that the effects of global urbanisation at the beginning of the 21st century have been linked to increased food demands and a lack of understanding of the ecological functions of wetlands, which has led to widespread abuse of wetlands and their resources.

Given the correlation between urbanisation and heightened food demands, ensuring food security and reducing poverty for the world's expanding population relies on the sustainability in the agricultural sector (Ben Ayed and Hanana, 2021). Utilising fertilisers as supplemental input in agricultural lands can boost wheat and maize yields, hence lowering food scarcity (Chi *et al.*, 2020). However, the intensification of

agricultural fertilisers such as nitrogen and phosphorus-based fertilisers may lead to a significant decline in wetlands water quality (Musabyimana and Bazimenyera, 2023). These fertilisers have the potential to seep into wetlands during surface runoff and cause water quality stress such as eutrophication and algae proliferation (Ajloon *et al.*, 2022).

Tariq and Mushtaq (2023) reported that around the world, there is an increase in the generation of wastewater. The main factors contributing to wastewater production are rapid industrial and population expansion. Due to the rising production of wastewater, wastewater treatment plants (WWTPs) are overloaded, resulting in excessive release of inadequately treated effluents, which have a severe negative impact on the world's water resources (Phungela *et al.*, 2022). There is increasing evidence of deteriorating water resource quality in natural ecosystems due to poor WWTP effluent discharges, thereby affecting wetlands water quality and its functionalities (Phungela *et al.*, 2022). According to Kumar (2022), wastewater significantly compromises the quality of wetlands by increasing chemical oxygen demand (COD).

Urbanisation has also been closely linked to mining operations (Kalembo, 2020). As urban areas grew, mining activities expanded, providing many materials which are used daily for urban development. Mining operations are associated with acid mine drainage (AMD), which is frequently formed when minerals in rocks are exposed to oxygen and water. This promotes the release of chemical elements such as heavy metals, which often accumulate in the surrounding water streams (Carvalho, 2017). Heavy metal accumulation in wetlands, resulting from AMD, is one of the major water quality issues in many fast-growing cities, according to Flores *et al.*, (2021), and it is reported that heavy metals such as chromium (Cr), manganese (Mn^{2+}), and zinc (Zn), have the potential to reduce the pH of wetlands' water, thus impacting aquatic life (Flores *et al.*, 2021).

Klip River Wetland (KRW) is in the south of Johannesburg city. This city is a popular location for inward migrants from other provinces and countries looking for better opportunities because it is a major hub for the economic sector (Thobejane, 2020). Johannesburg is a metropolitan area which was formed due to gold mining in the Witwatersrand Basin, and this later led to the formation of suburban areas such as

Protea Glen (PG) on the western side of Soweto, and Lenasia (LENZ), all located in the south of Johannesburg (Sekonyela *et al.*, 2024; Turton *et al.*, 2013). KRW is part of the Upper Vaal Water Management Area (Upper Vaal WMA), one of the most populous WMA in South Africa (Seretlo, 2019). The KRW flows southerly from Roodeport and discharges into the Vaal Dam. The bulk of surface water flow in the Upper Vaal WMA supplies most of the water essential in Johannesburg, Pretoria and the surrounding areas (Wepener *et al.*, 2015). However, mining operations that include heavy metals, the industrial complex, and WWTPs in Johannesburg are accountable for the KRW's significant degradation (Seretlo, 2019). Despite this, the KRW must continue to serve its functionalities as determined by the Department of Water Sanitation (DWS) (Wepener *et al.*, 2015). Previous studies on the wetland have not explored the impact of urbanisation on the wetland degradation occurring in the KRW (Chetty *et al.*, 2021, Wepener *et al.*, 2015). In this study, an evaluation of the impacts of urbanisation on the quality of water in the KRW, by laboratory water quality assessment, community perceptions and attitudes, and field observations are therefore undertaken.

1.2. Problem statement

With rapid urbanisation, wetlands are prone to degradation (Akhtar *et al.*, 2021). The study further highlighted that wetlands play a key role in preserving the quality of water and supporting wildlife. Johannesburg is the lifeline of the South African economy, the rate of migration to the area is constantly increasing, as individuals look for better opportunities. As a result, the region's wastewater treatment plants (WWTPs) are overloaded, increasing the discharge of effluents containing excess nitrates and other pollutants into the Klip River Wetland (KRW) (Kalembo, 2020). Gold mining in the region has also led to the contamination of the KRW, as there are reports about the extensive accumulation of acid mine drainage (AMD) in the KRW (Chetty *et al.*, 2021). This sets a drawback, because the KRW is known to serve as both a water source and a water purification system for the Vaal River (Marara and Palamuleni, 2019). As the KRW continues to degrade, it will be less effective at removing pollutants from water, which will eventually lead to eutrophication issues in the Vaal River (McCarthy *et al.*, 2007). This study therefore intended to understand the linkages between urbanisation, and socioeconomic dynamics of people living in the vicinity of the KRW,

i.e. Protea Glen (PG) and Lenasia (LENZ), in the south of Johannesburg, and the interactions of all these with the wetlands water quality.

1.3. Rationale

Wetlands in South Africa which have various ecological services continue to face severe contamination (Dalu *et al.*, 2020). This is attributed to agriculture, mining and industrial activities which are occurring in the economic hub of the country, as well as population increases which constantly interact with natural factors that threaten wetlands' water quality (Orimoloye *et al.*, 2020). The study focused on Johannesburg, as incentivised by its population growth. According to Census, (2022), Johannesburg is the economic centre, not only for South Africa, but also for other countries within Africa. The city is the biggest in South Africa with about 4.8 million population size and it is a metropolitan area that has undergone spatial change due to the rise of public housing, informal settlements, and new suburban districts (Ndevu, 2022). Johannesburg's extensive population growth and urbanisation have led to an increase in the rates of anthropogenic activities such as mining and industrial activities, which interact with the quality of water in the Klip River Wetland (KRW) (Motebejana, 2022). Subsequently, there's limited information about the integration of water quality assessment with community perceptions and field observations in the study area. Much of existing literature on water quality degradation within the KRW is based on general environmental modelling, laboratory assessment and remote sensing. These do not entirely capture the complexity of water pollution dynamics in rapidly urbanising areas, by incorporating the perception and attitude of the communities exposed to urbanisation impacts, to help assess the linkages between wetland degradation and urban growth. The use of community surveys to help validate the assessment of water quality offers the chance for community members in the vicinity of the KRW to express their critical knowledge of the state of their water resource, the frequency and sources of contamination, and the specific challenges they face in relation to urbanisation. This study therefore conducted an integrated assessment, to close this existing research gap in the study area. By providing an insight into the state of KRW water quality, examined through laboratory analysis, community survey, and field observation.

1.3.1. Aim

The study aimed to evaluate the impacts of urbanisation on Klip River Wetland degradation in Johannesburg South.

1.3.2. Objectives

The objectives of the study were to:

- (I) Evaluate the physicochemical and biological characteristics of water quality of the Klip River Wetland.
- (II) Assess the community's perceptions and attitudes on how urbanisation impacts local communities in the vicinity of the Klip River Wetland.
- (III) Evaluate the factors related to urbanisation in these communities that interact with the degradation of the Klip River Wetland.

1.3.3. Research questions

- (I) What is the relationship between the physicochemical and biological characteristics of Klip River Wetland's water quality, the possible pollutants that are most prevalent in the wetland due to urbanisation, and the water quality status?
- (II) What are the socio-demographic characteristics of people living in the vicinity of Klip River Wetland, the drivers of urbanisation within their locality, and how that has impacted their livelihood?
- (III) What types of urbanisation-induced factors are influencing the physicochemical and biological regimes of Klip River Wetland, and how are they linked to wetland degradation?

1.4. Scientific contribution

The outputs of this study have the potential to provide both a detailed insight into environmental characteristics of Klip River Wetland (KRW) water quality in the face of urbanisation and the socioeconomic understanding of how urbanisation interacts with and impacts the wetland ecosystem. The research would offer a holistic view of the problem, highlighting both wetland water degradation and the anthropogenic influences, and offering feasible mitigation strategies to help conserve and protect

wetlands. This could contribute to proper developmental planning and other relevant interventions to prevent further water quality degradation in KRW.

1.5. Ethical requirements

Appendix 1 presents the ethical clearance certificate awarded by the University of Limpopo, Turfloop Research Ethics Committee (TREC), to uphold academic integrity, safeguard the rights of research subjects, and improve the validity of the study. This ethical clearance and a letter of permission (**Appendix 2**) to conduct a study in Klip River Wetland (KRW) and areas in the vicinity of the wetland was submitted to relevant stakeholders in Johannesburg City Park. **Appendix 3** is the permission to collect data in Klip River Wetland (KRW) and communities located in the vicinity of the KRW. Throughout the community engagements activities, high ethical standards were adhered to, the confidentiality and storage of the collected data were guaranteed by keeping respondents' identities and personal information hidden from outside parties. To gather relevant data and verify the accuracy of the information gathered, this study recorded conversations with the consent of respondents.

1.6. Definition of concepts

Urbanisation is the process by which a growing percentage of a population moves from rural to urban regions, causing cities to grow and expand. Economic factors that generate income, such as mining and industrialisation, are the main drivers of this urbanisation (Sakketa, 2023).

A river **wetland** is an area found around a river's floodplain or alongside its banks. Water levels in the river have an impact on these wetlands and can change seasonally or in response to precipitation (Sohns, 2024).

Water quality is the state or condition of water, usually determined by analysing a variety of physical, chemical, and biological characteristics. According to Alum *et al.*, (2023), it shows how appropriate water is for a variety of use, including residential, agricultural, industrial, recreational, and aquatic life support.

1.7. Characteristics of the study area

The Klip River Wetland (KRW), in the Klip River Catchment (KRC), which forms part of the Upper Vaal Water Management Area (WMA), flows southerly from Roodepoort and discharges into the Vaal River (Chetty *et al.*, 2021). The water use of KRW

includes domestic, aquatic, agricultural, recreational, and industrial purposes (Wepener, 2015). The KRW consists of three sub-catchments, namely: upper Klip sub-catchment, Riet Spruit sub-catchment, and lower Klip sub-catchment (Wepener *et al.*, 2015). Therefore, this study focused on the upper Klip sub-catchment, which is characterised by mines, wastewater treatment activities, and settlements (**Figure 1.1**). According to Census (2011), PG has a total area of 13.12 km² and a population of 75,634 people, including 21,424 households. Further down PG, on the south side of Soweto, there is Lenasia (LENZ), which occupies 20.28 km² and is home to 89,714 people, with about 25,763 houses (Census, 2011).

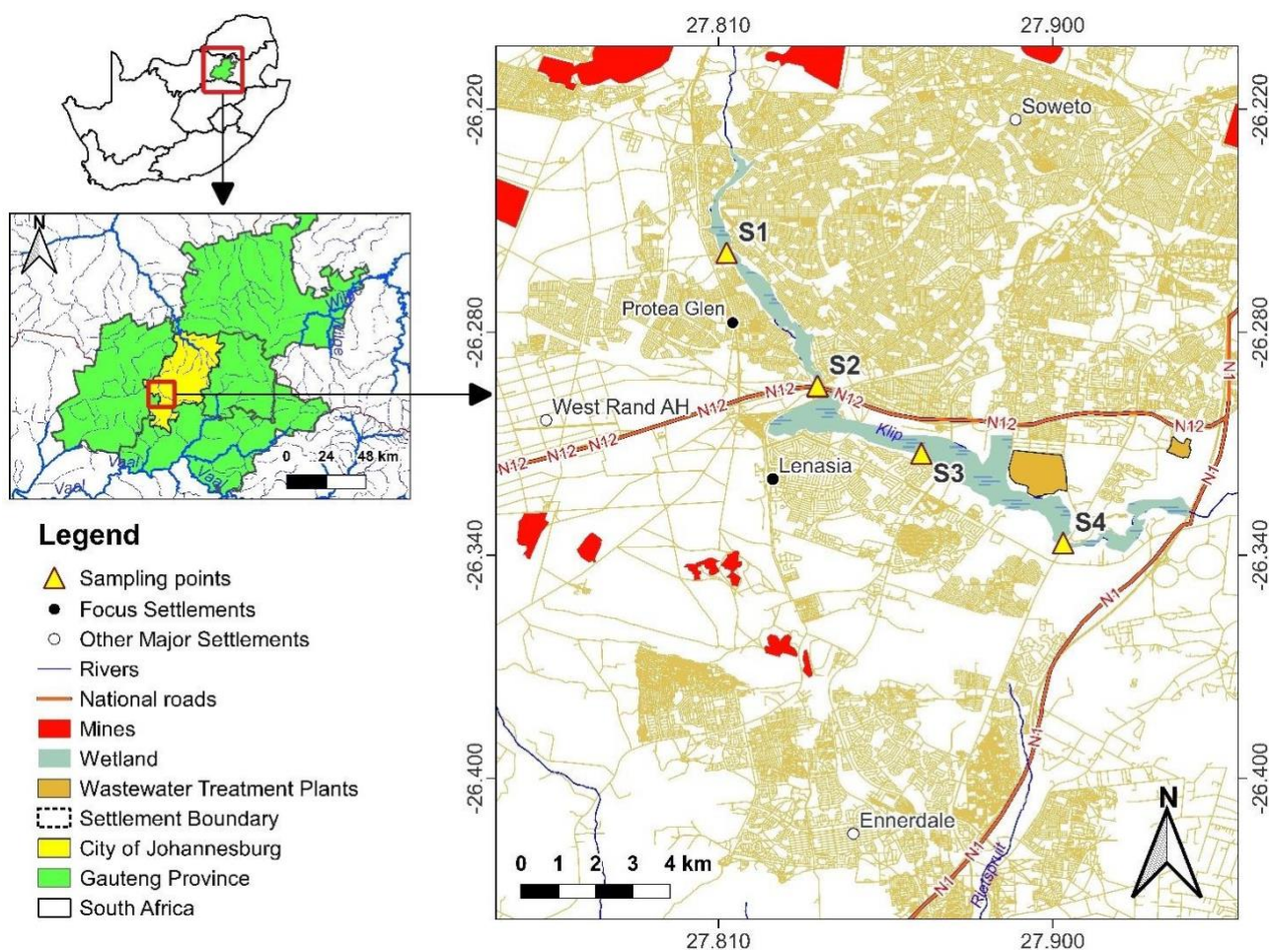


Figure 1.1: A geographic location of the Klip River Wetland (KRW).

1.7.1. Climate

The region has a sub-humid climate which tends toward semi-aridity (Vermaak, 2010). Most of the Klip River Wetland (KRW) is part of the Highveld ecoregion, which is distinguished by warm to hot summers and short, moderate winters with cool to warm days and cool nights. The summer months of October through March bring the most rainfall, which is frequently accompanied by powerful thunderstorms (Wepener *et al.*, 2015). The maximum temperature is 26°C in January dropping to an average minimum of around 16°C in June. Precipitation is confined to the summer season mostly in the form of conventional downpours of high intensity, which favours rapid runoff. The average summer rainfall is between 600-750 mm per annum (Vermaak, 2010). In the study area, Witwatersrand ridges are the source of the greatest amount of atmospheric convergence, which explains why rainfall is highest in the east and decreases towards the west, according to Marara & Palamuleni (2020).

1.7.2. Topography

The Witwatersrand basin where the Klip River Wetland (KRW) is located is characterised by hills, streams, and waterfalls that are connected to it. The area's natural topography has been modified by a variety of slime dams and mine dumps from recent and previous mining activities in the northern regions of Johannesburg (Durgapersad, 2005).

1.7.3. Geology

The surface geology of the wetland indicates that its top reaches are made up of porous, unconsolidated, and consolidated strata, while its middle reaches contain a sizable area of "water-sensitive" limestone and dolomite (Durgapersad, 2005). The Witwatersrand strata are conformably covered by dolomitic rocks of the Transvaal supergroup and basaltic volcanic rocks of the Ventersdorp Supergroup. The Klip River Wetland (KRW) is located on these karstic rocks (Chetty, 2021).

1.7.4. Geomorphology

The geomorphological investigation of the Klip River Wetland (KRW) identified two significant Knick points (Vermaak, 2010). The first is situated at the Olifantsvlei Sewage Works' exit, while the second is a rapid close to Kromvlei. Vermaak (2010)

added that KRW experienced the largest head cut advance of all the sections between Kibler Park and Kromvlei.

1.7.5. Vegetation

Rand Highveld Grassland is the predominant vegetation type of the Klip River Wetland (KRW). The Highveld Grassland is a classic example of a high inland plateau grassland, situated primarily between 1,300 and 1,635 meters in altitude, along the ridges of the Witwatersrand and the dolomite plains of Gauteng (Vermaak, 2010). Furthermore, *Cymbopogon-Themeda* veld with a mixed to sour grassveld climax predominates in the lower regions of the KRW (Wepener *et al.*, 2015).

1.8. Study limitations

The following are challenges encountered during the study period:

a) Water sample analysis:

Insufficient laboratory equipment such as an In-situ temperature meter which measures the degree of temperature on-site.

b) Community survey:

The questionnaire tool used to collect data related to how urbanisation has influenced the local communities in the vicinity of the Klip River Wetland (KRW), to capture all possible socioeconomic dynamics influenced by urbanisation, had to be consolidated and brief. This is because, during the pilot study (to enhance the validity of the study), concerns were raised about the length of the survey.

1.9. Organisation of the study

Chapter 1 introduces the study, covering the background, problem statement, objectives, research questions, scientific contributions, ethical considerations, and study limitations. Chapter 2 reviews existing literature on wetlands' ecological importance, the impact of urbanisation on water quality, and methods such as Pearson's correlation, Principal Component Analysis (PCA), and Water Quality Index (WQI) to assess and analyse wetland water quality. Chapter 3 outlines the research methodology, including the study area, water sampling, analysis techniques, and community survey methods. Chapter 4 presents the results, discussing the physicochemical and biological findings, the relationship between parameters, water quality status of the Klip River Wetland, and the socio-economic impacts of

urbanisation on local communities. Finally, Chapter 5 summarises the study, presents conclusions based on research questions, and offers recommendations for future research.

CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

A literature review is a thorough examination and analysis of previous studies, hypotheses, and publications about a certain subject or research question. The purpose of this review is to find research gaps and contradictions (Van Der Walddt, 2021). In this study, the literature view is based on the significant importance of wetlands, to give an overview of the ecological services that wetlands provide within the ecosystem. This section outlined the impacts of urbanisation on water quality on a global scale. The physicochemical and biological characteristics of water quality are reviewed, and to help answer the research question linked to this objective, Multivariate statistics such as Pearson's correlation and Principal Component Analysis (PCA) are reviewed, as well as Water Quality Index (WQI). Studies on community surveys which assess urbanisation impacts on local communities are reviewed, focusing on the socio-demographics, drivers of urbanisation, and impacts of urbanisation within local communities, to help integrate existing findings with the present study on the objective which assess community perceptions and attitudes on how urbanisation impacts local communities. Lastly, factors related to urbanisation in local communities which interact with water quality. This is to help integrate the relevant literature with the research objectives.

2.2. Wetlands and their ecological importance

The focus and incentive for examining the impacts of urbanisation on Klip River Wetland (KRW) was driven by the potential ecological services that wetlands provide within the ecosystem. Ferreria *et al.*, 2023 stated that approximately 121,106 km² of global area is covered by wetlands. Wetlands, which include rivers, marshes, and the likes, are hotspots for biodiversity and serve as habitats for the earth's environment (Xiong *et al.*, 2023). According to Zhang *et al.*, (2023), wetlands are unique ecosystems that provide significant services to the environment due to the relationships between water and land. Wetlands play a significant role in supporting ecological sustainability by managing floods, providing habitat for aquatic species, purifying water, sequestering carbon dioxide, reducing greenhouse gas (GHG) emissions, and water provision, among other ecosystem services (Nayak and Bhushan, 2022; Pedersen *et al.*, 2019). Key functions of wetlands are highlighted in

the sections below.

2.2.1. Flood control

According to Acreman and Holden (2013), floods are classified as natural disasters and have the potential to cause significant harm to property, infrastructure, and agricultural land, and in the worst-case scenario, they can cause death to humans and animals. However, whether natural or artificial, wetlands are crucial for controlling stormwater runoff and reducing the effects of flooding (Alikhani *et al.*, 2021). The full extent to which wetlands can reduce floods is debatable, according to Ferreira *et al.*, (2023), because their effects depend on a variety of factors, including topography, soil conditions, wetland size, and placement within a watershed. It is generally more likely that downstream wetlands can reduce floods than upland wetlands (Ferreira *et al.*, 2023).

2.2.2. Habitat for aquatic life and species

A wide variety of biotic life forms can be found in wetlands, including ducks, various migratory birds, carnivorous animals, algae, fish, and shellfish (Nayak and Bhushan, 2022). Birds are a crucial part of the biological population in wetland ecosystems, react fast to changes in habitat, and serve as a reliable indication of the stability and quality of wetland habitats (Kim *et al.*, 2023). Very few mammals are classified as wetland-dependent species, meaning they are suited to water and hydrophytes, unlike many members of the other wildlife groupings. However, a lot of animals have individual populations that, in some places and during some seasons of the year, are dependent on wetlands (Feirerabend, 2020).

2.2.3. Water purification

Water purification wetlands are commonly used in water treatment because they are efficient in eliminating pollutants, convenient to utilise, and cost-effective (Wang and Sheng, 2020). Ferreira *et al.*, (2023) have shown that wetlands can eliminate a variety of organic and inorganic substances from polluted water. They also act as a safeguard against deterioration of water quality by retaining contaminants due to sedimentation, filtration, and various other more sophisticated and connected processes between microbes and plants, as well as decontamination due to ultraviolet (UV) radiation from direct sunlight (Ferreira *et al.*, 2023). Additionally, adsorption of substrates is another process involved in removing pollutants accumulated in wetlands (Wang and Sheng,

2020). Hua and Haynes (2016) conducted a study aimed at removing heavy metals in municipal wastewater using constructed wetlands. According to their study findings, the average elimination rates for zinc (Zn) and copper (Cu) were 89.8% and 81.5, respectively. The Klip River Wetland (KRW) is responsible for the treatment of heavy metals and other pollutants accumulated because of acid mine drainage (AMD) and wastewater effluents (Chetty, 2021; Marara and Palamuleni, 2019). Vermaak (2010) stated that water quality parameters such as pH, electrical conductivity (EC), iron (Fe), and sulphate (SO_4^{2-}), improve to acceptable and ideal levels as the water moves south of the KRW towards the Vaal River.

2.2.4. Carbon sequestration

Villa and Bernal (2018) in their study provided an overview process of carbon sequestration by wetlands. They posited that carbon sequestration in wetlands is the process by which atmospheric carbon dioxide (CO_2) is moved and stored as soil organic matter (SOM) in the wetlands' soil carbon (C) pool (Villa and Bernal, 2018). Rosli *et al.*, (2017) in their study agreed to this, and stated that wetland soil is typically saturated and situated well below the water table. The atmospheric concentrations of greenhouse gases (GHGs) are lowered with the aid of carbon sequestration in wetlands (Makipaa *et al.*, 2023).

2.2.5. Cultural ecosystem services

The intangible benefits that humans derive from ecosystems play a crucial and unique role in improving human welfare. These benefits are part of ecosystem services, specifically cultural ecosystem services (Guo *et al.*, 2023). Cultural ecosystem service values by wetlands can be assigned depending on how communities view these contributions to their standard of living (Pedersen *et al.*, 2019). Metwane (2023) highlighted that wetlands offer a range of Cultural ecosystem benefits, including spiritual, religious, and recreational. They are valued ecosystems, serving as homes for gods, ancestors, and water spirits, and are sacred sites for worship and ritual. Additionally, Metwane (2023) suggests that wetlands possess sacred qualities, believed to have supernatural abilities to heal and protect against negative forces like evil spirits, misfortune, and witchcraft.

2.2.6. Water supply

Globally, wetlands play a vital role as natural water suppliers due to their ability to store, filter, and regulate water (Chakraborty *et al.*, 2023). They often help recharge groundwater supplies by allowing water to seep into the ground (Owen, 2021). According to Chetty (2021), the Klip River Wetland (KRW) is responsible for the supply of water to the Vaal River. Due to its significant water contribution to the Vaal Dam Reservoir, the Vaal River empties into the Vaal Dam Catchment area, one of the most vitally important regions in South Africa (Obaid *et al.*, 2023). Obaid *et al.*, 2023 further added that about 13 million people in the province of Gauteng and the surrounding area receive water from the Vaal Dam reservoir.

2.3. Physicochemical and biological characteristics of wetlands water quality

Assessment of the quality of wetland water, located in an urban region, serves a focal point for understanding the broader implications of urbanisation on wetland ecosystems. In the section below, a range of studies have assessed the physicochemical and biological characteristics of wetland water quality and were engaged to appraise the parameters examined.

2.3.1. Physical parameters: pH, electrical conductivity (EC) and turbidity

This section outlines a review of the physical parameters that determine the quality of wetlands' water.

2.3.1.1. pH

A water sample's pH value is a measure of its hydrogen ion activity. A pH of 7 is neutral, and when the concentration of hydrogen ions increases, pH falls below 7 and becomes acidic. The decrease in hydrogen ions leads to an increase in pH and the solution becomes alkaline (Kalembo, 2020). It is crucial to assess pH in wetlands' water, to help assess the impacts of urbanisation, because urban wetlands pollution is linked with fluctuations in pH levels (Joshi *et al.*, 2021). In the Lake Victoria basin, Shadrack *et al.*, (2015) assessed the pH values in wetlands, revealing that the dry season recorded higher pH values than in the rainy season. Moreover, this study stated that the rise in human activities is linked to these findings. Similarly, in Johannesburg South, Wepener *et al.*, (2015) assessed pH values in the Klip River Wetland (KRW), as well as the Klipspruit tributary that flows into the wetland, reporting

that the pH observed during the summer's rainy months was lower than that of the dry season.

2.3.1.2. Electrical Conductivity (EC)

A stream's dissolved salt content can be determined by its EC, a high EC indicates that there are more ions in the water (Kalembo, 2020). Chebet *et al.*, (2020) suggested that this could be related to ions like fluorides and chlorides as well as dissolved ionic components in water such as bicarbonate, sodium, sulphate, magnesium, and calcium salts. EC is a valuable parameter for evaluating the impacts of urbanisation on wetland degradation, because urban ecosystems reflect distinct trends of major ions (Carroll *et al.*, 2022). However, according to Akhter and Braich (2020), the wetlands with the lowest EC are those that receive more rainfall, which raises the water level. Conversely, wetlands with higher EC experience increase evaporation and the entry of organic materials like plant debris, which lowers the level of water. In Kenya, Chebet *et al.*, (2020) stated that the increment of salts has the potential to reduce the quality of wetlands water, thus increasing EC. The literature in this case highlights wetland's water level as a contributing factor to EC fluctuations, as well as salt increment. This diverse context regarding EC in urban wetlands is in alignment with the research scope, therefore, validating the need to incorporate this parameter in current assessment as a water quality indicator.

2.3.1.3. Turbidity

In the measurement of the environmental health of water bodies, turbidity is an important parameter to assess. It is an indicator of visibility that describes water's physical transparency. Water with high turbidity is muddy or cloudy whereas water with low turbidity is clear (Tomper *et al.*, 2022). In urban wetlands, it is vital to assess turbidity in urban areas because urbanisation-induced activities increase sediment in water, thus increasing turbidity and reducing water quality (Lin *et al.*, 2023). It reflects a complex interplay of physical, chemical, and biological factors within a wetland (Adiyaska *et al.*, 2022). However, literature in the case of turbidity in urban wetlands included studies which reported the cause and season variations of turbidity in wetlands. For instance, Zhang *et al.*, (2022) reported that high turbidity is caused by

combination of natural processes and human intervention, such as afforestation and snowmelt, while Molekoa *et al.*, (2022) reported seasonal variations of turbidity in wetlands, highlighting that the dry season water samples had higher turbidity levels than the wet season.

2.3.2. Chemical parameters: Dissolved oxygen (DO) and Chemical Oxygen Demand (COD)

To identify gaps in the chemical characterisation of wetlands water quality and to assist connect diverse findings with the assessment conducted in the current study, this part provides an overview of the chemical parameters, such as DO and COD, that determines the quality of wetlands water.

2.3.2.1. Dissolved Oxygen (DO)

DO is the gaseous oxygen content of water that is taken from the atmosphere or aquatic plants during photosynthesis and plays a crucial role in oxygenating aquatic organisms (Zhang *et al.*, 2022; Hanjanjamin *et al.*, 2023). Urbanisation often leads to increased nutrient runoff which lowers DO levels in aquatic ecosystem, thus harming aquatic life (Yang, 2023). There is recent information reported regarding DO in urban wetlands and how it contributes to more knowledge. However, whilst Singh *et al.*, (2022) assessed DO levels of wetlands of Punjab in India, highlighting that the highest DO value was recorded in winter, whereas the lowest value was recorded in summer, Koloti *et al.*, (2024) evaluated DO levels in water collected from Blesbokspruit wetland in South Africa, stating that low DO levels in freshwater systems often signify eutrophication and declining water quality. These studies highlight significant information about the seasonal variations of DO levels in wetlands, subsequently revealing the implications of low DO in water.

2.3.2.2. Chemical Oxygen Demand (COD)

COD is the amount of oxygen required to break down organic matter, and high COD signifies excess organic matter in water (Duncan *et al.*, 2023). In urbanised areas, increased wastewater runoff, and industrial discharges often contribute to higher levels of organic pollutants which increase COD level in wetlands (Anh *et al.*, 2023). Thus, it is essential to assess COD in a research topic related to urbanisation impacts on

wetlands degradation, also considering other physicochemical and biological characteristics of water quality because COD is linked to changes in some of the parameters (Du *et al.*, 2024). However, existing recent literature reported trends in the context of urbanisation and wetlands degradation. In Ghana, Duncan *et al.*, (2023) assessed the COD concentrations of the Iture-Abakam Natural Wetland in Cape Coast. According to the study's findings, the sampling sites undergo anaerobic conditions for most of the day because of the significant amount of organic matter they receive from communities located in the vicinity of the wetland. In South Africa, Koloti *et al.*, (2024) stated that the prolonged sewage overflow into the wetland from the poorly maintained wastewater drainage system in the Slovo Park informal community substantiates high COD levels in water. These studies report consistent information regarding COD which is influenced by wastewater, and this scope of research is related to the biological parameters, because fecal matter and other bacteria associated with wastewater are determined by biological indicators such as total coliforms. This strengthens the relationship of COD with other biological indicators and reveals strong alignment of COD analysis with the present research objective.

2.3.3. Chemical characterisation: Anions and cations

An overview of the chemical parameters, such as anions and cations that determine the quality of wetlands' water is provided in this section to substantiate the need to include these water quality indicators in the current study.

2.3.3.1. Chloride (Cl⁻)

Cl⁻ is a common constituent in water, it is highly soluble, and once in solution, it tends to accumulate (DWAF, 1996). In a study that examines how urbanisation affects wetland degradation, evaluating Cl⁻ is crucial since these pollutants, which are frequently linked to urban runoff, have a substantial impact on the physicochemical and biological characteristics of wetlands (Biswas *et al.*, 2024). In The river Molo water basin in Kenya was evaluated for Cl⁻ (Chebet *et al.*, 2020). The study's findings showed that the Cl⁻ levels were low and there will be no immediate health danger to consumers from these values because they are significantly lower than the recommended guidelines. In a natural wetland in South Africa, Shibambu and Gumbo (2020) reported high Cl⁻ levels which surpassed the recommended guidelines. The

objective of these studies is relevant to the present study; therefore, the reviewed consistent findings will significantly contribute to the interpretation of the present study's findings.

2.3.3.2. Fluoride (F^-)

F^- ions which are present in water sources are essential when assessing the impacts of urbanisation on Klip River Wetland (KRW), because in urban regions, industrial activities and geological processes are the contributors of F^- in wetlands water (Lacson *et al.*, 2021). In Kenya, F^- levels were evaluated by Chebet *et al.*, (2020) in water samples taken along the Molo River water basin. According to the study's findings, the recommended guideline was significantly exceeded by the values of the F^- . Chebet *et al.*, (2020) further stated that drinking fluoridated water can cause dental fluorosis and, in the worst instance, skeletal issues. According to this research's findings, people living in the vicinity of the Molo River area may be in danger of skeletal fluorosis. Water bodies contain fluoride in large quantities, and the human body has it mostly in the bones and teeth (Yang *et al.*, 2023). These studies reveal consistent trends of F^- in water and highlighting health impacts of excess F^- .

2.3.3.3. Nitrate (NO_3^-)

NO_3^- in water refers to the presence of nitrate ions, a form of nitrogen in water bodies, and it is a global concern due to its detrimental effects on aquatic environments (Fernández-López *et al.*, 2023). Assessing NO_3^- levels in a research study that evaluates the impacts of urbanisation on wetland degradation is crucial, especially when the research objective is to assess the physicochemical and biological characteristics of wetlands' water quality, because globally, NO_3^- is associated with urban growth induced factors, and it has interactions with other physicochemical and biological indicators of water quality (Akhtar *et al.*, 2021). The reviewed literature shows consistent information regarding NO_3^- in urban areas. While Fathi *et al.*, (2021) linked high NO_3^- level in the wetlands with agricultural effluents, in the Loukkos Wetlands Complex in Morocco, Koloti *et al.*, (2024) in South Africa also reported similar findings, outlining that NO_3^- concentrations in wetlands are linked to agricultural run-offs from neighbouring agricultural areas. These reviewed studies show consistent

global trends regarding NO_3^- concentrations in urban wetlands. Thus, it is vital to incorporate this existing knowledge about NO_3^- in urban wetlands, to help contextualise information about NO_3^- in wetlands located in urban regions.

2.3.3.4. Sulphate (SO_4^{2-})

SO_4^{2-} is the anion of sulfuric acid, and it is ubiquitous in the natural environment. SO_4^{2-} is a common constituent of water and it arises from mineral weathering and sulphide oxidation (Vidya *et al.*, 2024). Urban wetland water's SO_4^{2-} concentrations are becoming more widely acknowledged as a crucial sign of urban-induced deterioration in water quality (Rajora and Sarma, 2024). There are existing consistent findings about SO_4^{2-} in urban wetlands. A study by Anh *et al.*, (2023) revealed that there is a correlation between SO_4^{2-} with mining and geological processes. Subsequently, Levin *et al.*, (2024) stated that the crushing and grinding of ores that include platinum group elements (PGEs) during the mining and extraction process exposes many newly reactive mineral surfaces to oxidation. When oxygenated water comes into touch with these reactive minerals, highly mobile dissolved SO_4^{2-} is released and it has the potential to accumulate in wetlands, thus affecting water quality. The consistent trends of associating SO_4^{2-} with mining and geological processes is a global trend in the discipline of urbanisation and wetlands degradation, therefore this information is critical when assessing SO_4^{2-} in urban wetlands like the Klip River Wetland (KRW), in Johannesburg South.

2.3.3.5. Sodium (Na^+)

Na^+ occurs naturally in the environment or is a result of rock weathering (Oguchi and Yu, 2021). In alignment with the present study's research objective on the assessment of physicochemical and biological characteristics of Klip River Wetland (KRW), with the aim to evaluate the impacts of urbanisation on the wetland's degradation, Rahimi *et al.*, (2023), conducted a study based on the assessment of water quality stress in Amirkalayah Wetland. This study assessed Na^+ concentrations, which was found to be the predominant cation in the water samples collected along the wetland. Moreover, Rahimi *et al.*, (2023) illustrated the spatial distribution of Na^+ concentration in the wetland, indicating that the concentration of Na^+ in the southern parts is higher than the recommended level for surface waters. Vidya *et al.*, (2024) evaluated the

hydrogeochemical properties of the Thrissur Kole Wetland, reporting that Na^+ is a highly significant seasonal ion produced by salt dissolution (Vidya *et al.*, 2024).

2.3.4. Chemical parameters: Heavy metals

An overview of the chemical parameters, such as heavy metals, is provided in this section to highlight contradictions or inconsistencies in the chemical assessment of wetlands water quality and to help correlate disparate findings with the current study's findings.

2.3.4.1. Iron (Fe^{2+})

Fe^{2+} is a common element in the Earth's crust, and it is essential for the growth and metabolism of all aquatic organisms (Grzybowski, 2024). Gendle *et al.*, (2024) assessed Fe^{2+} in Indian River wetlands. These study's results revealed that although Fe^{2+} is necessary for nearly all living things, including humans and microorganisms, Fe^{2+} recorded exceeded the recommended guidelines, being the most abundant heavy metal in the study area. In Ghana, Okyere *et al.*, (2023) reported similar results, where Fe^{2+} exceeded recommended guidelines, and it was reported that high Fe^{2+} concentration is attributed to waste dumped in the vicinity of the wetland. Subsequently, Fe concentration which did not comply with the guidelines was observed in a study by Kamzati *et al.*, (2020), conducted in South Africa. It was concluded that the discharge of Iron-containing pollutants into water bodies such as wetlands through direct runoff from the land could be the cause of the presence of increased Fe^{2+} in the water (Kamzati *et al.*, 2020).

2.3.4.2. Manganese (Mn^{2+})

Mn^{2+} is an abundant element, constituting approximately 0.1 % of the earth's crust (DWAF, 1996). In Kenya, Robert *et al.*, (2021) assessed Mn^{2+} and the findings highlighted that Mn^{2+} levels rose with downstream distance during the wet season, while this trend was not seen during the dry season. During the wet season, the Mn^{2+} value was four times higher than during the dry season. Edokpayi *et al.*, (2016), assessed Mn^{2+} contents in water samples collected from Mvudi River wetland, South

Africa. The study's findings indicated that Mn^{2+} concentrations surpassed the South African Water Quality Guidelines (SAWQGs) range of 0.02-0.05 mg/R.

2.3.4.3. Copper (Cu^{2+})

Cu is a trace element that is essential to humans, animals, and plants. Cu occurs in three oxidation states, i.e. metallic, Cuprous, and Cupric Cu (DWAF, 1996). The oxidation state of Cu affects its solubility (Manne *et al.*, 2022). In India, Brraich and Jangu (2015) examined Cu^{2+} in the water of Harike wetland in water quality assessment research, aligning with the present study's objective. Allegedly, the results of the investigation showed that the water's Cu^{2+} levels were beyond the allowable limit, and it was reported that industries that produce metal, fertilizer, storage batteries, and mining are the sources of Cu^{2+} in the wetlands. Setiu Wetland's Cu^{2+} levels were measured by Sallan *et al.*, (2023), in Malaysia. The results of the study showed that the Ular and Setiu Rivers' riverine inputs, along with the runoff of materials containing high Cu^{2+} from the land, are presumably the cause of the increased Cu^{2+} level in the study area. In South Africa, Agoro *et al.*, (2020) assessed Cu^{2+} contents in wetlands water. The results of the investigation indicated that high Cu^{2+} levels were attributed to copper-containing fungicides and larvicides (Agoro *et al.*, 2020). These studies reveal information about the levels of Cu^{2+} in water, subsequently highlighting potential source of Cu^{2+} . Therefore, engaging these existing trends of Cu^{2+} with the present study's findings will contribute significant knowledge when interpreting the results, to help answer the research question.

2.3.5. Biological parameters: *Escherichia coli* (*E. coli*) and total coliforms

This section examines existing research on the assessment of *E. coli* and total coliforms in wetlands ecosystems, with a particular focus on their relevance to evaluating the impacts of urbanisation on wetlands.

2.3.5.1. *E. coli*

As a member of the fecal coliform group, *E. coli* is frequently utilised as an indicator microorganism for fecal contamination due to its abundance in warm-blooded animals' and humans' intestines (Zarić *et al.*, 2023). Globally, urbanisation has been linked with high counts of *E. coli* in wetlands' water (Wanek *et al.*, 2021). The presence of *E. coli* in wetlands offence correlates with changes in the physicochemical and biological conditions of water, aligning with the objective integrated in evaluating the impacts of urbanisation on Klip River Wetland (KRW). In Paraguay, Vergara-Franco *et al.*, (2023) conducted research on bacterial indicators in three wetlands, and it has been highlighted that amongst the three wetlands, only one wetland surpassed the average bacterial count limit of 100 CFU/100mL for surface waters. Consistently, Fuhrmann *et al.*, (2015) evaluated the level of microbiological pollution in the wetland area of Uganda, and reported similar findings, where counts surpassed the average bacterial count limit of 100 CFU/100mL for surface waters, whereas a study by Iwu *et al.*, (2023) in South Africa, expanded information from wetlands exceeding the average bacterial count limit, to reporting that high counts of *E. coli* deemed the wetland's water unfit for the residential, commercial, industrial, and recreational uses. These three studies show consistent trends in different regions across the globe, with the same research scope, but one further extends it into the quality status of the wetland. Integrating these existing findings with the present study will enhance research in the body of wetlands degradation and urbanisation.

2.3.5.2. Total coliforms

Total coliforms in wetlands are a common result of urbanisation and a crucial indication of water quality (Ferreira *et al.*, 2022). The total coliform group is a broad category of various rod-shaped, gram-negative bacteria that are found in the environment (Bai *et al.*, 2022). As total coliforms indicate broader changes in the wetland's biological dynamics, such as shifts in microbial communities and potential threats to aquatic ecosystems, their evaluation is highly aligned with the research objective of evaluating the physicochemical and biological characteristics of water quality in the Klip River Wetland (KRW). However, the reviewed studies contextualised significant information regarding total coliforms and urban wetlands. Kothari *et al.*, (2021) evaluated total coliforms in wetlands of Uttarakhand in India, and concluded that there is a possibility that other pathogenic bacteria such as *Salmonella* and *Shigella*, responsible for water-

borne diseases will also be found in the water if significant amounts of total coliforms prevail. In Africa, Moshi *et al.*, (2022) stated that total coliforms concentrations were found to be higher during the rainy season, as opposed to the dry season. Additionally, Wepener *et al.*, (2015) linked microbiological contamination in the Klip River Wetland (KRW) with Lenasia (LENZ) metropolitan region. Information from these studies contribute to literature, by highlighting health risks associated with total coliforms, seasonal variations of total coliforms within urban wetlands and lastly, the potential source of total coliforms in wetlands ecosystem. Integrating this diverse information when assessing KRW's water quality degradation brought on by urbanisation, will significantly contribute to assessing the dynamics of urbanisation on wetland's water quality.

2.3.6. Pearson's correlation

The present study's research objective on the evaluation of physicochemical and biological characteristics of Klip River Wetland (KRW) water quality, culminates to a research question which seek information about the relationship between the physicochemical and biological characteristics of KRW's water quality. Therefore, a review of Pearson's correlation, which is a multivariate tool applied to a wide range of fields to measure the strength and direction of a relationship between two variables, has been made (Backhaus *et al.*, 2021). In China, Hong *et al.*, (2020) used Pearson's correlation to assess the relationship between water quality parameters in wetlands along the Yellow River in Henan Province, thereby showing positive correlation between Chemical oxygen demand (COD) with ammonia nitrogen (NH₃-N) and total nitrogen (TN). This study highlights the interactions of chemical parameters within the wetland, whereas a study by Asfi *et al.*, (2023), conducted in Malaysia showed microbial interactions (Positive correlation of *Escherichia coli* (*E. coli*) with total coliforms) and how they correlate with physical parameters (*E. coli* and total coliforms exhibiting a strong negative correlation with temperature).

2.3.7. Principal Component Analysis (PCA)

Globally, urbanisation has been linked with various sources of pollution which exert pressure on urban wetland (Stokal *et al.*, 2021). In alignment with the present study's objective on the physicochemical and biological characteristics of Klip River Wetland (KRW), and part of the research question on the potential sources of pollution within

KRW is a rationale for reviewing studies which conducted PCA. PCA is widely used in various fields to reduce the number of variables without losing significant data and it presents large data in terms of principal components (PCs) (Greenacre *et al*, 2022). In this study's context, studies that used PCA to reduce the large data set of physicochemical and biological characteristics of wetlands were reviewed, to help determine the possible source of pollution in wetlands. However, there exists conflicting findings in the knowledge of PCA. For example, Dar *et al.*, (2021) used PCA to identify pollution contribution in wetlands and the PCA resulted in PCs which showed fecal matter as potential source of pollution in the vicinity of the wetland, whereas in Morocco, Hammoumi *et al.*, (2024) revealed that the PCs accounted for thermal pollution in wetland area. These findings in the same scope of research highlight microbiological and physical status of wetlands, contextualising significant information which aligns with the research objective.

2.3.8. Water quality index (WQI)

WQI is a crucial assessment for determining the overall water quality status of wetlands (Bilgin, 2018). It is integrated in the present study, emphasising the strong linkage with the assessment of physicochemical and biological characteristics, to help engage existing information with the present study's findings about the water quality status of water samples collected along the Klip River Wetland (KRW). However, Kujiek and Sahlile (2024) used physicochemical and biological characteristics data of a river to assess the Canadian Council of Ministers of the Environment-Water Quality Index (CCME-WQI) in Ethiopia, indicating poor water quality, therefore opposing findings by Atangana (2023) in Mpumalanga, which revealed that the CCME-WQI calculation upstream resulted in a score that indicated good to acceptable water quality. These findings reveal different geographic location impacts of urbanisation on wetlands, and different pressure exerted by pollutants on wetlands, which affects the water quality status. Therefore, incorporating these trends in the present study on the WQI assessment provides a richer context, enhancing credibility, and strengthening the relevance and impacts of the findings.

2.4. Community perceptions and attitudes on how urbanisation impacts local communities

This section outlines the literature on the opinions of community residents in various areas across the globe on how urbanisation has impacted their communities. Socio-demographics information is reviewed to place a stronger alignment with the objective of the present study which assess the community perceptions and attitudes on how urbanisation impacts local communities, opting to answer a research question about trends of socio-demographic characteristics of people living in the vicinity of Klip River Wetland (KRW), the drivers of urbanisation within their locality, and how that has impacted their livelihood.

2.4.1 Socio-demographics

The socio-demographic characteristics of respondents such as gender, age, educational background, and economic status, are considered significant influences of high pollution in wetlands (Ssanyu *et al.*, 2023). Socio-demographic assessments provide depth and nuance to understanding community perceptions of urbanisation impact on wetlands. The current global research on the perceptions of community members about urbanisation dynamics within their locality has revealed consistent and discrepancies findings. In the Yala Wetland of Kenya, Githiora *et al.*, (2023) assessed community perspectives, trends, and adjustments concerning climate change induced by urbanisation, and the findings revealed that factors such as gender, age, and education had negligible impact on climate change knowledge and awareness. A study by Ssanyu *et al.*, (2023) in Uganda's Lake Victoria Wetlands showed that the community's perception of the risk of high pollution in the wetlands was significantly influenced by factors such as age, education, and occupation, subsequently stating that a wetland's status as polluted or not was more likely to be stated by those with at least a secondary education (Ssanyu *et al.*, 2023). Lapointe *et al.*, (2021) evaluated how urbanisation affects the perception of people's benefits from ecosystem service and highlighted that a higher formal education level among community members may play a role in determining the degree of environmental deterioration.

2.4.2 Drivers of urbanisation

The drivers of urbanisation are the urban pull factors which highlight the attraction in urban areas, due to education, employment, health services, etc. (Olise *et al.*, 2024). Knowing the factors that contribute to urbanisation leads to grasping the larger social,

economic, and environmental dynamics (Jia *et al.*, 2024). The available information outlines a variety of pull factors, allowing a coherent link with the present study's research objective. Wassem and Talpur (2021) said that pull factors including varied lifestyles, easy access to utilities, and improved job possibilities have been accountable for the massive urbanisation. According to a study by Tyagi *et al.*, (2023), pull factors comprise better career prospects, access to healthcare, education, and improved quality of life in urban areas. Consistently, Olise *et al.*, (2024) also reported that access to income and services are one of the most significant drivers of urbanisation. These consistent trends regarding the drivers of urbanisation, originating from relevant sources, are imperative when interpreting the present study's findings, to help bridge gaps in research.

2.4.3 Impacts of urbanisation on community livelihood

The impacts of urbanisation on community livelihood, particularly in urban areas have been widely documented. The integration of the existing knowledge and the information brought on by the present study contributes to adding more concrete knowledge regarding how urbanisation impacts local communities. However, various recent studies have contextualised the impacts of expanding urban areas on living dynamics within communities, whereby there's similarities and diversities in the findings. For example, a study by Malambana and Visco, (2021) revealed that urbanisation can impact on a community, because an increase in the population increases physical assets such as buildings, roads, and water lines. Subsequently, Malambana and Visco, (2021) stated that although this made living easier and services more accessible, it also caused problems with the water supply, traffic congestion, and increased waste. A community engagement study by Lapointe *et al.*, (2021) stated that the increase in agricultural uses and the conversion of ecosystems into built-up regions caused ecosystem services to deteriorate in and around urban communities. Samat *et al.*, (2019) examined community perceptions about urban growth, in a study which emphasised positive and negative impacts of urbanisation within the local community, and it was found that despite most respondents believing that urban growth has a detrimental influence on the environment and nearby populations. Some respondents went on to say, "*Increased employment opportunities, improved transportation, and higher living standards are all benefits of urban expansion*".

2.5. Factors related to urbanisation within local communities that interact with wetlands' water quality

This section outlines findings from other studies which assessed the factors related to urbanisation that have the potential to affect the quality of water.

2.5.1. Education

Education serves as a means of spreading information and promoting environmental conservation (Van de Wetering *et al.*, 2022). Environmental education, according to Erhabor and Don (2016), raises people's awareness of environmental issues at all educational levels. The historical evolution of environmental education, according to Wu *et al.*, (2023), revealed that education for sustainable development is crucial for social justice, cultural freedom, and the eradication of poverty. Also, Wu *et al.*, (2023) highlighted that a region's environmental quality is highly influenced by the educational background of its community. According to Liu *et al.*, (2022), education, employee education, and household education are the three pillars of sustainable development. Education, skilful labour, and knowledge are all things that advance humankind. An accurate perception of reality can be attained through education. Businesses with knowledgeable staff members are less likely to harm the environment (Liu *et al.*, 2022). Moreover, education will eventually result in a reduction in environmental pollutants including greenhouse gas emissions, according to Liu *et al.*, (2022). Higher greenhouse gas emissions induce climate change, which affects water quality (Yoro and Daramola, 2020). Water quality will likely be impacted by climate change as it is expected to intensify and occur more frequently in natural disasters like floods and increasing precipitation in wetlands (Kibria, 2017).

2.5.2. Economic growth (Income)

According to Jacobs *et al.*, (2023), urbanisation leads to economic development, which is characterised by a rise in the production of products and services for income. However, due to rising non-renewable resource consumption, significant greenhouse gas (GHG) emissions, and potential habitat destruction, economic expansion has been associated with lower environmental quality (Liu *et al.*, 2022; Gao and Fan, 2023). Huang *et al.*, (2021) stated that environmental issues including water pollution will inevitably arise because of the rapid urban economy growth. The association between economic growth and water pollution was examined (Cai *et al.*, 2020). The

Gross Domestic Product (GDP) of the research region has grown, yet the nation's water quality has been steadily declining, as this study has shown. Furthermore, the study's findings indicate that COD and ammonia have rendered the surface water quality of river basins unsafe for human consumption. Bailey *et al.*, (2022) revealed that economic progress intensifies the production sector. The production of wastewater is one of the most well-known effects of the textile and clothing sectors on the environment (Bailey *et al.*, 2022).

2.5.3. Agriculture

According to Pawlak and Kołodziejczak (2020), protecting food security has grown to be a critical concern for nations with varying levels of economic development, and the agricultural sector is strategically important in enhancing food availability. Pawlak and Kołodziejczak (2020) added that ensuring food provision through increased agricultural output and expanding the use of agricultural land appears to be a potential strategy for ending hunger. Fertilisers, insecticides, herbicides, and other agrochemicals are being used more frequently to promote agricultural production due to pressure from economic investment in agricultural commodities (Chaud *et al.*, 2021). Although agriculture promotes social and economic aspects by providing food, it has led to environmental resource degradation. According to Zahoor and Mushtaq (2023), the use of pesticides, fertilisers, and other chemicals in farming techniques makes agriculture a major source of water pollution in developed nations. These contaminants could contaminate adjacent rivers and lakes, leading to eutrophication and damaging aquatic life. Furthermore, eutrophication leads to several issues, such as algal blooms, oxygen depletion, and deterioration of water quality (Varol and Tokatli, 2023).

2.5.4. Construction

Construction land has expanded erratically because of urbanisation (Wang *et al.*, 2022). Because building activities increase the amount of silt that enters waterways and downstream aquatic habitats, Zhu *et al.*, (2018) state that they are one of the main causes of water quality damage in urban streams. Large-scale construction projects of this kind pollute waterways, harming food webs and degrading aquatic ecosystems. There is evidence that sediments from construction sites can contaminate aquatic environments. Furthermore, Zhu *et al.*, (2018) reported that the construction of highways might cause a rapid degradation in the quality of stream water, by increasing

sediments. Li *et al.*, (2022) link the decline in wetland area to construction because of urban development. Hydrological changes caused by construction have been reported to affect wetlands. Wetland physical conditions, such as depth, length, and frequency of flooding, are significantly and rapidly affected by hydrologic changes (Ajibola *et al.*, 2012). According to Asumadu *et al.*, (2023), the most significant negative consequences of construction activities in wetlands areas include the extinction of aquatic and terrestrial life, the loss of the ability to manage flooding, and the degradation of the water quality.

2.5.5. Mining

The provision of mineral resources is one feature that mining activities share globally (Jiao *et al.*, 2021). These natural resources support the area's economic growth by supplying energy and mineral raw materials, which in turn promotes the expansion of the mining sector. While the mining industry has grown rapidly and has been a major contributor to economic progress, it has also posed threats to the ecology (Liu *et al.*, 2022). In China, urbanisation has fastened the development of mines which contribute to the development of the world economy through the supply of minerals. Consequently, this has caused environmental issues such as water pollution (Jiao *et al.*, 2021). Okyere *et al.* (2021) claim that Ghana's mining industry has grown significantly. The nation's overall export income has benefited greatly from the mining sector. Even though mining creates jobs, the use of hazardous materials like mercury in most mining towns harms the water quality. According to Chetty (2021), the mining industry in South Africa is the main driver of economic growth. As stated by Kalembo (2020), one of the biggest dangers to South Africa's water resources today is gold mining, despite having been the driving force behind the development of Johannesburg and the nation's economy for more than a century. During mining operations, sulfuric acid is created when pyrite oxidises, causing AMD. Toxic metals are released when the acid generated mobilizes materials found in waste materials and underground mine workings. In addition, Kalembo (2020) claimed that these harmful elements are released into KRW by runoff from the Central Rand Goldfield, lowering the quality of the water.

2.5.6. Traffic congestion

As a result of increased traffic, roads are overflowing with vehicles. This is primarily seen in urban areas where there is a greater need for mobility. In turn, this results in

higher emissions of greenhouse gases such as CO₂, CH₄, and N₂O due to the increased fuel usage (Sitati, 2021). According to Yoro and Daramola (2020), these greenhouse gas emissions cause climate change. Globally, increasing urbanisation has changed the climate (Helbling and Meierrieks, 2023). Raihan (2023) claims that during the last 65 years, there has been a dramatic change in the global climate. Climate change is a complex intergovernmental issue since its consequences have implications across social sectors and the environment. Wang *et al.*, (2023), stated that climate change is a factor behind the fluctuations observed in wetlands. Moreover, Wang *et al.*, (2023) reported that the degradation in wetland areas is notable on a regional level and is escalating with the increasing intensity of climate extremes. Climate change can affect a wetland environment by altering the hydrological patterns, which can change the ecosystem's biogeochemistry (Salimi *et al.*, 2021). Kibria (2017) investigated the effects of climate change on wetlands in Bangladesh. The report emphasized how climate change will increase both the intensity and frequency of disasters such as floods and more precipitation in wetlands. In Sub-Saharan Africa, Turyasingura *et al.*, (2023) studied the effects of climate change on water resources. The study's findings illustrated the effects of unpredictable rainfall on water quality. Furthermore, Rankoana (2020) highlighted the influence of climate change on water resources in South Africa. This research emphasized a decrease in river water quality and quantity, leading to an unsustainable water supply.

2.5.7. Wildfires

Paul *et al.*, (2022) studied how wildfires induce changes in receiving waters. The results of this study demonstrate that there is a greater chance of direct damage to water infrastructure when wildfire frequency rises in conjunction with urbanisation. Nutrients are one of the chemical water quality parameters that showed fluctuations due to wildfires that are researched more frequently, according to the study data. Water after wildfires usually contains higher levels of phosphate and nitrogen. In addition to increasing electrical conductivity in water due to wildfires, this can stress biota. Paul *et al.*, (2022) added that metal concentration in water also increased. Subsequently, the effects of wildfires on the quality of surface water were examined by Raelison *et al.*, (2023). According to the study's results, surface runoff carries burned ash and residue from wildfires into surface waters, where they degrade the quality of the water. Because wildfires alter the features of the ground surface, such

as tree cover and water repellence, they may accelerate and increase runoff volume. The study's results also indicated an increase in the following parameters related to water quality: pH, nutrients, heavy metals, total suspended solids (TSS), and polycyclic aromatic hydrocarbons (PAHs).

2.5.8. Waste

Globally, urbanisation has led to a huge increase in solid waste production in recent years, making it one of the most critical concerns (Voukkali *et al.*, 2024; Anvi, 2020). In India, rapid population expansion and urbanisation have led to a significant rise in the country's municipal solid waste generation (Prajapati *et al.*, 2021). Radioactive waste, bio-medical waste, battery waste, catering and market waste, commercial waste, institutional waste, and sanitary waste are all comprised of this solid waste (Prajapati *et al.*, 2021). However, one of the main problems facing Indian cities is the safe collection, transportation, and treatment of solid waste. Only 21% of solid waste in India is currently treated; the remaining waste is dumped in filthy landfills without the use of recycling or treatment technologies (Prajapati *et al.*, 2021). One of the problems is that solid waste makes its way into surface water during storms and strong rains (Anvi, 2020). Mekonnen *et al.*, (2020) evaluated the effects of solid waste dump sites on river water quality in Ethiopia. The results of this study show that the amount of waste produced every day by each household rises in conjunction with the urban population growth and the growing need for food and other necessities. Mekonnen *et al.*, (2020) added that uncontrolled waste disposal can contaminate water with many toxicants, including heavy metals, which can lead to environmental damage. The results of the study demonstrated that the presence of solid waste dumps has led to elevated concentrations of metals and COD, above recommended level.

2.6. Summary

This chapter reviewed that urbanisation is a global phenomenon, which is occurring rapidly, due to population increase and the prospects of meeting better opportunities. It has been noted that rapid urbanisation has both positive and negative impacts on human habitat and the environment. Anthropogenic activities such as mining, industrialisation, and agriculture, are intensified within urban areas, for economic development and job creation, as needed by the growing population. However, in some cases, urbanisation has led to insufficient road networks which are linked to

infrastructure services. The influx of people into urban areas has led to traffic congestion, as more people need mobility. This section of the study also reviewed improper waste disposal and wildfire ashes within communities. These issues in urban areas are proliferating, thus exerting pressure on wetlands. The natural atmosphere is negatively affected by these urbanisation-induced factors which interact with the climate and results in severe floods and loads of sediments in water, and affecting the physical, chemical and biological regimes wetlands.

CHAPTER 3: METHODOLOGY

3.1. Introduction

This chapter describes the procedures utilised to attain the study's objectives, thus answering the research questions. It details the data requirement, collection processes, and methods used, as well as the characteristics of the Klip River Wetland (KRW). An overview of the natural characteristics of KRW such as the topography, climate, geology, geomorphology, and vegetation, are outlined. The research design (quantitative and qualitative) is explained to ensure that the investigation is carried out methodically and chronologically. For the first objective, the approach used for water quality assessment is explained. For the second objective, the determination of sample size, questionnaire description, and administration, and the analysis of community perceptions and attitudes on how urbanisation impacts local communities, are outlined. Lastly, the procedure for assessment of factors related to urbanisation that interact with KRW water quality is discussed, for objective 3.

3.2. Research design

This study employed a convergent mixed-method approach (**Figure 3.1**). This method includes both quantitative and qualitative data, which are analysed independently, then combined during interpretation, and finally, a conclusion is made based on the two converged data tools (Hatta *et al.*, 2020).

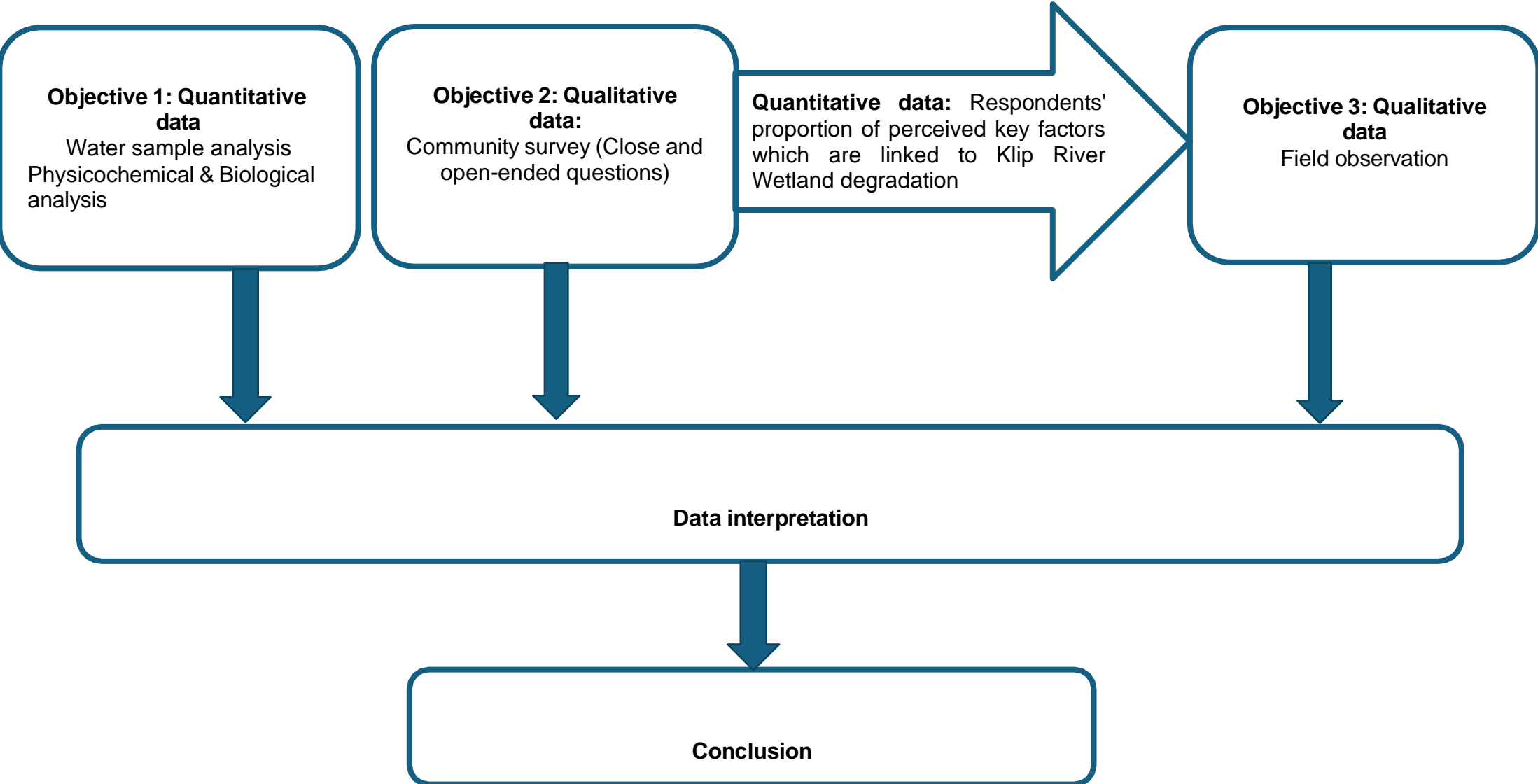


Figure 3.1: Flow diagram of the convergent mixed method approach used in the study.

3.3. Detailed methodology

The section below presents the detailed methodology on how the objectives of the study were undertaken to achieve the aim and answer the research questions.

3.3.1. Objective 1: Evaluation of the physicochemical and biological characteristics of water quality of the Klip River wetland

In this objective, 18 water quality parameters were divided into physical, chemical, and biological characteristics for feasible analysis and the results obtained were integrated and compared. Physical parameters included pH, electrical conductivity (EC), and turbidity. Chemical parameters included dissolved oxygen (DO) and chemical oxygen demand (COD), anions such as chloride (Cl^-), fluoride (F^-), nitrate (NO_3^-), and sulphate (SO_4^{2-}), as well as cations such as magnesium (Mg^{2+}), calcium (Ca^{2+}), sodium (Na^+) and heavy metals including chromium (Cr^{2+}), copper (Cu^{2+}), iron (Fe^{2+}) and manganese (Mn^{2+}). Biological parameters included *Escherichia coli* (*E. coli*) and total coliforms. This section outlines water sampling periods, sites, collection, quality control measures, laboratory analysis, statistical analysis and water quality index (WQI) used to compute the overall water quality status of this study's monitoring sites and seasons, from the 18 water quality parameters.

3.3.1.1. Sampling periods

Assessing the temporal dynamics of urban wetlands pollution requires assessment at seasonal scales to determine the influence of temporal changes on the wetland's water quality (Marara and Palamuleni, 2020). This was corroborated by the Ojok *et al.*, (2017) in their study. They posited that assessing seasonal fluctuations in surface water quality parameters is a crucial component of assessing water quality degradation. In this study, sampling was conducted seasonally during wet and dry seasons to assess the seasonal variations in water quality of the Klip River Wetland (KRW).

3.3.1.2. Sampling sites

A stratified sampling method was used to locate sites for water sample collection based on the potential pollution characteristics within the outskirts and vicinity of the Klip River Wetland (KRW). **Table 3.1** below represents the study's monitoring sites, coordinates of the sites, site description, and potential characteristics linked to water quality degradation.

Table 3.1: The spatial location of water sampling sites and potential pollution characteristics along the Klip River Wetland (KRW)

Sites	Coordinates	Description of sites	Pollution characteristics
S1	-26.25853 (Latitude) 27.812064 (Longitude)	KRW at the bridge between Protea City and Naledi. This site represents upstream Protea Glen (PG)	Mines uphill PG PG settlement (waste dumped on open land, traffic congestion, wildfires)
S2	-26.294441 (Latitude) 27.836665 (Longitude)	KRW at N12 Highway. This site represents downstream PG/Upstream Lenasia (LENZ)	PG settlement (sewage flow)
S3	-26.312546 (Latitude) 27.864612 (Longitude)	Downstream LENZ before wastewater treatment plant (WWTP) discharge	LENZ settlement, at extension 13 Nana's farm informal settlement
S4	-26.336596 (Latitude) 27.903122 (Longitude)	Downstream LENZ after WWTP discharge	LENZ settlement at extension 9 Klipspruit tributary WWTPs discharge into KRW

3.3.1.3. Water sample collection and quality control

Prior to sample water sample collection, 1-liter polyethylene bottles and 1-liter glassware bottles were thoroughly rinsed with de-ionized water before collecting the water samples, following Agwu *et al.*, (2023), for quality control. An autoclave was used to sterilise the glassware bottles to avoid cross-contamination (**Figure 3.2**). The glassware bottles were used to collect water samples for biological assessment.

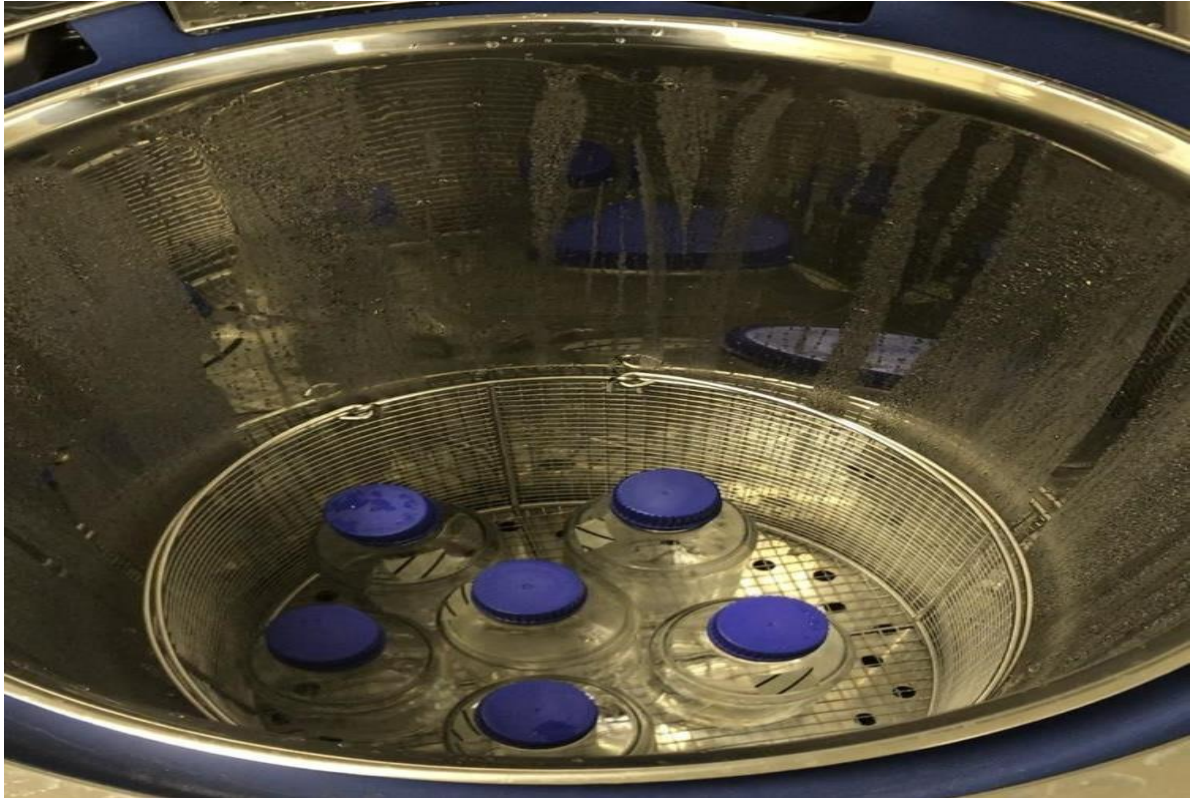


Figure 3.2: Autoclaving process using high-pressure steam to sterilize glassware bottles used to collect water samples for biological indicator assessment.

Source: Mabale, 2024.

For acclimation purposes, the bottles were rinsed three times at designated sampling locations with water from the Klip River Wetland (KRW) before the actual water samples to be analysed were collected. At a depth of 0 to 30 cm, following the approach utilised by Agwu *et al.*, (2023). The triplicates set water samples collection to ensure accurate results were only limited to physicochemical parameters such as pH, electrical conductivity (EC) turbidity, dissolved oxygen (DO), and chemical oxygen demand (COD). This was due to insufficient laboratory materials to analyse other parameters in triplicates. Thereafter, the water samples were promptly put in an ice-filled cooler box and transported to the laboratory, as shown in **Figure 3.3**, to preserve the samples and minimise the changes in the natural state of the water (Bessah *et al.*, 2021).



Figure 3.3: The preservation of water samples collected within the Klip River Wetland.
Source: Mabale, 2024.

3.3.1.4. Water Sample Analysis

This section details the analysis of water samples collected along four monitoring sites in the Klip River Wetland (KRW).

3.3.1.4.1. Physical parameters: pH, electrical conductivity (EC) and turbidity

Following Estifanos *et al.*, (2022), Hach HQ40d multi-parameter, as displayed in **Figure 3.4**, was used to analyse pH and Electrical conductivity (EC) values of water samples collected along the Klip River Wetland (KRW). The motive for the selection of this methodological analysis is because Hach HQ40d is a well-suited choice for analysing pH and EC in water samples because it offers precision, portability, multi water quality parameter assessment, and the durability needed to perform broader research framework assessments that are crucial to understanding the wetland's physicochemical and biological characteristics of water quality. Following the Hach HQ40d manual guide, the analytical instrument was calibrated by cleaning the electrode with deionized water and stabilising it in buffers with pH values of 4.0, 7.0, and 10. After this, the electrode was put inside the water samples for running tests.



Figure 3.4: Analytical pH and EC assessment in water samples using a multi-parameter.

Source: Mabale, 2024.

Turbidity, which is one of the key indicators for water quality status was analysed using a turbidity meter (Lovibond TB300IR). This method contributes to addressing the research objective of evaluating the physicochemical and biological characteristics of water in the Klip River Wetland (KRW) by providing essential data on water clarity and suspended particles (Wardi *et al.*, 2023). This is critical for understanding the impact of urbanisation on water quality. Through its accurate, reliable and user-friendly turbidity measurement, TB300IR help establish a clear observation for water quality changes, making it a significant method to be applied in a broader research framework, by providing information about ecosystem health, supporting conservation efforts, advancing scientific understanding and fostering sustainable management practices (Mahanna *et al.*, 2024). To measure turbidity values, TB300IR was calibrated, by placing the standard of <math><0.1</math> NTU (Nephelometric Turbidity Unit) on the sample chamber, aligning both marks on the standard cuvette and the sample chamber. After this, the sample chamber was covered and the reading started

automatically after the countdown. 20, 200, and 800 NTU standards were also used to calibrate the meter, using the same procedure as for <0.1 NTU standard. For analysis, the vials were rinsed three times with the water samples. Following this, the water samples to be analysed were then put inside the vials and placed in the sample chamber, aligning both marks on the vials and the sample chamber. Thereafter, the sample chamber was covered and reading started.

3.3.1.4.2. Chemical parameters: Dissolved oxygen (DO) and chemical oxygen demand (COD)

Analysing dissolved oxygen (DO) levels in water samples collected in the Klip River Wetland (KRW) makes a significant alignment with the objective which intend to evaluate the physicochemical and biological characteristics of the KRW, because DO, it being a chemical parameter, it plays a crucial role in support life for aquatic organisms, according to Hanjanjamin *et al.*, (2023), which incentivise DO analysis in the present study, because the KRW is known for aquatic life purposes, amongst other significant, important ecological services (Wepener, 2015). Using Hanna Iris Spectrophotometer (HI801-01), the collected water samples along the KRW were analysed for DO (**Figure 3.5**). The use of Hanna Iris Spectrophotometer (HI801-01) reduces the need for hazardous chemical and reagents unlike the Winkler titration, making it a more environmentally friendly option. Following the manual guide, 60 ml of unreacted water sample was added into a glass bottle, and subsequently, 5 drops of DO reagent A (HI93732A-0) and reagent B (HI93732B-0) were added and filled the glass bottle with more samples. The bottle was inverted several times until the sample turned orange-yellow, and a flocculating agent appeared. The flocculating agent was allowed to settle for 2 minutes. When the top of the bottle was clear, 10 drops of the reagent C (HI93732C-0) were added. The bottle was inverted until the settled flocculating agent dissolved completely and the water sample was ready for measurements when it turned yellow and completely clear. To zero the meter, the first cuvette was filled with 10 ml of the unreacted sample and put into the cuvette holder. 10 ml of the reacted water sample was added to the second cuvette, which was then put into the cuvette holder for readings.

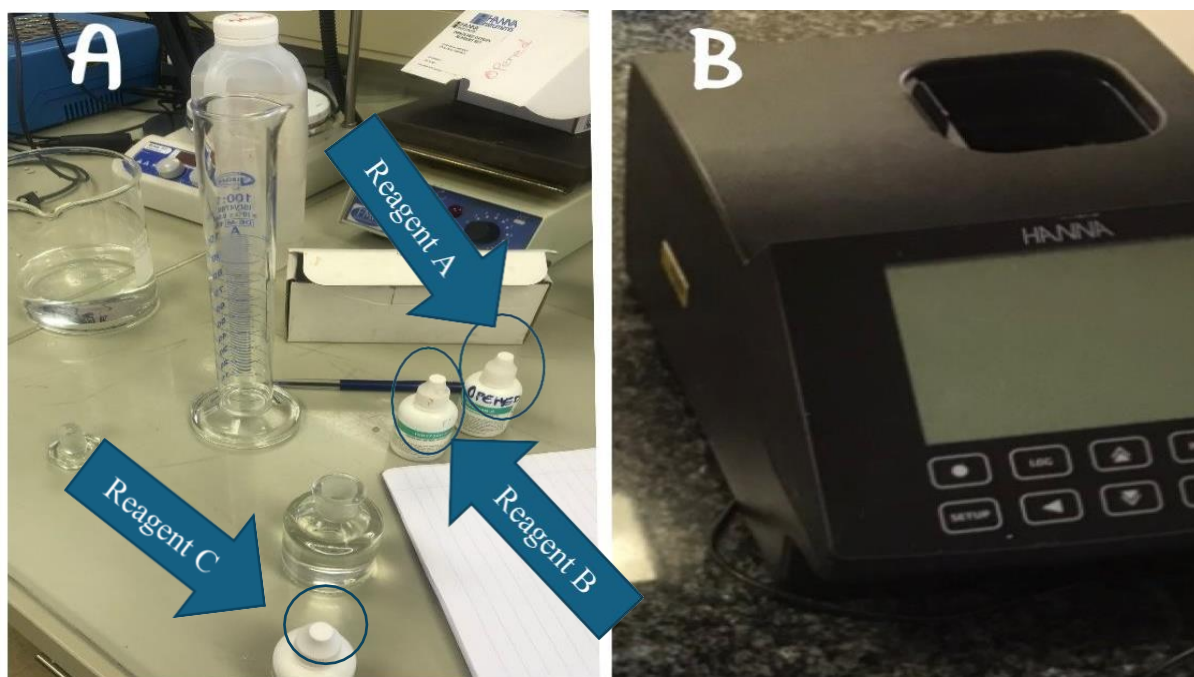


Figure 3.5: Analytical assessment of Dissolved Oxygen (DO) using Hanna Iris Spectrophotometer.

Source: Mabale, 2024.

Hanna COD reactor (HI839800) and Hanna Iris Spectrophotometer (HI801-01) were used to analyse COD (**Figure 3.6**) in water samples, following. The selection of these methods is grounded by their ability to provide accurate and reliable COD measurements, playing a significant role in broader research, supporting the comprehensive understanding of the wetland's ecological health, and informing conservation frameworks. These methods align with the research objective, which evaluated the physicochemical and biological characteristics of the Klip River Wetland (KRW), as they directly inform the organic pollutant level in water samples. Subsequently, other relevant alignment of COD analysis with the study's objective is due to the correlation of COD with other water quality parameters (Makumbura *et al.*, 2024). For preparations, the Hanna COD reactor (HI839800) was heated to 150°C. Following this, HI93754B-0 COD medium-range reagent vials, which range from 0 to 1500 mg/l, were used. The first vial was prepared and 2 ml of deionized water in it, as it was used as a blank for each set of measurements, for improved accuracy assessment. Thereafter, 2 ml from the unreacted water samples was extracted using a pipette and added to vials. The vials were inverted several times to mix. Thereafter, the vials were inserted into the Hanna COD reactor (HI839800) and heated for 2 hours

at 150°C (Morales *et al.*, 2024). At the end of the digestion, the vials were allowed to cool to about 120°C. While still warm, the vials were inverted several times and placed on the test tube rack, to cool to room temperature (25°C). After this, the blank vial was used to zero the Hanna Iris Spectrophotometer (HI801-01), and the rest of the vials were inserted into the meter for analysis.

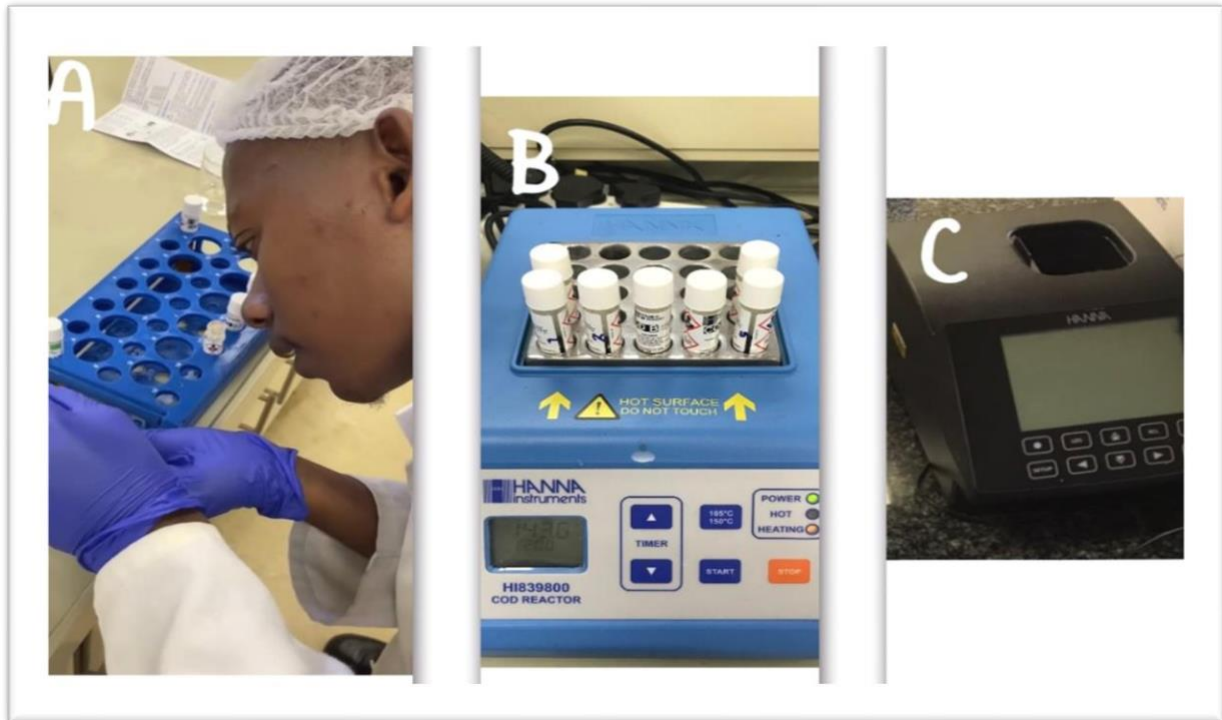


Figure 3.6: Analytical assessment of Chemical Oxygen Demand (COD) using Hanna COD reactor and Hanna Iris Spectrophotometer.

Source: Mabale, 2024.

3.3.1.4.3. Chemical parameters (anions)

Ion Chromatography (IC) (ME-012), a widely used analytical method for the separation and measurement of anions in water samples, was utilised to analyse anions such as chloride (Cl^-), fluoride (F^-), nitrate (NO_3^-), and sulphate (SO_4^{2-}) (Avdalovic and Liu, 2021). The accuracy of IC is essential for evaluating possible contaminants in the wetland's water and their effects on Klip River Wetland (KRW). It is a very effective technique for the simultaneous analysis of multiple anions, enabling efficient and high-resolution detection of these critical ions at low concentration (Nesterenko, 2023). By linking changes in anion concentrations to the physiological and biological characteristics of the wetland, IC contributes valuable insights into how urbanisation affects the wetland ecosystem. For analytical assessment, IC principle involved

sample preparation, ion exchange column, mobile phase, separation, detection, and quantification. Water samples were filtered to eliminate particle matter during sample preparation (Huang *et al.*, 2024). The ion exchange column, which features a stationary phase that selectively retains anions according to their size and charge, is the primary part of IC, according to Poole (2024). The anions in the water samples compete with the counterions in the stationary phase when the samples are injected. As the water samples passed through the column, various anions interacted with the stationary phase in different ways to facilitate separation. Anions were identified as they elute from the column following separation. To measure the anion content in water samples, the detected signals were processed and compared to the calibration curves derived from the standards (Nesterenko, 2023).

3.3.1.4.4. Chemical parameters (cations and heavy metals)

The collected water samples were subjected to Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) analytical instrument to detect the concentrations of cations such as magnesium (Mg^{2+}), calcium (Ca^{2+}), sodium (Na^+), and heavy metals such as chromium (Cr^{2+}), copper (Cu^{2+}), iron (Fe^{2+}) and manganese (Mn^{2+}). This analytical tool is essential for gathering precise, trustworthy, and thorough data on the levels of heavy metals and cations in the Klip River Wetland (KRW). It helps provides information on the impact of pollutants on the wetland ecosystem and guides future conservation and management plans (Khan *et al.*, 2022). To apply and use ICP-OES in this present study, water samples collected were filtered to remove particulate matter via a 0.45 μm filter. Nitric acid (HNO_3) was used to acidify the samples to preserve them and avoid metal precipitation for the heavy metal examination. To obtain the cation and heavy metal concentrations within the calibration range of the instrument, the water samples were diluted. The argon plasma in the ICP-OES was then lighted to guarantee stable plasma conditions, and a blank was prepared to provide the starting point for the analysis. Using a nebulizer, which turns the sample into an aerosol, the samples were moved into the ICP-OES for analysis. After that, the aerosol enters the plasma, where the temperature atomizes and excites the heavy metals and cations in the sample. A spectrometer recorded the distinctive light that the excited atoms released when they settled back to their ground state. The intensity of light corresponding to the target heavy metals and cations was then measured by the ICP-OES. The results were interpreted and reported after the concentrations of the

heavy metals and cations were quantified using the calibration curve, which was based on the intensity of the light emitted.

3.3.1.4.5. Biological indicators

The Colilert-18 or Quanti-Tray method was used for the most probable number (MPN) enumeration of *Escherichia coli* (*E. coli*) and Total Coliform bacteria in the collected water samples with the aid of Bilodeau (2023) (**Figure 3.7**). This technique's ability to rapidly and accurately detect *E. coli* and Total Coliform supports the research objective by providing critical information about microbial contamination in the Klip River Wetland (KRW). It contributes to understanding the wetland's ecological function and resilience, while its integration into the broader research framework allows for a holistic assessment of the wetland's health and its response to anthropogenic pressures. For preparation, the substrate medium (A) was added into a 100 ml bottle containing a measured 100 ml of the water sample (B). Following the dissolution of the substrate medium powder in the 100 ml bottle, the mixture was poured into a Quanti-Tray with 97/51 wells (C). The Quanti-Tray was then heat-sealed following this (D) and incubated (E) for 24 hours at 37°C. After incubation, ultraviolet (UV) light was used to observe the presence of *E. coli* and total coliform. Under UV light, the number of yellow wells, representing total coliforms, and yellow wells that fluoresced, representing *E. coli* were counted, i.e. number of wells giving positive reaction per 100 ml sample and MPN table (**Appendix 4**).

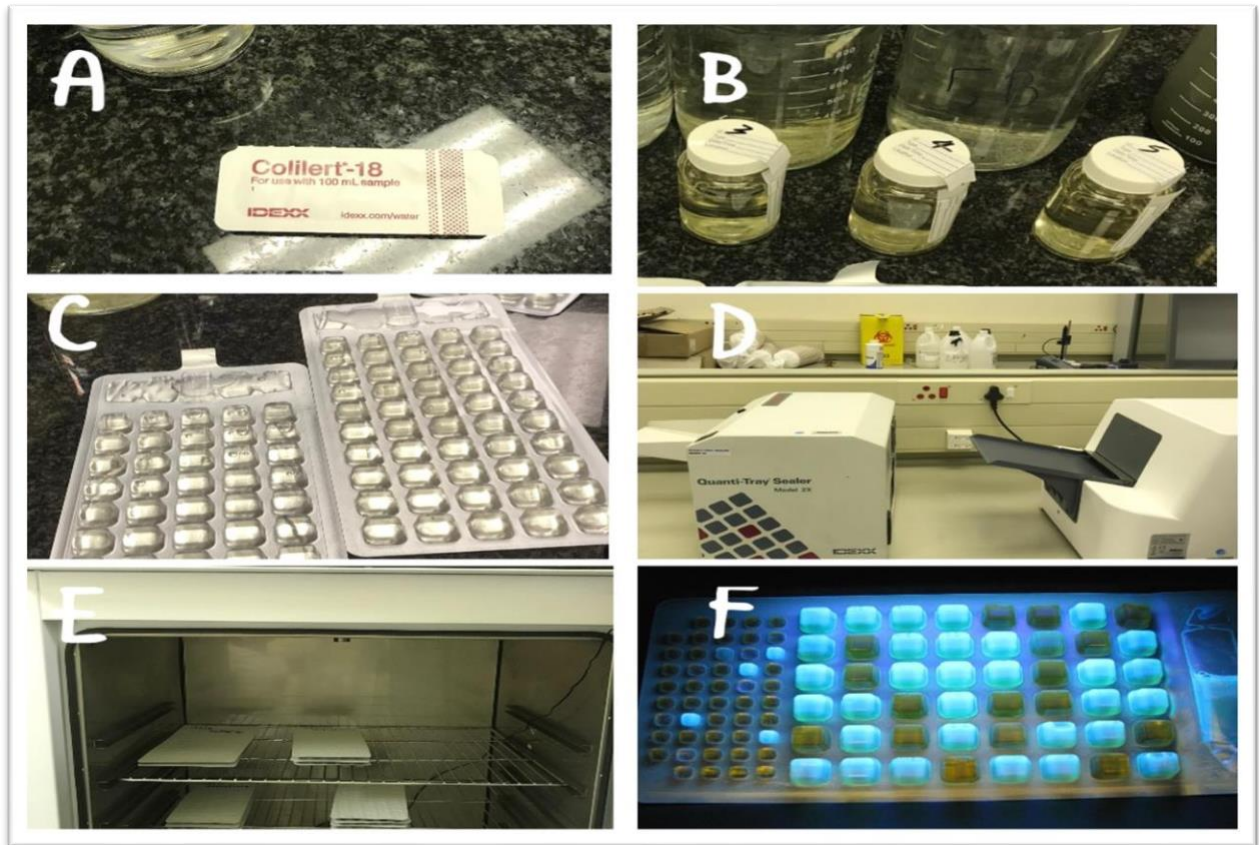


Figure 3.7: Assessment of *Escherichia coli* (*E. coli*) and total coliforms using Colilert-18 technique.

Source: Mabale, 2024.

3.3.1.5. Water Quality Guidelines

This study considered the domestic purposes of the Klip River Wetland (KRW), as stated by DWAF (1996) that the characterisation of domestic water use includes water drinking, bathing, laundry, and gardening which may include water for fishponds. Therefore, physicochemical and biological water quality results were compared with South African Water Quality Guidelines (SAWQGs) volume 1 for domestic use (DWAF, 1996) and the In-stream Water Quality guidelines (ISWQGs) for the Klip River Catchment (KRC), sourced from the Resource Quality Information Services (RQIS, 2003).

3.3.1.6. Statistical analysis

Statistical analysis helps to assess how urbanisation influences the physicochemical and biological characteristics of Klip River Wetland (KRW), by quantifying the changes in the water quality parameters, identification of casual relationships, trend analysis, and not only contributing to the understanding of urbanisation impacts on KRW but also provides a broader framework for making evidence-based recommendations for wetland management. For application of statistical analysis, Statistical Package for Social Science (SPSS), version 29.0, was used to determine the descriptive statistics of physicochemical and biological characteristics. Multivariate statistics such as Pearson's correlation were also determined using SPSS. Pearson's correlation is comprised of the direction (negative or positive), correlation coefficient (r), and level of significance of a relationship (p). With regards to the direction, negative (-) means inverse proportion, and positive (+) means direct proportion. The (r) value which lies between -1 and 1 determines the strength of the relationship. The correlation is significant at $p < 0.01$ and $p < 0.05$ (Han and Bu, 2023). Origin Lab Pro (OLP), version 2024, was used for Principal Component Analysis (PCA), a multivariate statistics tool, to determine possible sources of pollution in the KRW (Ma *et al.*, 2023).

3.3.1.7. Water Quality Index (WQI)

To be able to conclude the final state of water quality of the Klip River Wetland (KRW), according to sampling sites and seasons, WQI was computed to reduce the large water quality data set of 18 water quality parameters and represent it simply and understandably. Amongst the WQI used in water quality research, the Canadian Council of Ministers of the Environment-Water Quality Index (CCME WQI) was used in this study because it offers several advantages over other methods, including compliance with different legal requirements and different water uses, eligibility for water quality assessment in specific areas, flexibility in the selection criteria, and tolerance for missing data (Bilgin, 2018). Moreover, this CCME-WQI has recently been used in South Africa and other parts of Africa due to its feasibility. CCME WQI quantified three essential factors (F₁, F₂, F₃) for the calculation of a single unitless number that eventually indicated the overall water quality (Panagopoulos *et al.*, 2022). F₁ (scope) represented the percentage of parameters (variables) that did not meet their guideline (objective) at least once during the period under consideration (failed variables), relative to the total number of variables measured, i.e. $F_1 =$

$\left(\frac{\text{No. of failed variables}}{\text{Total No. of variables}} \times 100\right)$. F_2 (frequency) represented the percentage of individual

tests that did not meet the objective (failed tests). A test is a single comparison of a parameter's value from a certain sampling campaign with the respective objective for that parameter, i.e. $F_2 = \left(\frac{\text{No. of failed tests}}{\text{Total No. of tests}} \times 100\right)$. F_3 (Amplitude) represented the

amount by which failed test values did not meet their objectives, and it was calculated in three steps. Step 1: The number of times an individual concentration was greater than (or less than, when the objective is a minimum) the objective was termed an excursion and was expressed as $\text{excursion} = \left(\frac{\text{Failed test value}}{\text{Objective}} - 1\right)$, when the test value

was supposed not to exceed the objective, and $\text{excursion} = \left(\frac{\text{Objective}}{\text{Failed test value}} - 1\right)$, when

the test value was supposed not to fall below the objective. Step 2: The collective amount by which individual tests were out of compliance was calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those that met the objectives and those which did not meet the objectives). This parameter, referred to as the normalized sum of excursions, or *nse*, was calculated as $\text{nse} =$. Step 3: F_3 was then calculated by an asymptotic function that scaled the normalized sum of the excursions from objectives (*nse*) to yield a range between 0 and 100, i.e. $F_3 = \left(\frac{\text{nse}}{0.01\text{nse}+0.01}\right)$. Once the factors were obtained, the CCME

WQI was calculated by summing the three factors as follows: $\text{CCME WQI} = 100 - \left(\frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}\right)$ (Mukut *et al.*, 2023). The divisor 1.732 normalized the resultant values

to range between 0 and 100, where 0 represented the 'worst' water quality and one hundred represented the 'best' water quality (Saw *et al.*, 2021). Once the CCME WQI value has been determined, water quality was ranked by relating it to the CCME WQI classes (Brand and Barnes, 2014) (**Appendix 5**).

3.3.2. Objective 2: Assessment of community perceptions and attitudes on how urbanisation impacts local communities in the vicinity of the Klip River wetland

In this objective, the description and sampling method for a community survey is outlined, focusing on Protea Glen (PG) and Lenasia (LENZ) communities which are in the vicinity of the Klip River Wetland (KRW), to capture the socio-demographic

characteristics of people living in the vicinity of the KRW, the drivers of urbanisation within their locality, and how that has impacted their livelihood.

3.3.2.1. Description and data collection processes

A community survey is a method for gathering information and comments from members of a particular community or population to comprehend the demographics and viewpoints of the group under study (Nardi, 2018). In this study, a questionnaire (**Appendix 6**) was used to gather information related to community perceptions and attitudes about urbanisation impacts within their local communities. According to El Naggari and Abdelrazi (2024), this data collection tool provides valuable first-hand information from residents who live through, and experience changes related to urbanisation within their local communities, aligning closely with the present research objective by enabling direct engagement with residents, capturing both qualitative and quantitative data, and ensuring that the voices of the community are central to the research. By integrating the survey data into the broader research framework, there's a great contribution to understanding the impacts of urbanisation and guide more sustainable and inclusive urban planning processes in Johannesburg South.

The pilot study was conducted week before the main community survey to evaluate the effectiveness of the survey, identify potential issues in the data collection process, and assess the overall feasibility of the study. Specifically, the pilot aimed to gather preliminary data on how residents within the study areas perceive the effects of urbanisation on their communities. It also provided an opportunity to engage ward committees, ensuring the study was culturally and contextually relevant, and enhancing the reliability and validity of the data collection process. After the pilot study, the actual community survey included close-ended questions, which gathered data by asking the respondents' sociodemographic characteristics such as age, gender, educational background, economic status, and the drivers of urbanisation in their area, as well as how urbanisation impacts their living dynamics. With open-ended questions, respondents were given sufficient time to express and articulate how urbanisation has affected their social life, the environment and the economy within their community. The type of sampling used was a stratified sampling method which targeted respondents who are 28 years old or above and have lived in PG and LENZ for 10 years or above, for validity of results. This sampling was done from a total sample size of 192 respondents, which was derived from a total population of PG (75634) and a total

population of LENZ (89714), using a Raosoft sample calculator, available online (Raosoft.com). A 95% confidence interval and margin error of 10% were used in this calculator. The confidentiality and storage of the collected data were adhered to by keeping respondents' identities and personal information hidden from outside parties. To gather relevant data and verify the accuracy of the information gathered, conversations were recorded with the respondents' consent.

3.3.2.2. Statistical analysis

The rationale for conducting the statistical analysis in a community survey is that it provides rigorous approach to understanding the objective measurement of perceptions and attitudes, identifying trends and patterns, and also integrating the statistical analysis of the data within broader research frameworks ensures actionable findings, by giving urban planners and policymakers, reliable and validated data to make informed decision about development, infrastructure, social services, and other areas impacted by urbanisation. Statistical Package for Social Science (SPSS), version 29.0, was used to analyse the responses from the close-ended questions which included the sociodemographic characteristics of respondents and their opinions about the main drivers of urbanisation in the study area. These statistics were presented in the form of pie charts which depicted the proportion of responses by respondents. Moreover, cross-tabulation statistics were used to assess the relationship between the sociodemographic characteristics of respondents. For open-ended questions, Microsoft Excel was used to thematically analyse the long responses into main themes and the results were reported in a tree graph.

3.3.3. Objective 3: Evaluation of the factors related to urbanisation in these communities which interact with the degradation of the Klip River wetland.

Field observations (**Appendix 7**) were conducted to assess factors related to urbanisation in Protea Glen (PG) and Lenasia (LENZ), which interact with Klip River Wetland (KRW) water quality. Because wetland's water quality is influenced by urbanisation related factors, field observations help visualise specific indicators of water quality degradation, by capturing data that cannot always be captured through remote sensing or secondary data sources, and this can be tied back to the broader research framework, offering a ground-truthing element to the study. The observed

factors were scaled (1-5) and augmented with open-ended responses which highlighted the influence of urbanisation within the communities and the KRW. The scaling factors allows for the systematic measurement of urbanisation's impact on KRW, while the open-ended responses provide the local knowledge, personal perspectives, and community dynamics that enrich the understanding of urbanisation-induced impacts. The combination of these methods enhances the rigor of the study, adding depth to the analysis, and ensuring that the research is grounded in the live experiences of the communities in the vicinity of KRW. These assessment tools were integrated systematically by involving two steps:

Step 1: Scaling field observations factors

- a) 1=Minimal
- b) 2=Low
- c) 3=Moderate
- d) 4=Significant
- e) 5=Severe

Step 2: Establishing weights

The weighting was assigned by multiplying the scale from the field observations with the proportion of respondents' answers.

3.4. Summary

This chapter explained the convergent research design, a type of mixed method approach, which analyses quantitative and qualitative data separately and then converges the data collection tools at a later stage, to compare, contrast and synthesize the data, to provide a more comprehensive answer to the research questions. The study area has been described to give a clear insight into interconnections between Klip River Wetland (KRW), human communities in the vicinity of the wetland, anthropogenic activities and natural characteristics of the wetland. A detailed methodology for water quality assessment, community perceptions and attitudes on how urbanisation impacts communities along the KRW, and urbanisation-induced factors which interact with the wetland's water quality, has been outlined.

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Introduction

This section organises the results and discussion of the study according to the objectives and the corresponding research question. It details data obtained after undergoing analytical assessment of water samples collected along the KRW, during wet and dry seasons, from four monitoring sites. The data obtained from the community survey to determine their perceptions and attitudes of how urbanisation has impacted local communities and livelihood, i.e. Protea Glen (PG) and Lenasia (LENZ) located in the vicinity of the KRW is also presented. The questionnaire survey further assessed urbanisation-induced factors which interacted with KRW water quality. The questionnaire is subdivided into three main parts, where the first section highlighted the demographic and socioeconomic background of people living in PG and LENZ, the second and third sections were designed to address the studies' second and third objectives. The chapter also discussed the reported results and supported the findings with relevant literature. The implications of the results were also deliberated and possible contributors to KRW's water quality degradation were emphasised.

4.2. Objective 1: Evaluation of the physicochemical and biological characteristics of water quality of the Klip River Wetland

In this objective, the water quality results obtained from the analysis are compared with the South African Water Quality Guidelines (SAWQGs) Volume 1, published by the Department of Water Affairs and Forestry (DWA, 1996). Additionally, the results were compared with the In-stream Water Quality Guidelines (ISWQGs) for Klip River Catchment (KRC), to assess the compliance of the results with the national recommended guidelines. Multivariate statistics such as Pearson's correlation and Principal Component Analysis (PCA), are shown in this objective for the relationship between water quality parameters and possible sources of pollution in the Klip River Wetland (KRW). Furthermore, the Canadian Council of Ministers of the Environment-Water Quality Index (CCME-WQI) is shown for the water quality status of the KRW.

4.2.1. Physicochemical (pH, electrical conductivity, turbidity, dissolved oxygen, and chemical oxygen demand) characterisation of water samples

The physicochemical characterisation of water samples collected at four monitoring sites is shown below (**Table 4.1**). The results in Table 4.1 display the average data determined from the triplicate set of data in **Appendix 8**. According to the study's findings, the mean pH values recorded during the wet season ranged from 5.66 to 7.32, and during the dry season, pH values observed ranged from 7.37 to 7.68 S1. Electrical Conductivity (EC) mean values ranged from 30.66 $\mu\text{S/cm}$ to 70.63 $\mu\text{S/cm}$, for the wet season. During the season, EC range was as follows: 40.30 $\mu\text{S/cm}$ to 69.37 $\mu\text{S/cm}$. Turbidity during the wet season was between: 2.42 NTU to 69.03 NTU and during the dry season, turbidity was recorded as: 1.81 NTU to 48.87 NTU. Dissolved Oxygen (DO) values recorded are as follows: 1.50 mg/L to 7.76 mg/L for the wet season and dry season, DO values ranged from 0.90 mg/L to 6.90 mg/L. Chemical Oxygen Demand (COD) during wet season ranged from 28.33 mg/L to 622.67 mg/L and during dry periods, it ranged from 3.67 mg/L to 204.67 mg/L.

Table 4.1: Physicochemical characteristics of water samples collected in the Klip River Wetland during wet and dry seasons, from four monitoring sites

Season	Site	pH	EC	Turbidity	DO	COD
			($\mu\text{S/cm}$)	(NTU)	(mg/L)	(mg/L)
Wet	S1	7.32	40.20	2.63	7.10	50.33
Wet	S2	6.10	61.93	54.20	3.76	237.33
Wet	S3	6.99	30.66	2.42	7.76	28.33
Wet	S4	5.66	70.63	69.03	1.50	622.67
Dry	S1	7.67	41.90	1.81	6.90	7.33
Dry	S2	7.68	44.67	39.80	2.07	78.67
Dry	S3	7.64	40.30	2.26	7.47	3.67
Dry	S4	7.37	69.37	48.87	0.90	204.67
SAWQGs volume 1						
(DWAf, 1996)		6-9	<700	<1	–	–

ISWQGs for Klip River

Catchment	(RQIS,	–	–	–	>6	<15
2003)						

4.2.1.1 pH

The result of the study, as shown in (Figure 4.1), indicated that, except for site 4 during the wet season, all sites recorded mean pH values that fell within the optimal Target Water Quality Range (TWQR), i.e. 6.0-9.0, according to the South African Water Quality Guidelines (SAWQGs) volume 1 (DWAF, 1996). The acidic pH (5.66) recorded at S4 can be attributed to the effluent discharge into the Klip River Wetland (KRW) from the wastewater treatment plant (WWTP) and the Klipspruit tributary which flows from central Soweto into the KRW (Wepener *et al.*, 2015). Moreover, the acidic pH might be due to weathering of rocks, whereby minerals that contain sulphide, such as arsenopyrite and pyrite, are released and react with water through an oxidation process. Therefore, this oxidation causes a reduction in pH values (Ayiwouo *et al.*, (2022). This acidic pH also has negative impacts on domestic use of the KRW, such as subsistence fish farming, as acidic pH hinders fish reproduction and existence of fish species such as *Labeobarbus Kimberleyensis* and *Austroglanis Sclateri* (Dewangan *et al.*, 2023; Wepener *et al.*, 2015). According to the descriptive statistics in **Appendix 9**, the mean pH for the wet season is lower than dry season, signifying that rainfall during the wet season might have washed pollutants from the adjacent land surfaces into KRW, which reduce its pH (Wepener *et al.*, 2015). These findings revealed consistent trends with the findings by Shadrack *et al.*, (2015), who stated that the dry season recorded higher pH values than in the rainy season. In some cases, it was stated that increased rainfall dilutes urbanisation related pollutants in water, therefore supporting the findings by Shadrack *et al.*, (2015). The discrepancies trends of pH level in wetlands shows valuable insight into how natural and anthropogenic activities affects wetlands water quality.

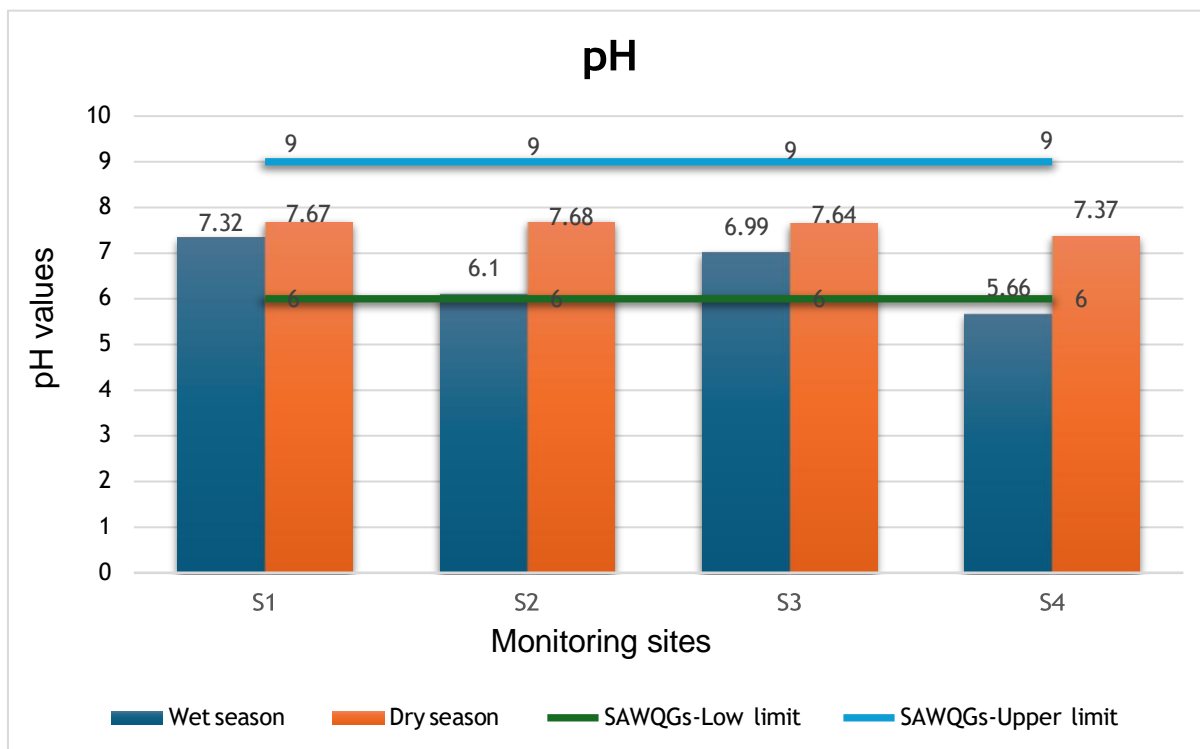


Figure 4.1: A bar graph depicting KRW's pH values for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's optimal pH range (6-9).

4.2.1.2 Electrical Conductivity (EC)

In this study, EC did not surpass the South African Water Quality Guidelines (SAWQGs) Volume 1 (700 $\mu\text{S}/\text{cm}$) for both wet and dry seasons, as shown in **Figure 4.2**. However, the wet season recorded a high mean of EC than the dry season according to **Appendix 9**. This can be explained by wet season surface runoff which carries anions such as fluorides (F^-) and chlorides (Cl^-), as well as cations such as sodium, sulphate (SO_4^{2-}), magnesium (Mg^{2+}), and calcium (Ca^{2+}), into the wetland from organic waste Chebet *et al.*, 2020). Conversely, Akhter and Brraich (2020) reported that wetlands with the lowest EC could be those that receive more rainfall, which raises the water level, thus diluting ions. Similar to pH findings, the integration of EC levels recorded in the present study with the existing literature emphasize seasonal variations, with both wet and dry seasons contributing to fluctuations in EC levels.

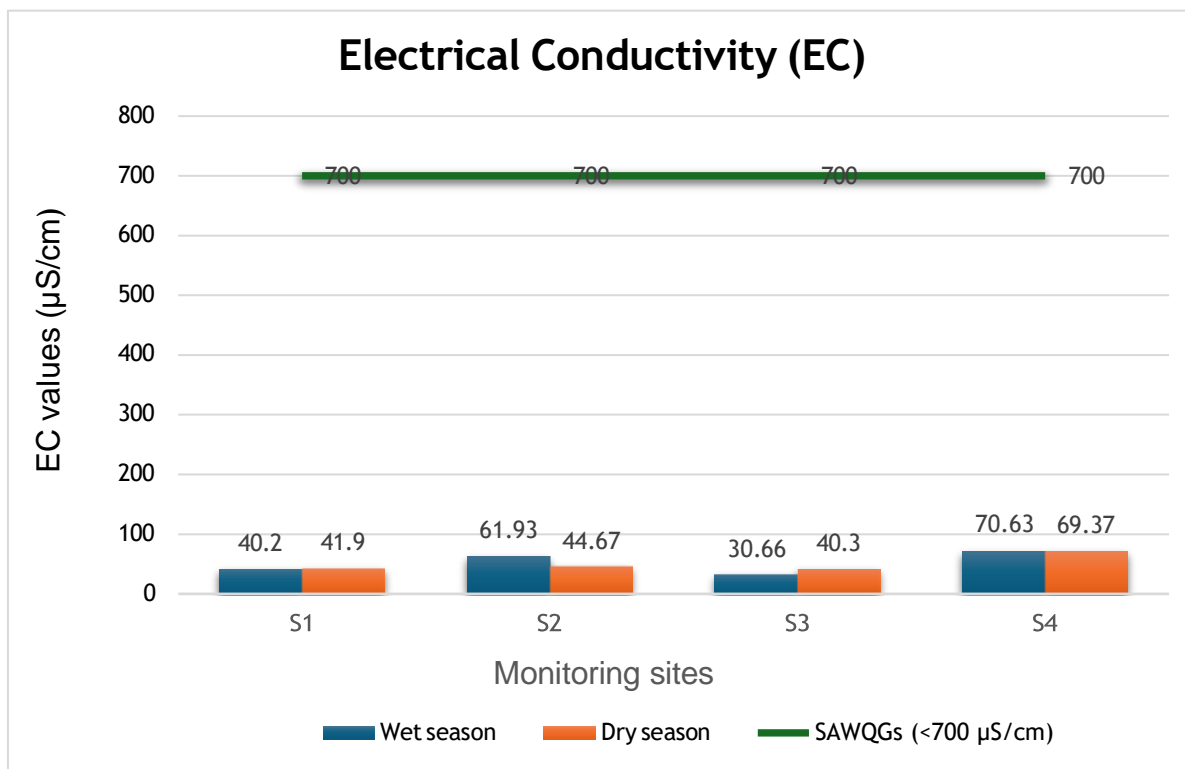


Figure 4.2: A bar graph depicting KRW's EC values for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit (<700 µS/cm).

4.2.1.3 Turbidity

Figure 4.3 illustrates the value of turbidity for sites and seasons. According to the findings, all sites in both wet and dry seasons, recorded turbidity values that surpassed the South African Water Quality Guidelines (SAWQGs) volume 1 (<1 NTU). These findings indicate that urbanisation-induced activities increased sediments in water, thus affecting light penetration into the water, and reducing water quality (Lin *et al.*, 2023). According to the descriptive statistics in **Appendix 9**, the wet season recorded a higher mean of turbidity than the dry season, meaning that surface runoff might have dissolved debris, and silt, and washed into the wetland, thus making the wetland's water less clear. Conversely, a study by Molekoa *et al.*, (2022) showed different results. This can be attributed to reduced vegetation cover during dry seasons, which have the potential to cause soil erosion, and an increase of sediment in water, thus raising turbidity (McMahon *et al.*, 2020). According to Lu *et al.*, (2023) and Tomper *et al.*, (2022), fish gills can become irritated by excessive water turbidity in aquatic

environments, therefore leading to fish kill and food insecurities, as the KRW is known for domestic use such as fishing (Wepener, *et al.*, 2015). The conflicting findings integrated deduce that in urban regions, seasons have drastic impacts on water quality.

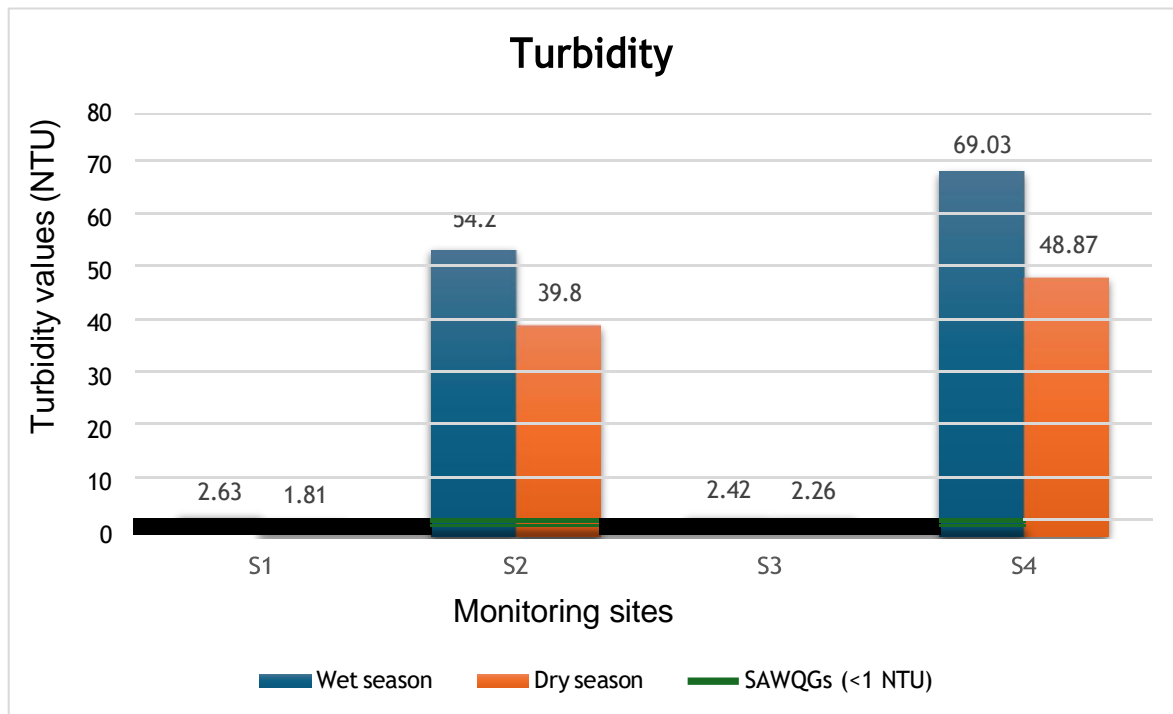


Figure 4.3: A bar graph depicting KRW’s turbidity values for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1’s standard limit (<1 NTU).

4.2.1.4 Dissolved Oxygen (DO)

In this present study, S2 and S4 in both wet and dry seasons recorded values that are less than the In-Stream Water Quality Guidelines (ISWQGs) for KRW (>5 mg/L), as shown in **Figure 4.4**. The spatial findings for S2 and S4 are attributed to the observed sewage flow, Klipspruit tributary and wastewater treatment effluent discharge into the Klip River Wetland (KRW), during sample location. High volume of wastewater caused by the expanding population are rich in nutrients which runoff into wetlands and lowers DO levels in aquatic ecosystem, thus harming aquatic life (Yang, 2023). Subsequently, this is due to the addition of organic waste, particularly household and animal sewage, industrial waste, and crop wastewater (Bozorg-Haddad, 2021). According to **Appendix 9**, wet season recorded high mean DO value than the season. Conversely,

Singh *et al.*, (2022) assessed DO levels in wetlands and it is shown that the highest DO value was recorded during dry season, whereas the lowest value was recorded during the wet season. However, these DO levels highlight possible threat to the aquatic life (Ipeaiyeda and Obaje, 2017). In alignment with the present study's objective, which is related to assessing the health of wetlands, the interpretation of available reviewed studies and the present study, note that urbanisation-induced pollutants such as nutrients harm the quality of wetlands water with the influence of spatial and temporal factors.

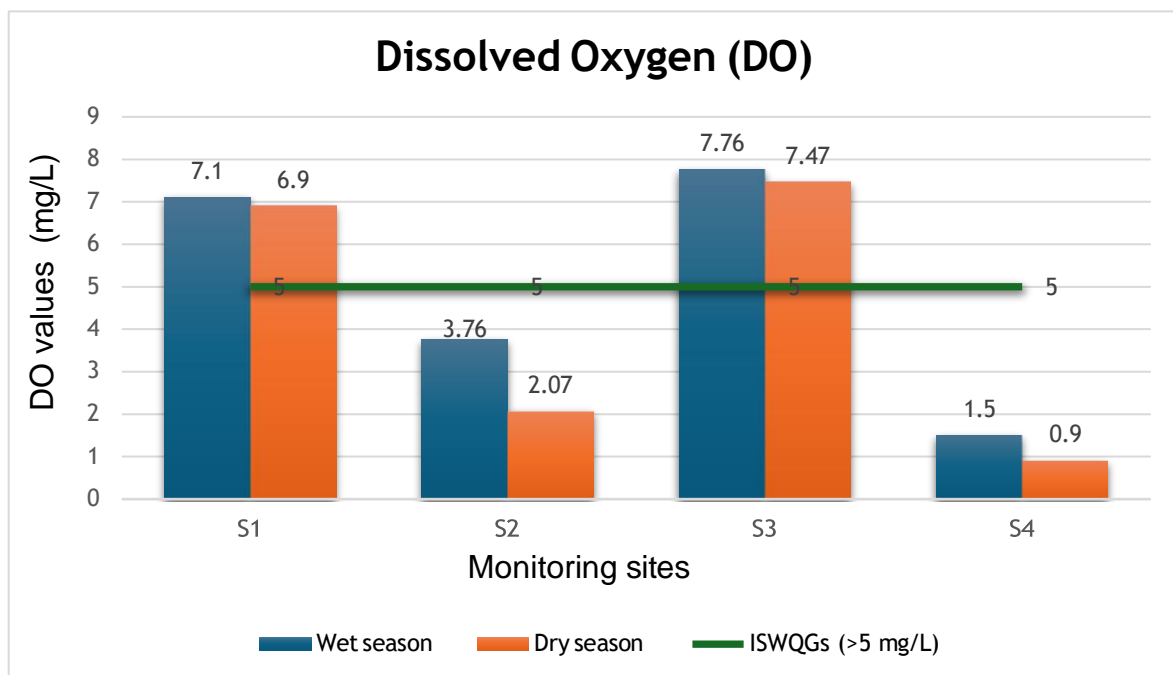


Figure 4.4: A bar graph depicting KRW's DO values for wet and dry seasons, from four monitoring sites, and a comparison with In-Stream Water Quality Guidelines (ISWQGs) for Klip River Catchment's (KRC) optimal DO levels (>5 mg/L).

4.2.1.5 Chemical Oxygen Demand (COD)

Figure 4.5 highlighted that all sites during the wet season exceeded the In-Stream Water Quality Guidelines (ISWQGs) for KRW (<15 mg/L). This implies that these sites are polluted by chemical organic matter which deteriorates the quality of water. Such pollutants might originate from urban settlements, mining, and industrial activities. According to Koloti *et al.*, (2024), sewage overflow into the wetland from the poorly maintained wastewater drainage system may be the cause of the increased COD levels. As for the dry season, only S2 and S4 exceeded the ISWQGs for KRW (<15

mg/L). These findings strengthen the argument presented regarding the possible pollutants which affected DO levels at S2 and S4. This is because the sewage flow and organic matter observed increase COD in water (Koloti *et al.*, 2024). **Appendix 9** depicted that the wet season recorded a high mean of COD in contrast with the dry season. Ojo *et al.*, (2022) observed similar results, where the overall mean COD value of rivers assessed during the wet season recorded higher values than dry season. This substantiates that surface runoff during the wet season has the potential to leach organic matter out of the soil and run it off to the KRW, thus increasing COD (Ojo *et al.*, 2022). These findings deduce that the KRW water required treatment before any use. It is noted that in the scope of urbanisation, anthropogenic activities impact wetlands directly by disposing organic matter in water, and by affecting the climate which results in seasonal fluctuations.

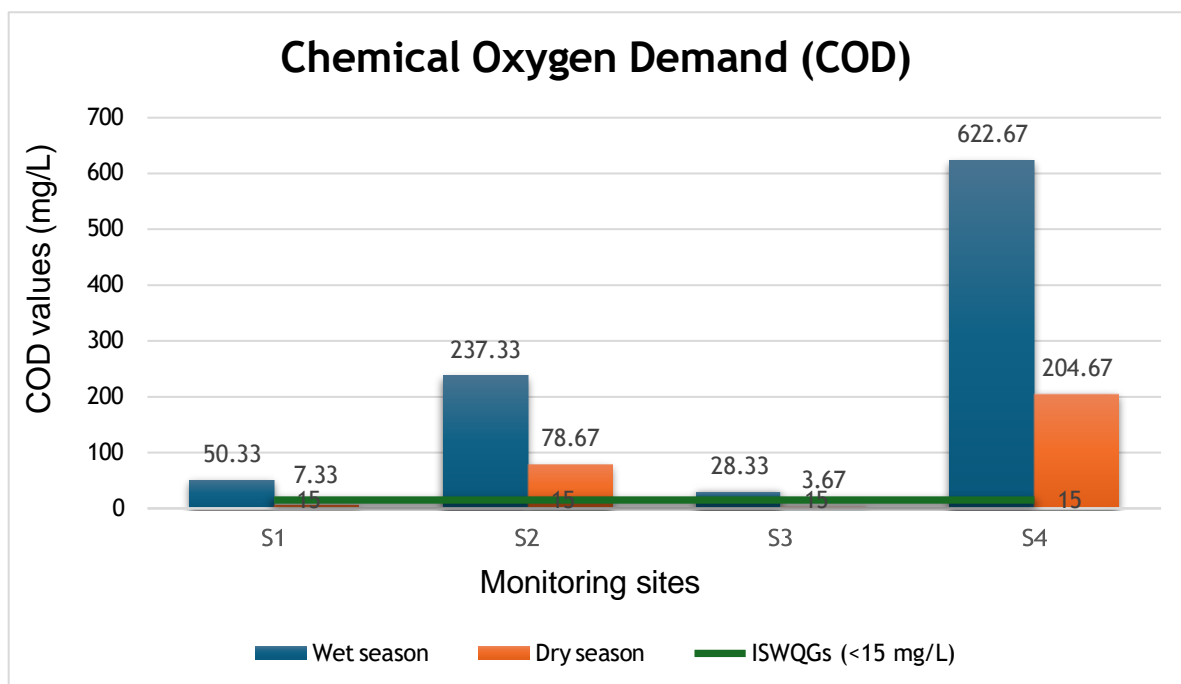


Figure 4.5: A bar graph depicting KRW's COD values for wet and dry seasons, from four monitoring sites, and a comparison with In-Stream Water Quality Guidelines (ISWQGs) for Klip River Catchment's (KRC) standard limit of <15 mg/L.

4.2.2. Chemical characterisation (anions and cations) of water samples

The chemical characterisation, such as anions and cations, of water samples collected at four monitoring sites are shown below (**Table 4.2**). According to the findings, Cl⁻ during the wet season ranged from 34.32 mg/L to 64.54 mg/L and as for dry season,

the range was from 29.11 mg/L to 68.18 mg/L. F^- values for the wet season ranged from 0.16 mg/L to 0.30 mg/L and as for dry season, F^- ranged from 0.25 mg/L to 0.26 mg/L. NO_3^- concentrations during wet season ranged from 0.13 mg/L to 6.60 mg/L, and as for dry season, NO_3^- concentrations ranged from 0.02 mg/L to 5.22 mg/L. SO_4^{2-} during wet season ranged 70.23 mg/L to 90.08 mg/L and for dry season, SO_4^{2-} concentrations ranged from 14.11 mg/L to 97.02 mg/L. As for cations, Mg^{2+} recorded values that ranged from 17.06 mg/L to 46.72 mg/L during wet season and as for dry season, Mg^{2+} values ranged from 21.57 mg/L to 41.63 mg/L. Ca^{2+} during wet season ranged from 33.87 mg/L to 66.19 mg/L and as for dry season, it ranged from 39.84 mg/L to 60.34 mg/L. Na^+ during wet season ranged from 14.65 mg/L to 55.71 mg/L, and as for dry season, it ranged 14.65 mg/L to 59.34 mg/L.

Table 4.2: Chemical characteristics (anions and cations) of water samples collected in the Klip River Wetland during wet and dry seasons, from four monitoring sites

Season	Site	Cl ⁻	F ⁻	NO ₃ ⁻	SO ₄ ²⁻	Mg ²⁺	Ca ²⁺	Na ⁺
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Wet	S1	36.88	0.21	2.46	90.08	20.49	43.92	33.13
Wet	S2	38.29	0.23	3.93	79.53	21.57	48.02	38.19
Wet	S3	34.32	0.16	6.60	84.33	46.72	66.19	14.65
Wet	S4	64.54	0.30	0.13	70.23	17.06	33.87	55.71
Dry	S1	39.96	0.26	3.07	97.02	24.70	46.54	38.30
Dry	S2	42.25	0.26	0.17	81.81	21.57	42.75	38.58
Dry	S3	29.11	0.25	5.22	77.82	41.63	60.34	14.65
Dry	S4	68.18	0.25	0.02	14.11	23.14	39.84	59.34
SAWQGs volume 1 (DWAF, 1996)		<100	<1	<6	<200	–	–	<100
ISWQGs for Klip River Catchment (RQIS, 2003)		–	–	–	–	<30	<32	–

4.2.2.1 Chloride (Cl⁻)

According to **Figure 4.6**: A bar graph depicting KRW's Cl⁻ values for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit (<100 mg/L). **4.6**, all monitored sites in both wet and dry seasons recorded Cl⁻ values within the South African Water Quality Guidelines (SAWQGs) volume 1 (<100 mg/L), meaning that there will be no immediate health danger to consumers (Chebet *et al.*, 2020). These findings show consistent trend with the findings by Chebet *et al.*, (2020), but they are contradicting findings by Shibambu and Gumbo (2020), which revealed Cl⁻ values surpassed the South African Water Quality Guidelines (SAWQGs) volume 1 (<100 mg/L). According to the descriptive statistics in **Appendix 10**, the wet season recorded the lowest mean of Cl⁻ whereas the dry season recorded the highest. The findings are like a study by Chai *et al.*, (2023), which recorded high Cl⁻ during the dry season in contrast with the wet season. Because Cl⁻ increase salt content in water, the increased Cl⁻ values in the dry season in contrast with the wet season can explain low rainfall which is insufficient for diluting the salinity of a wetland and a study by Valsala, (2022), reported that heavy rainfall can decrease the conductivity of a water body as it dilutes the salinity concentration.

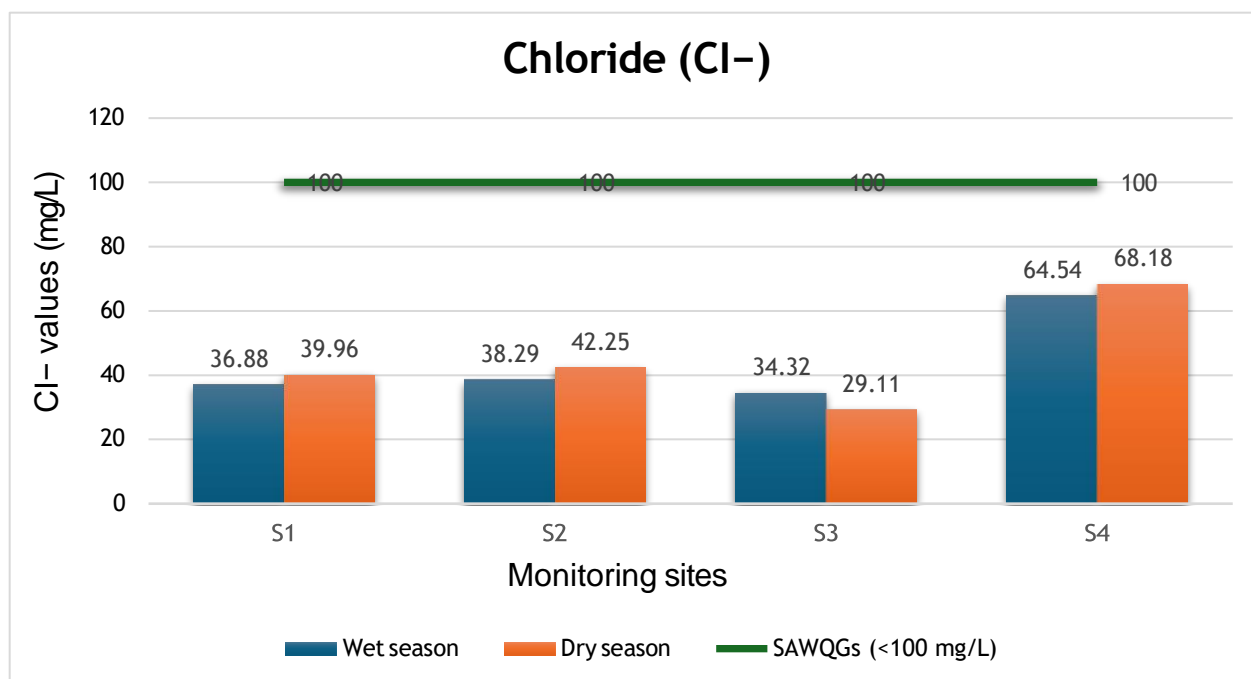


Figure 4.6: A bar graph depicting KRW's Cl⁻ values for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit (<100 mg/L).

4.2.2.2 Fluoride (F⁻)

According to the study's findings (**Figure 4.7**), all sites in both wet and dry seasons, recorded values within the South African Water Quality Guidelines (SAWQGs) volume 1 (<1 mg/L), showing less impact of F^- on the wetland's water quality. Similar results were observed in a study by Kothari *et al.*, (2020), which recorded values within recommended guidelines. Conversely, a study by Chebet *et al.*, (2020) recorded F^- values which surpassed the guidelines, and it was stated that drinking fluoridated water can cause dental fluorosis and, in the worst instance, skeletal issues. Fluctuations of F^- in water might be due to volcanic eruptions and weathering of rocks (Lacson *et al.*, 2021). The consistency and discrepancies highlighted by the interpretation of these findings deduce that F^- in water bodies varies due to geological processes and increased F^- pose significant threat to human health

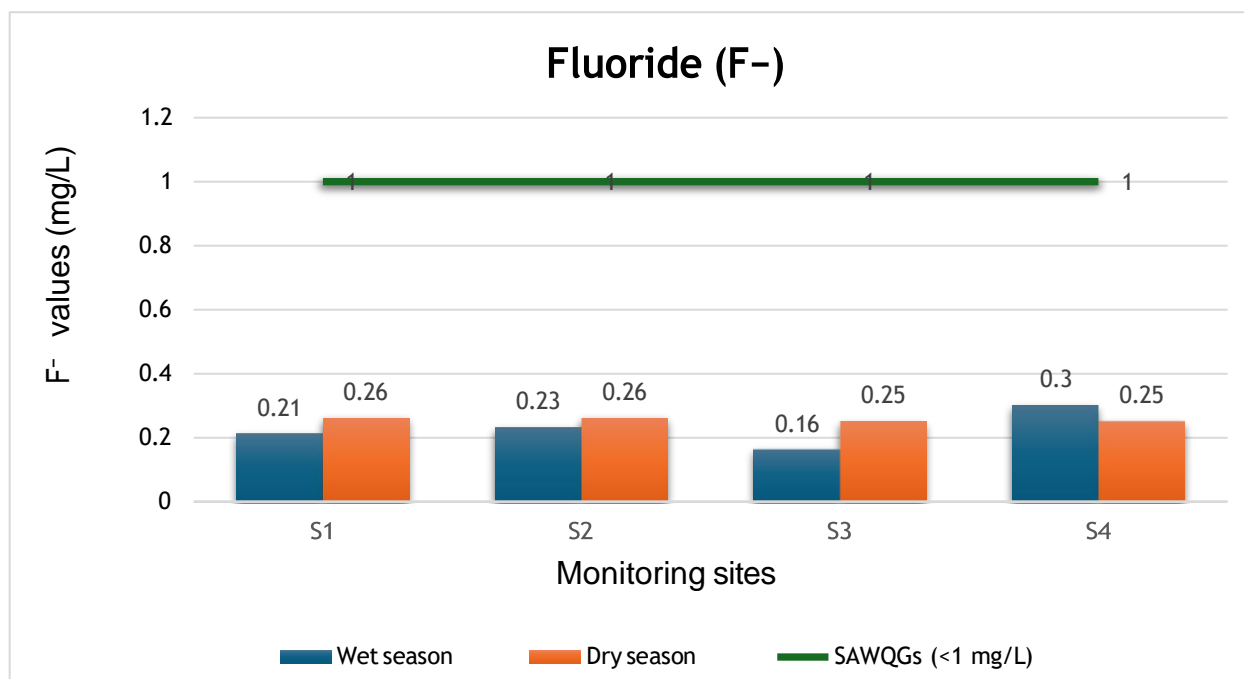


Figure 4.7: A bar graph depicting KRW's F^- values for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit (1 mg/L).

4.2.2.3 Nitrate (NO_3^-)

Figure 4.8 shows that all sites in both wet and dry seasons recorded NO_3^- which ranged within the SAWQGs volume 1 (<6 mg/L) except for S3. The highest recorded NO_3^- values at S3 might be attributed to laundry washing people observed informal settlements located in the vicinity of S3 (Yousaf *et al.*, 2021). This is because washing powders contain nutrients such as phosphates and nitrates (Quevedo and Paganini, 2018). Studies by Fathi *et al.*, (2021) and Koloti *et al.*, (2024) linked high NO_3^- level in the wetlands with agricultural effluents, whereby NO_3^- in the present study's case is not substantial to the study's findings.

In consideration of KRW water user groups, domestics use such as drinking before treatment is prohibited because high levels of NO_3^- can be harmful to human health by causing gastrointestinal tract issues (Picetti *et al.*, 2022).

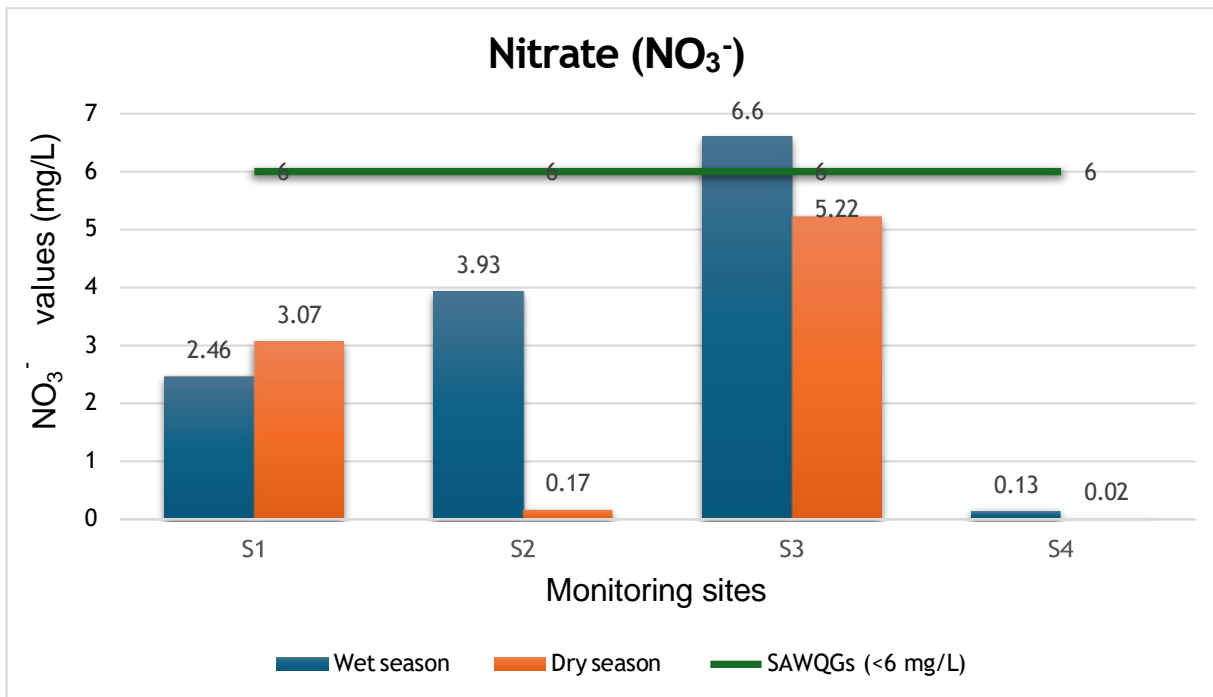


Figure 4.8: A bar graph depicting KRW's NO_3^- values for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit of <6 mg/L.

4.2.2.4 Sulphate (SO_4^{2-})

Figure 4.9 indicated that all sites in both wet and dry seasons recorded SO_4^{2-} values within the South African Water Quality Guidelines (SAWQGs) volume 1 (<100 mg/L), suggesting less pollution by sulphide minerals. Although SO_4^{2-} recorded values adhere to the guidelines, further discussion of what might have caused the highest mean of SO_4^{2-} in the wet season in contrast with the dry season, as shown by the descriptive statistics (**Appendix 10**) significantly help to conclude the potential impact of seasons on water quality. However, the increased rainfall during the wet season might have leached SO_4^{2-} from the soil and run it off to water (Zak *et al.*, 2021). The geology of Klip River Wetland (KRW) might be the cause of the increased SO_4^{2-} at S1, as studies reported that SO_4^{2-} can be released by geological processes such as the dissolution of minerals Anh *et al.*, 2023). Additionally, the ongoing mining activities on the north side of the KRW can be attributed to fluctuations of SO_4^{2-} although didn't surpass the limit.

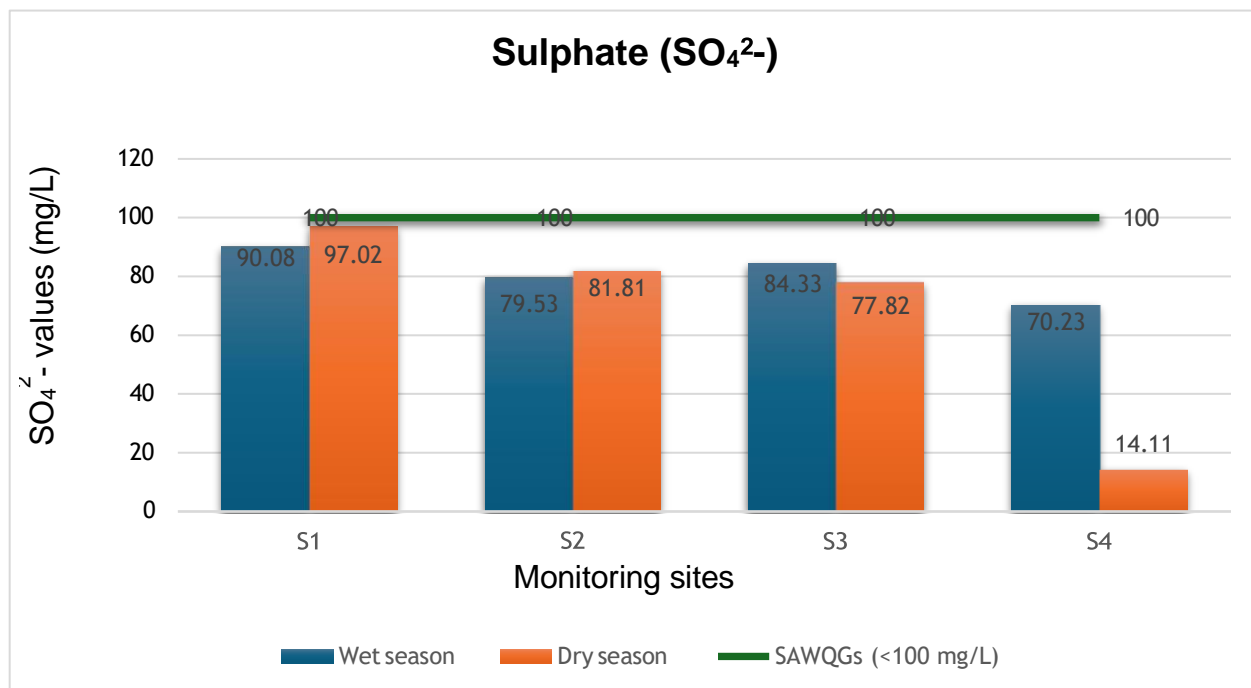


Figure 4.9: A bar graph depicting KRW's SO₄²⁻ variances between wet and dry seasons, from four monitoring sites and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit of <100 mg/L.

4.2.2.5 Magnesium (Mg²⁺)

According to the findings (**Figure 4.10**), S3 in both wet and dry seasons surpassed the In-Stream Water Quality Guidelines (ISWQGs) (<30 mg/L). Madene *et al.*, (2023) stated that excess Mg²⁺ in water is caused by the dissolution of dolomites, and according to Chetty (2021), the geology of the Witwatersrand basin, where the Klip River is located, is characterised by dolomitic rocks, substantiating excess Mg²⁺ recorded. In wetlands, excessive Mg²⁺ can lead to algal growth, which lowers the water's oxygen content (Gondwal *et al.*, 2023). Low oxygen levels in water put aquatic organisms such as fish at risk, because oxygen needed in water is crucial for oxygenating aquatic organisms; therefore, supporting ecological life. These findings highlight natural effect on the wetland's water quality over the human derived process such as urbanisation. However, it is reported that in some cases, human activities related to urbanisation have the potential to alter natural processes (Aravinda *et al.*, 2024).

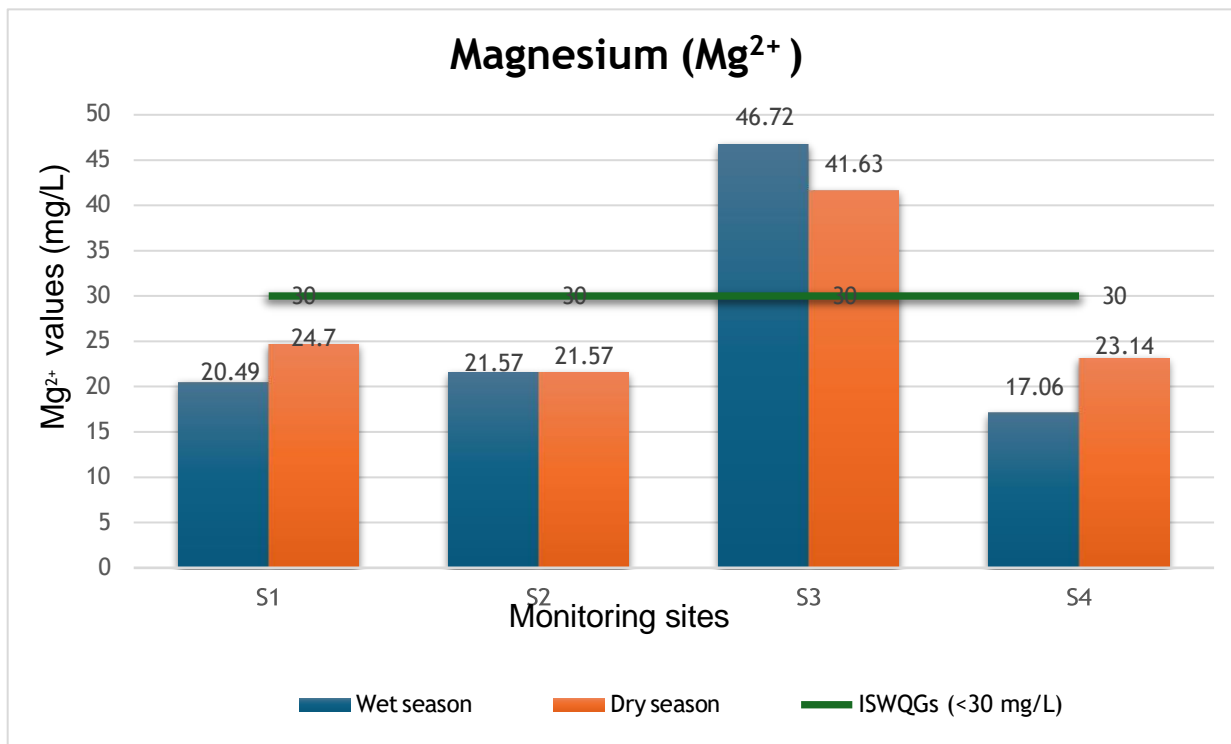


Figure 4.10: A bar graph depicting KRW's Mg²⁺ variances between wet and dry seasons, from four monitoring sites and comparison with In-Stream Water Quality Guidelines (ISWQGs) for Klip River Catchment's (KRC) standard limit of <30 mg/L.

4.2.2.6 Calcium (Ca²⁺)

In this study, the presence of Ca²⁺ in both wet and dry seasons, for all the study's monitoring sites, exceeded the In-Stream Water Quality Guidelines (ISWQGs) (<32 mg/L), as shown in

Figure 4.11: A bar graph depicting KRW's Ca²⁺ values between wet and dry seasons, from four monitoring sites, and a comparison with In-Stream Water Quality Guidelines (ISWQGs) for Klip River Catchment's (KRC) standard limit of <32 mg/L. Similar results were observed in a study by Rajora and Sarma (2024), and according to Kumar *et al.*, (2022), urbanisation and industrialisation are one of the factors which contribute to ions such as Ca²⁺ and others in water. The mean of Ca²⁺ for the wet season is higher than dry season (**Appendix 10**). This might imply that urbanisation which intensify industrial activities in the study area has caused climate change which resulted in heavy rainfall that had eroded soil containing ions into the Klip River Wetland (KRW). Kumar *et al.*, (2022), stated that ions in water put pressure on aquatic plants and fish.

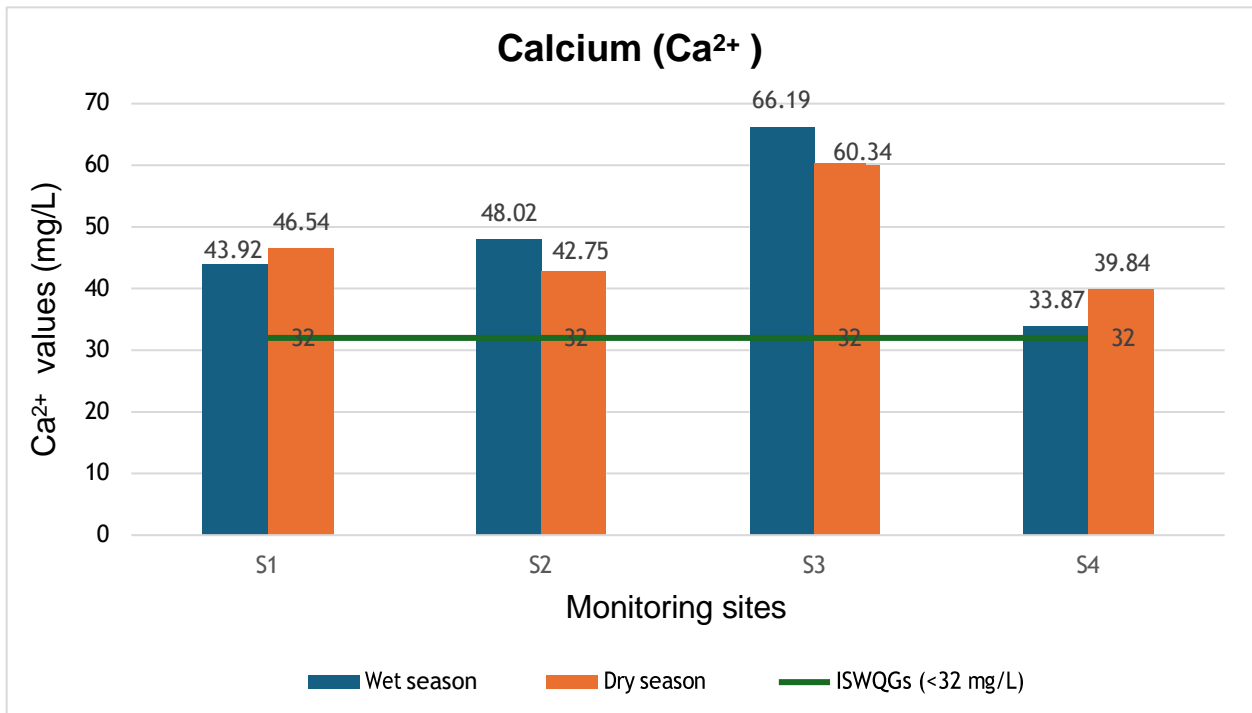


Figure 4.11: A bar graph depicting KRW's Ca^{2+} values between wet and dry seasons, from four monitoring sites, and a comparison with In-Stream Water Quality Guidelines (ISWQGs) for Klip River Catchment's (KRC) standard limit of $<32 \text{ mg/L}$.

4.2.2.7 Sodium (Na^+)

In this study, Na^+ values as shown in **Figure 4.12:** A bar graph depicting KRW's Na^+ values between wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit of $<100 \text{ mg/L}$. are within South African Water Quality Guidelines (SAWQGs) volume 1 ($<100 \text{ mg/L}$) for both seasons and all four monitoring sites. However, the mean values of Na^+ in the dry season are higher than wet season (**Appendix 10**). Conversely, Madene *et al.*, (2023) reported high Na^+ during the wet season and it was stated that precipitation leaches ions from rocks, and additionally, the decrease in Na^+ concentration is observed during the summer period due to the drought condition (Madene *et al.*, 2023).

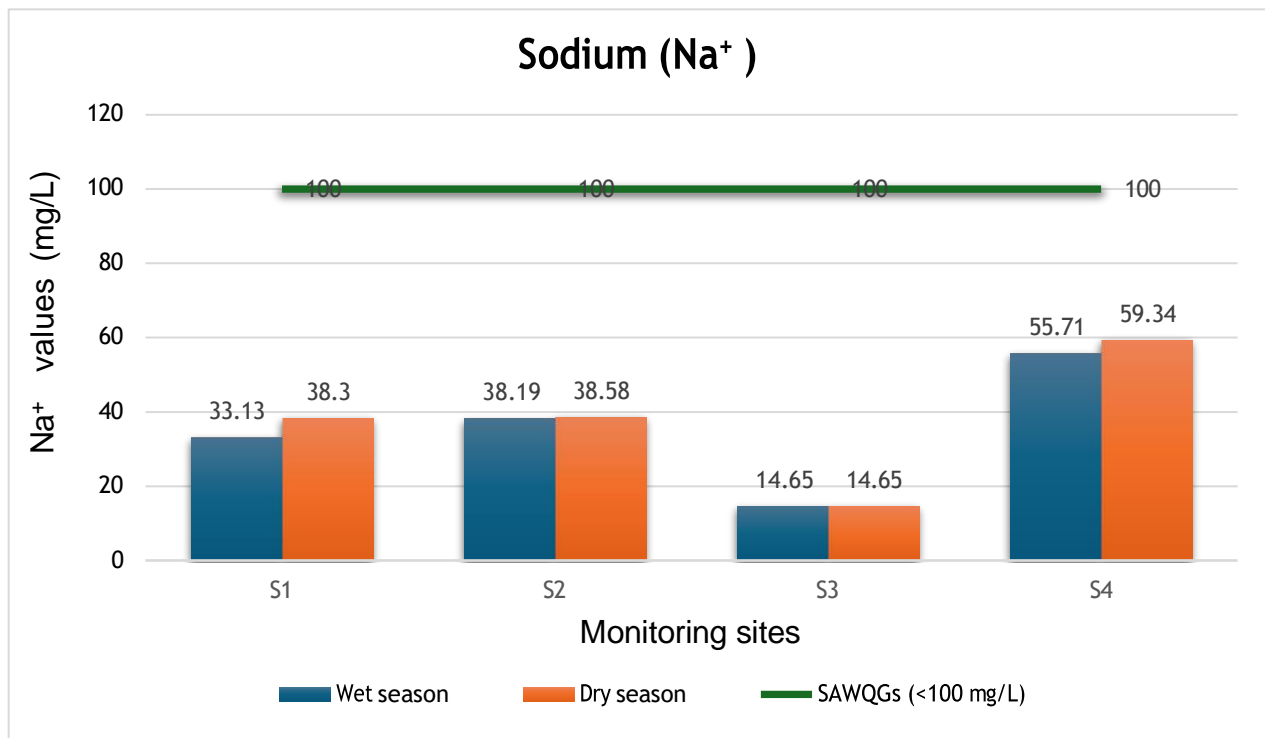


Figure 4.12: A bar graph depicting KRW’s Na⁺ values between wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1’s standard limit of <100 mg/L.

4.2.3. Chemical characterisation (heavy metals) of water samples

The chemical characterisation, such as heavy metals, of water samples collected at four monitoring sites are shown below (**Table 4.3**). According to heavy metals assessment results, Cr²⁺ ranged from 0.001 mg/L to 0.013 mg/L during the wet season and as for the dry season, Cr²⁺ ranged from 0.002 mg/L to 0.003 mg/L. Cu²⁺ concentrations recorded during wet season ranged from 0.001 mg/L to 0.006 mg/L and as for dry season, Cu²⁺ concentrations ranged from 0.000 mg/L to 0.003 mg/L. During the wet season, Fe²⁺ concentrations ranged from 0.000 mg/L to 0.004 mg/L and during the dry season, Fe²⁺ concentrations ranged from 0.000 mg/L to 0.104 mg/L. Mn²⁺ concentrations measured during the wet season ranged from 0.001 mg/L to 0.003 mg/L and during dry season, Mn²⁺ ranged from 0.038 mg/L to 0.227 mg/L.

Table 4.3: Chemical characteristics (heavy metals) of water samples collected in the KRW during wet and dry seasons, from four monitoring sites

Season	Site	Cr ²⁺	Cu ²⁺	Fe ²⁺	Mn ²⁺
		(mg/L)	(mg/L)	(mg/L)	(mg/L)
Wet	S1	0.013	0.003	0.004	0.001

Wet	S2	0.011	0.001	0.004	0.003
Wet	S3	0.004	0.006	0.000	0.002
Wet	S4	0.001	0.004	0.000	0.001
Dry	S1	0.003	0.003	0.007	0.123
Dry	S2	0.002	0.002	0.035	0.092
Dry	S3	0.002	0.000	0.000	0.038
Dry	S4	0.003	0.002	0.104	0.227
SAWQGs volume 1 (DWAF, 1996)					
		<0.05	<1	<0.1	<0.05

4.2.3.1 Chromium (Cr²⁺)

Cr²⁺ values were within the SAWQGs volume 1 (<0.05 mg/L), as highlighted in **Figure 4.13**. The recorded Cr²⁺ values according to DWAF (1996) are not toxic to human health and the environment. Although this, it is crucial to assess the potential attributes that could have led to the variations of Cr²⁺. According to Prasad *et al.*, (221), Cr is ubiquitous in the environment and can occur naturally or anthropogenically. Rock weathering, microbial contact with mafic and ultramafic rocks, and geogenic processes are the main, possible natural sources of Cr (Tumolo *et al.*, 2020). The production of chemicals, minerals, leather tanning, textile dyeing, and cement are among the industrial processes that might cause Cr anthropogenically (Prasad *et al.*, 2021).

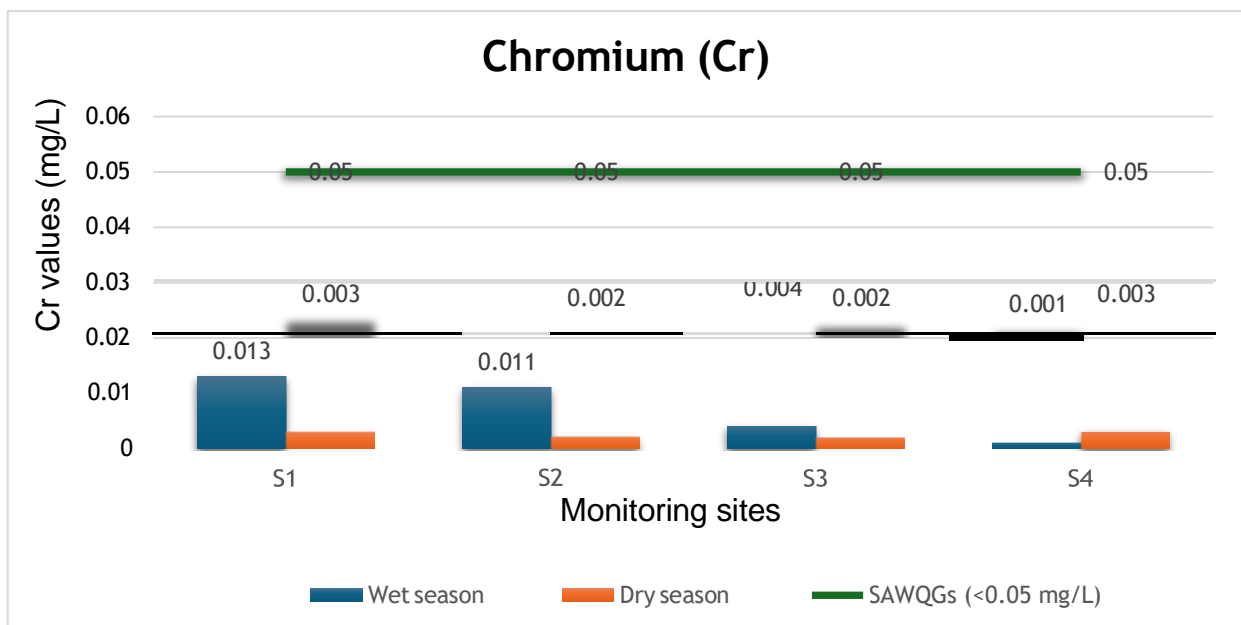


Figure 4.13: A bar graph depicting KRW's Cr values for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit of <0.05 mg/L.

4.2.3.2 Copper (Cu²⁺)

The results of the study in **Figure 4.14** revealed that Cu²⁺ recorded in the study's monitoring seasons and sites fell within the SAWQGs volume 1 (<1 mg/L), meaning that the water is not contaminated by Cu²⁺ and no negative effects can be experienced by humans and living organisms present on the environment. These findings are contradictory to findings by Humphries *et al.*, (2017), which stated that acid mine drainage (AMD) resulted in excess amounts of Cu²⁺, among other elements, in the Klip River Wetland (KRW). However, it is possible to assess the potential source of Cu²⁺ to mitigate the risk characterised by this toxic metal on the environment. Manne *et al.*, 2022 stated that the release of Cu²⁺ into water is due to soil weathering, the discharge of industrial waste into water, and sewage treatment plants' effluent discharge. Moreover, Lenka *et al.*, (2021) reported that Cu²⁺ can be discarded in water because of anthropogenic activities such as bathing, tire industries, coal burning, and electroplating.

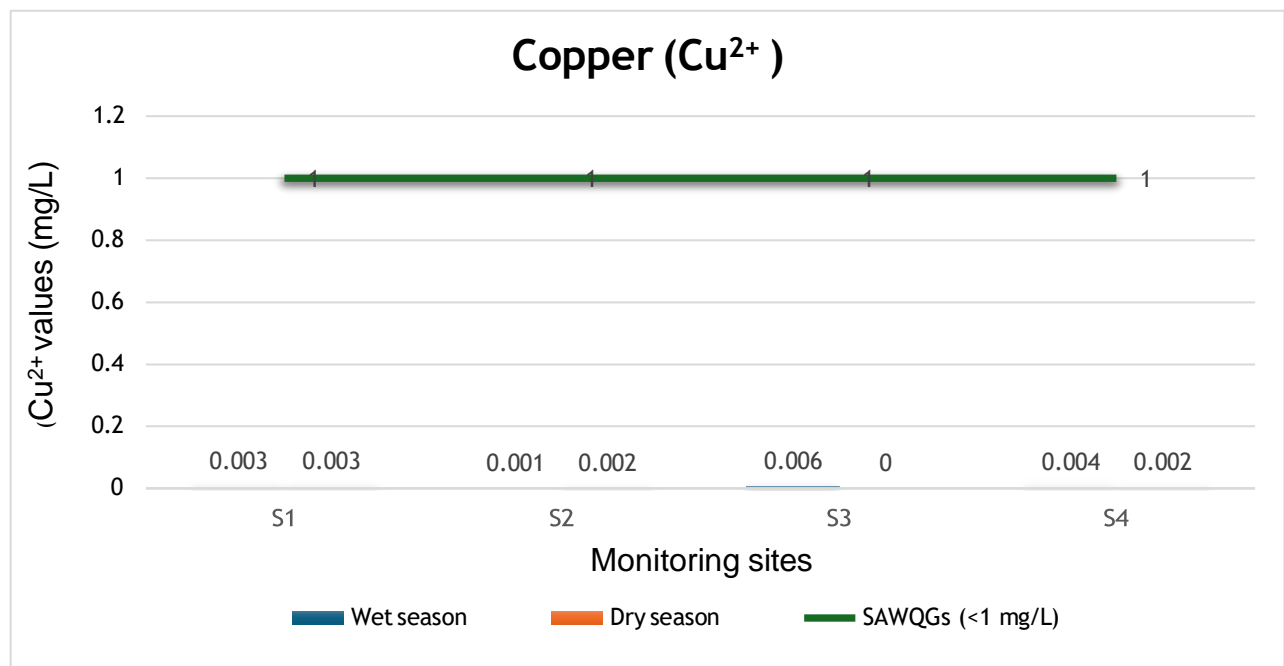


Figure 4.14: A bar graph depicting KRW's Cu²⁺ values for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit of <1 mg/L.

4.2.3.3 Iron (Fe²⁺)

In this study, **Figure 4.15** Figure 4.15: A bar graph depicting KRW's Fe^{2+} values for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit of <0.1 mg/L. highlighted that, except for S4 during the dry season, all sites in both wet and dry seasons recorded Fe^{2+} values within the South African Water Quality Guidelines (SAWQGs) volume 1's standard limit of <0.1 mg/L. These findings for S4, which surpassed the recommended guidelines, are consistent with a study by Gendle *et al.*, (2024). However, these findings might be due to the resuspension of Fe-rich sediments from riverbeds which increase Fe^{2+} in water (Longhini *et al.*, 2021). Moreover, Kamzati *et al.*, (2020) stated that direct runoff from the land could be the cause of the presence of increased Fe^{2+} in the water (Kamzati *et al.*, 2020).

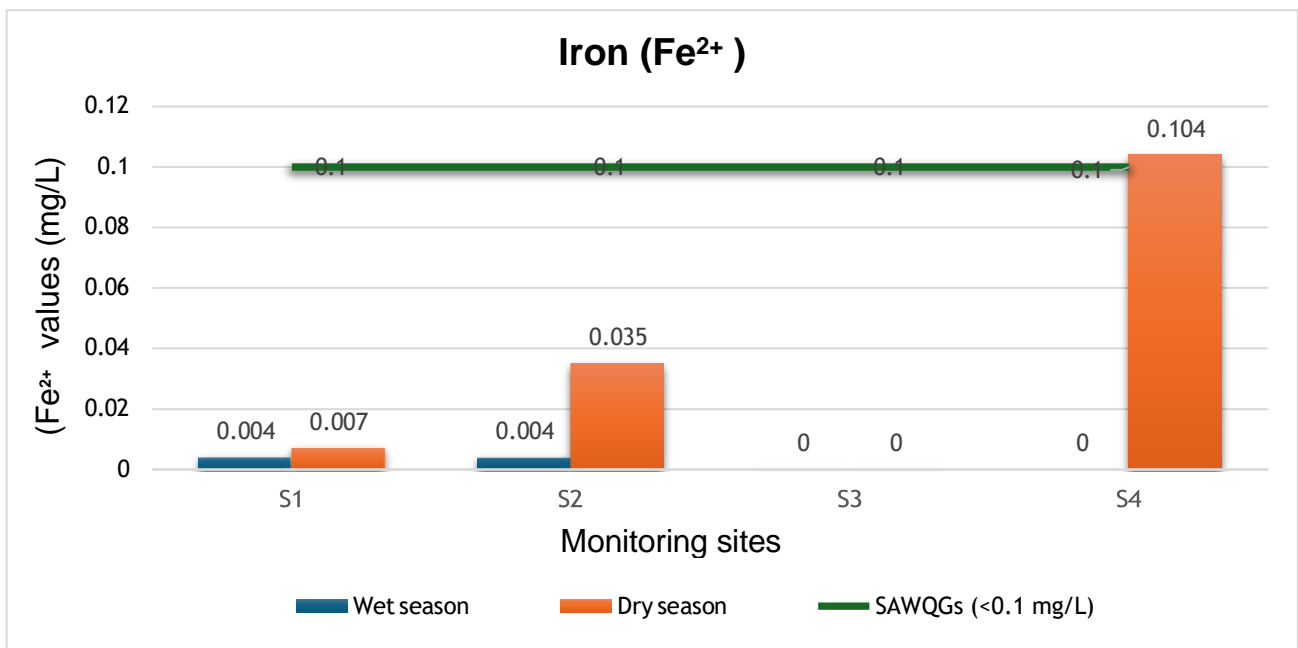


Figure 4.15: A bar graph depicting KRW's Fe^{2+} values for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit of <0.1 mg/L.

4.2.3.4 Manganese (Mn^{2+})

Figure 4.16 Figure 4.16: A bar graph depicting KRW's Mn^{2+} values for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit of <0.05 mg/L. revealed that all sites during the wet season recorded Mn^{2+} values within the South African Water Quality Guidelines (SAWQGs) volume 1 (<0.05 mg/L). This is usually due to high water volumes in wetlands which dilute pollutants. All sites in the dry season, except for S3, recorded values that exceeded the guidelines. The findings for S3 are like the findings by Edokpayi *et al.*, (2016), which indicated that Mn^{2+} exceeded the recommended guidelines. This is because mining activities release iron and sulphide minerals, which undergo an oxidation reaction when exposed to air and

water. This process results in Acid Mine Drainage (AMD), which releases acidic water containing toxic metals like Mn^{2+} (Plante *et al.*, 2021). According to DWAF (1996), excess Mn^{2+} in water used for domestic purposes is associated with staining of plumbing fixtures and laundry. Although essential for human nutrition, exposure to excess Mn^{2+} has been correlated with harmful health impacts such as neurological damage (Iyare, 2019).

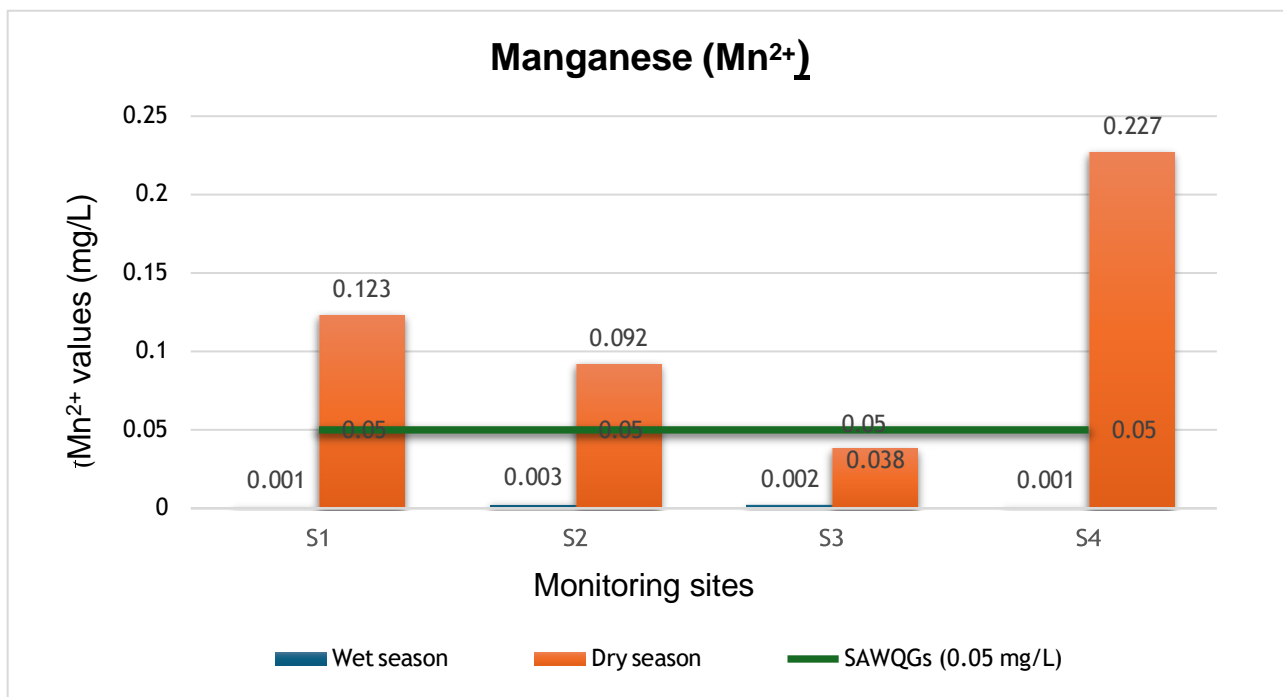


Figure 4.16: A bar graph depicting KRW’s Mn^{2+} values for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1’s standard limit of <0.05 mg/L.

4.2.4. Biological characterisation (*Escherichia coli* and total coliforms) of water samples

The biological characterisation of water samples collected at four monitoring sites is displayed below (**Table 4.4**). According to the study’s findings, *Escherichia coli* (*E. Coli*) values during the wet season are as follows: S1 (>201 CFU/100 mL), S2 (>201 CFU/100mL), S3 (11 CFU/100mL), S4 (>201 CFU/100mL), and during the dry season, *E. Coli* values are as follows: S1 (>201 CFU/100mL), S2 (>201 CFU/100 mL), S3 (>201 CFU/100mL), and S4 (>201 CFU/100mL). The results showed that total coliform counts in all the monitoring sites, for both wet and dry seasons, were greater than 201 CFU/100mL. However, >201 counts of these bacteria were denoted as 201 throughout the study for feasible statistics analysis.

Table 4.4: Biological characteristics (*E. coli* and total coliforms) of water samples collected in the KRW during wet and dry seasons, from four monitoring sites

Parameters

Season	Site	<i>E. coli</i> (CFU/100 mL)	Total coliforms (CFU/100 mL)
Wet	S1	>201	>201
Wet	S2	>201	>201
Wet	S3	11	>201
Wet	S4	>201	>201
Dry	S1	>201	>201
Dry	S2	>201	>201
Dry	S3	24	>201
Dry	S4	>201	>201
SAWQGs volume 1 (DWAF, 1996)			
		<1	<5

4.2.4.1 *Escherichia coli* (*E. coli*)

According to the study's findings in **Figure 4.17**, all sites in both wet and dry seasons recorded *E. coli* values that surpassed the South African Water Quality Guidelines (SAWQGs) volume 1 (<1 CFU/100 ml). The descriptive statistics in **Appendix 12** revealed that mean *E. coli* for the wet season is less than that of the dry season, and these results are in contrast with a report by Hong *et al.*, (2010), which stated that bacteria in surface water often prevails during wet season. *E. coli* counts increase more as the water passes through a nearby settlement area (Darko *et al.*, 2022). Various sources of fecal materials flowing into the KRW were observed during the dry season than in the wet season, as displayed in **Figure 4.18**. This can be attributed to lower levels of water during the dry season, whereby fecal matter is concentrated in a smaller volume of water, leading to high *E. coli* counts (Ronoh *et al.*, 2020). Elevated *E. coli* levels in wetlands water indicate that the water might be contaminated with dangerous organisms that could endanger human health if consumed or if there's contact between humans and the water. The usage of this water could cause acute or long-term health problems if it is not properly treated (Iwu *et al.*, 2023).

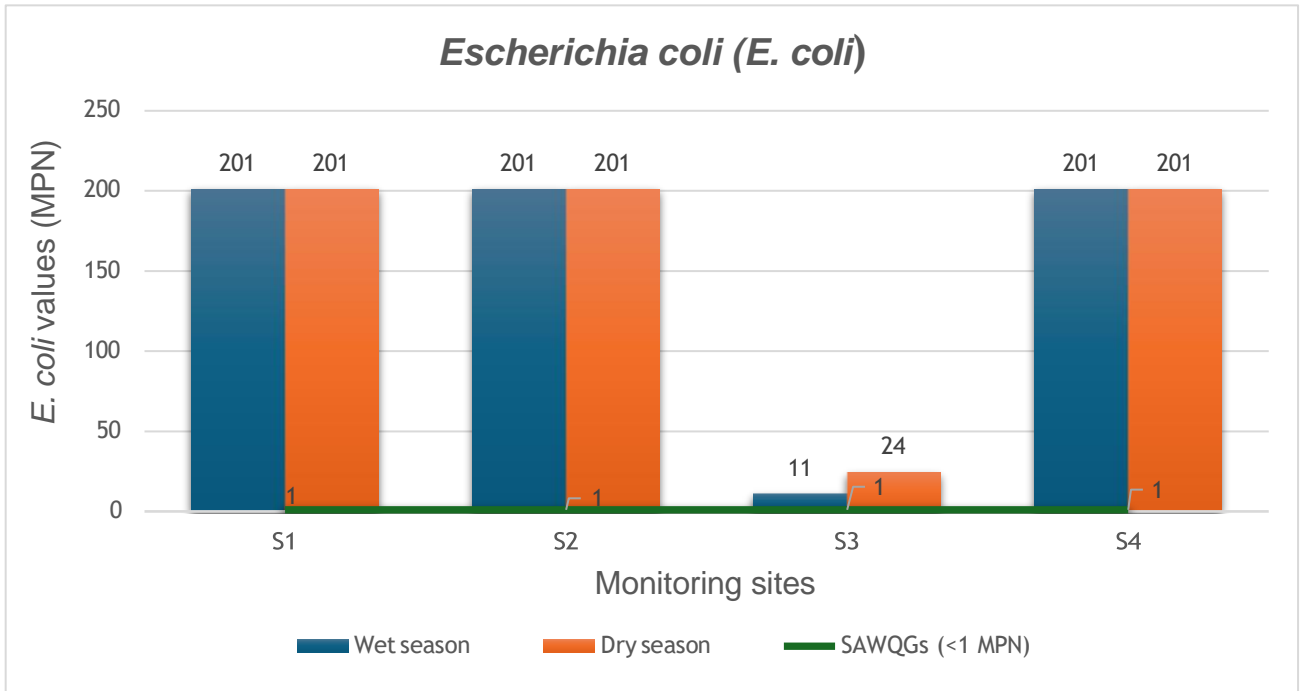


Figure 4.17: A bar graph depicting KRW's *E. coli* counts for wet and dry seasons, from four monitoring sites, and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit of <1 MPN.



Figure 4.18: Potential contributors of *E. coli* in the collected water samples along the Klip River Wetland (KRW).

Source: Mabale, 2024.

4.2.4.2 Total coliforms

In this study, total coliform counts in both seasons and all the study's sites were >201. When running statistics, the greater than sign (>) was omitted for the feasibility of chart creation, as shown in **Figure 4.19**. These counts of total coliforms exceeded the South African Water Quality Guidelines (SAWQGs) volume 1 (<5 CFU/100 ml). This suggests that the sites in both wet and dry seasons are intensively deteriorated by bacteria. Hong *et al.*, (2010) stated that bacteria in wetlands water are attributed to surrounding commercial activities, land use patterns, and stormwater runoff. This implies that the land use of areas in the vicinity of the KRW, i.e. PG, LENZ, and others might have contributed to the high counts of total coliforms. These results are substantial with a report by Wepener *et al.*, (2015), which highlighted bacteriological contamination in the upper catchment of KRW, due to the urban sprawl of LENZ. High counts of total coliforms can cause diseases such as typhoid, hepatitis, and diarrhea if the water is consumed by humans (Bhatt *et al.*, 2024; Kairunnisa *et al.*, 2021).

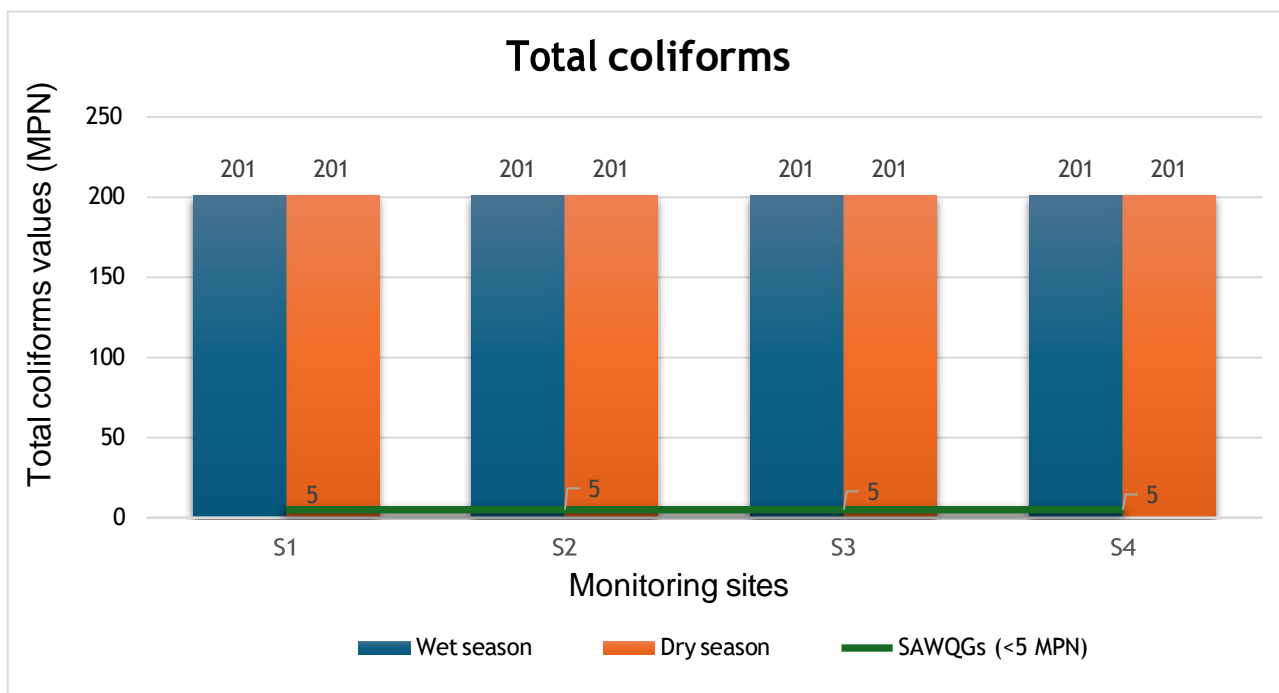


Figure 4.19: A bar graph depicting KRW's total coliform counts for wet and dry seasons, from four monitoring sites and a comparison with South African Water Quality Guidelines (SAWQGs) volume 1's standard limit of <5 MPN.

4.2.5. Pearson's correlation

The results of the relationship between the physicochemical and biological characteristics are shown in this section, in relation to the study objective. In This study's context, the correlation coefficient (r) value between -1 and 1 is reported in two decimal places. The strength of the relationship, i.e. $\pm .00$ (r), means no correlation, $\pm .10$ to $\pm .30$ signifies very weak correlation,

$\pm .30$ to $\pm .50$ means weak correlation, $\pm .50$ to $\pm .70$ means moderate relation, $.70$ to $\pm .90$ means strong relation and $.90$ to ± 1.00 means very strong relation. The significance of the correlation was determined by $p < 0.05$ and $p < 0.01$, level of significance.

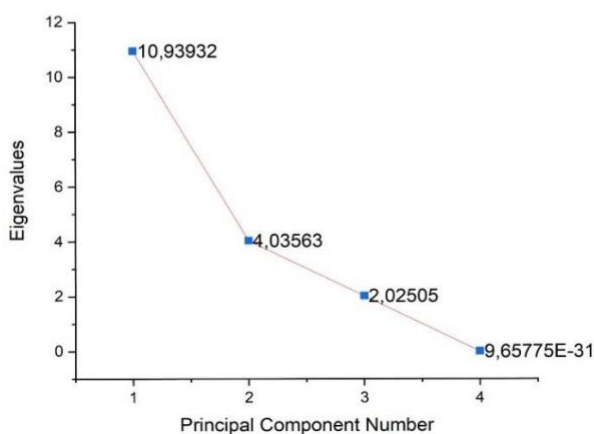
Appendix 13 revealed the correlation between the physicochemical and biological characteristics of water samples collected in the Klip River Wetland (KRW) during the wet season. The bold strength of correlation (r) in **Appendix 13** represents the strongest correlation between the water quality parameters. However, only three cases of correlation are discussed in this section. According to the findings, pH showed a very strong, positive, significant correlation with DO ($r = .96^*$; $p < 0.05$). This strong positive correlation between pH and dissolved oxygen (DO) during wet season, was also observed in a study by Ngabirano *et al.*, (2016). Anaerobic conditions during the wet season may result in the generation of acidic compounds that lower DO levels, thus reducing pH levels (Ngabirano *et al.*, 2016). Electrical conductivity (EC) showed a very strong, negative, significant correlation with DO ($r = -.99^*$; $p < 0.05$), suggesting that as the EC rises, DO falls. Salinity, or the amount of salt in water, which is measured by EC, has implications for wetlands aquatic ecosystems. According to Thorslund and van Vliet (2020), aquatic ecosystems can be adversely affected by high salt levels, which rise with EC, as they lower DO levels. Moreover, turbidity showed a very strong, negative, significant correlation with DO ($r = -.99^*$; $p < 0.05$). This relationship might be attributed to the surface runoff which washes waste and wildfire ashes on the outskirts of KRW, thus increasing the turbidity of water (Tahiru *et al.*, 2023). High turbidity water scatter light in wetlands water and reduces the quantity that will penetrate deeply into the water (Boyd and Boyd, 2020). DO levels may drop if light penetration is reduced, which is necessary for aquatic ecosystems to perform photosynthesis (Dey *et al.*, 2021).

Appendix 14 depicts the correlation between the physicochemical and biological characteristics of water samples collected during the dry season. According to the findings, the EC showed a very strong, positive, significant correlation with COD ($r = .97^*$; $p < 0.05$). These findings are like the ones reported in a study by Rahman *et al.*, (2021). The increased organic pollutants brought on by mining and industrial operations increase ion contents in wetlands, thus increasing EC. Because the amount of oxygen needed to oxidize these organic pollutants is determined by the COD content in the water, COD rises as organic pollutants increase (Duncan *et al.*, 2023). These findings deduce that an increase in EC, which is dependent on ion contents, is an increase in COD, and a positive correlation between ions such as Cl^- with COD ($r = .96^*$; $p < 0.05$) was observed in the study.

4.2.6. Principal Component Analysis (PCA)

The PCA was carried out to extract essential principal components (PCs), and to measure the component loadings of the physicochemical and biological characteristics of Klip River Wetland (KRW) and to help track sources of pollution in the wetland. The PCA reduced the large water quality data set of 18 parameters to three PCs with Eigen values greater than one, for wet and dry seasons (**Figure 4.20**). **Table 4.5** depicts the extracted PCs and the loadings of each component in each season. For the wet season, the presence of three PCs is explained with a total variance of 100%, whereby 64.35%, 23.74%, and 11.91%, are the percentage of the variance by each PC. Although three PCA were extracted in this study, PC1 and PC2 are only included in the interpretations because they are the main PCs with high Eigenvalues and contributed the highest percentage of variance. The results on PCA revealed that PC1 contributed 64.35% of the variance and it had moderate positive loading for electrical conductivity (EC), turbidity, chemical oxygen demand (COD), chloride (Cl^-), fluoride (F^-), sodium (Na^+) and *Escherichia coli* (*E. coli*). PC2 contributed 23.74% of the variance and it had moderate positive loading for chromium (Cr), iron (Fe^{2+}), and *E. coli*. For the dry season, three PCs are extracted, and they explain 100% of the total variance, whereby 68.23%, 22.52%, and 9.26% are the percentages of the variance by each PC. The main PCs (PC1 and PC2) are highlighted and PC1 accounted for 68.23% of the variance. This PC had moderate positive loading for EC, turbidity, COD, Cl^- , Na^+ , Fe^{2+} , Manganese (Mn^{2+}), and *E. coli*. PC2 accounted for 22.52% of the variance and it had moderate positive loading for F^- , sulphate (SO_4^{2-}), copper (Cu^{2+}), and *E. coli*.

A



B

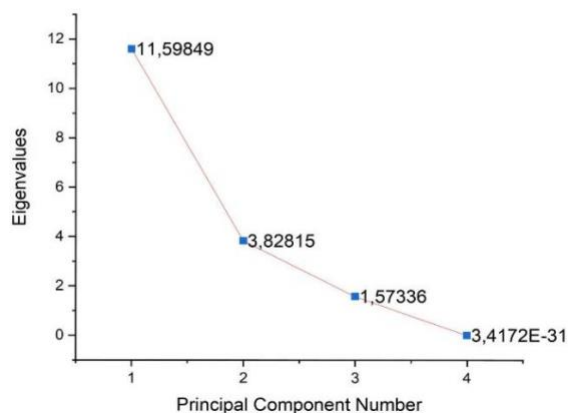


Figure 4.20: Scree plots showing the number of principal components (PCs) extracted with eigenvalues greater than one for wet (A) and dry (B) seasons.

Table 4.5: The loadings of the three extracted principal components (PCs) for wet and dry seasons, with bolded significant loadings for two main PCs (PC1 and PC2).

Water quality parameters	Wet season			Dry season		
	PC1	PC2	PC3	PC1	PC2	PC3
pH	-0,26	0,13	-0,30	-0,23	0,29	-0,18
EC	0,29	0,04	0,18	0,27	-0,20	0,08
Turbidity	0,28	-0,04	0,27	0,25	-0,05	-0,39
DO	-0,29	0,05	-0,16	-0,26	0,01	0,37
COD	0,29	-0,15	0,02	0,28	-0,16	-0,10
Cl ⁻	0,27	-0,19	-0,15	0,29	-0,08	0,09
F ⁻	0,30	-	-0,08	-0,03	0,50	-0,11
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NO ₃ ⁻	-0,27	-0,08	0,31	-0,26	-0,14	0,30
SO ₄ ²⁻	-0,25	0,23	-0,20	-0,23	0,31	-0,02
Mg	-0,24	-0,28	0,14	-0,22	-0,33	0,08
Ca ²⁺	-0,27	-0,14	0,24	-0,26	-0,22	0,07
Na ⁺	0,30	0,06	-0,08	0,29	0,08	0,10
Cr	-0,10	0,47	0,00	0,17	0,08	0,63
Cu	-0,12	-0,42	-0,25	0,15	0,40	0,25
Fe	-0,03	0,50	0,06	0,28	-0,15	-0,05
Mn ²⁺	-0,07	0,10	0,67	0,28	-0,03	0,25
<i>E. coli</i>	0,22	0,33	-0,10	0,22	0,34	0,03
Total coliforms	0	0	0	0	0	0
Eigenvalues	10,93932	4,03563	2,02505	11,59849	3,82815	1,57336
% of variance by PC	64.35%	23.74%	11.91%	68.23%	22.52%	9.26%
Cumulative %of variance	64.35%	88.09%	100.00%	68.23%	90.74%	100%

The possible attributes which caused the physicochemical and biological parameters such as pH, turbidity, dissolved oxygen (DO), chemical oxygen demand (COD), nitrate (NO_3^-), magnesium (Mg^{2+}), calcium (Ca^{2+}), manganese (Mn^{2+}), *Escherichia coli* (*E. coli*) and total coliforms, to not comply with the South African Water Quality Guidelines (SAWQGs) volume 1 and the Klip River Catchment's (KRCs) In-stream Water Quality Guidelines (ISWQGs) at specific sites and seasons are explained by **Figure 4.21** and **Figure 4.22**.

4.2.6.1. Wet season

The significant positive loadings of EC, turbidity, COD, chloride (Cl^-), fluoride (F^-), Sodium (Na^+), and *E. coli*, on PC1 (**Figure 4.21**), although some of these parameters complied with the guidelines, signify that these physicochemical and biological water quality parameters are correlated, and there are high possibilities that their fluctuations in concentration levels are influenced by a common pollutant. According to the positive axis on PC1, the association of anions such as Cl^- , F^- , Na^+ and EC reflects salinity (Asare *et al.*, 2021). Although these ions were within the guidelines, the fluctuations of EC, which is an indicator of ions in water did not comply with the guidelines, and a negative correlation between EC and DO was observed. Thorslund and van Vliet (2020) also revealed similar results in their study. Turbidity, COD, as well as *E. coli*, which are linked to animal or human waste, all indicate total dissolved solids in the water. The correlation of water quality parameters (EC, turbidity, COD, chloride (Cl^-), fluoride (F^-), Sodium (Na^+), and *E. coli*) on PC1 typically explains common sources such as weathering of rocks, human activities, and urban wastewater. Total coliform counts which were denoted as 201 counts, were constant across the sites and that is why total coliforms are at the center of the Biplot, meaning that it was evenly present at all sites. However, the possible sources of pollution according to PC1 signify degradation on S4 (Hammoumi *et al.*, 2024). Water quality parameters such as Cr^{2+} , Fe^{2+} , and *E. coli* with positive loadings on PC2 reveal the presence of heavy metals and fecal matter. The presence of Cr^{2+} and Fe^{2+} suggests potential anthropogenic sources such as mining and industrial discharge, whereas *E. coli* suggests wastewater (Zarić *et al.*, 2023). These sources of pollution had an impact on S2 and S1. S3 is less polluted as compared to all sites because the parameters which are associated with S3 had low loading, and it is displayed in **Figure 4.21** that S3 is on the negative side of both PC1 and PC2, which substantiates the low impact of pollutants on S3, in comparison with S4, S2, and S1. These findings deduce water pollution that follows this trend: $\text{S4} > \text{S2} > \text{S1} > \text{S3}$, which is influenced by pollutants originating from geological processes, human activities, urban wastewater, mining, and industrial activities.

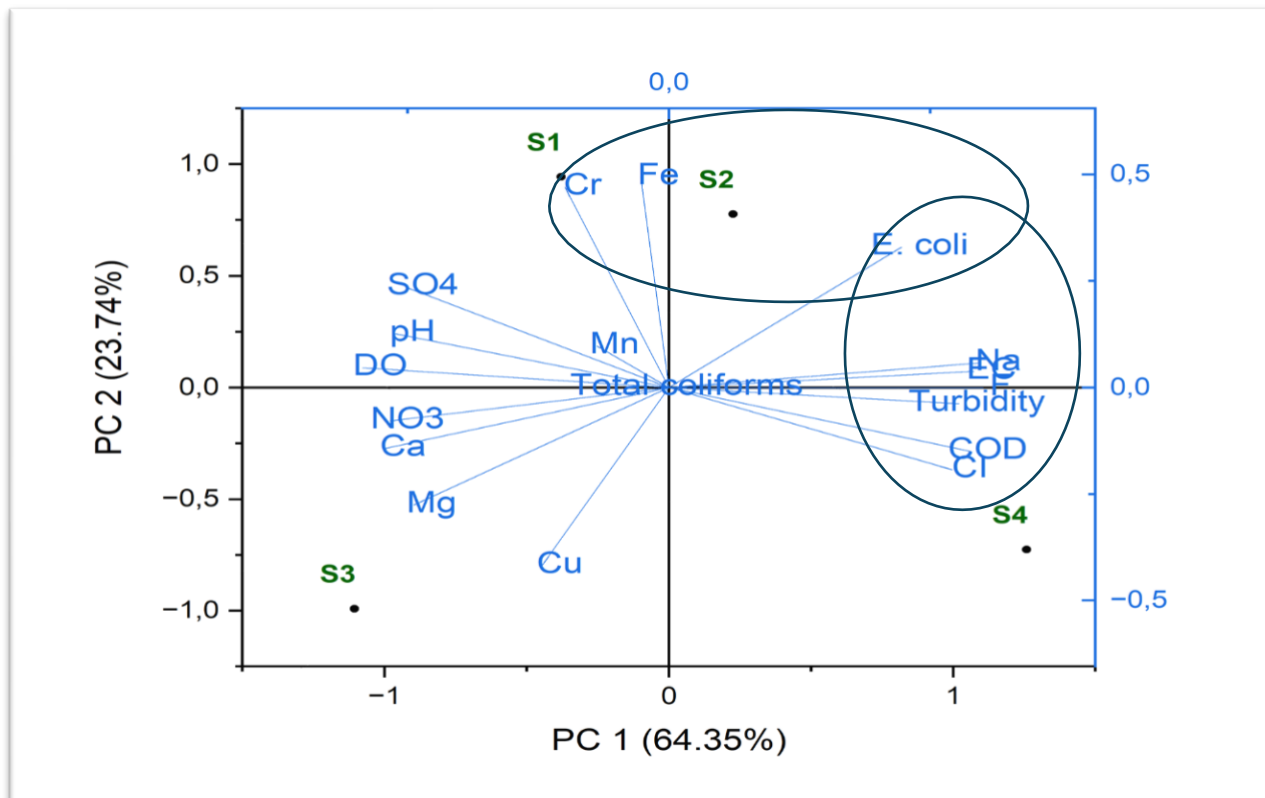


Figure 4.21: Biplot showing the PC loadings and scores of the physicochemical and biological characteristics of water samples collected during the wet season.

4.2.6.2. Dry season

As for the dry season, PC1 in **Figure 4.22** accounted mostly for water quality parameters such as EC, turbidity, COD, Cl^- , Na^+ , Fe^{2+} , Mn^{2+} , and *E. coli*. These water quality parameters have positive significant loadings, and they reflect pollution due to salinity, heavy metal, and fecal pollution. The pollution is due to the weathering of rocks, anthropogenic activities such as mining and industrial activities, as well as wastewater (Plante *et al.*, 2021; Valsala, 2022). Data points such as S4 experience pollution arising from these sources. The significant positive loadings of F^- , SO_4^{2-} , Cu^{2+} , and *E. coli* on PC2 imply that there is a correlation amongst these water quality parameters, and this explains the potential common origin. The possible source of F is geological processes such as weathering of rocks and mineral dissolution. As per Zak *et al.*, (2021), SO_4^{2-} is associated with AMD which releases toxic elements such as Cu^{2+} and this deduces that SO_4^{2-} and Cu^{2+} on PC2 are a result of mining activities. Moreover, this link is explained by the positive correlation between SO_4^{2-} and Cu^{2+} from Pearson's correlation analysis. These sources of pollution are accountable for water quality degradation at S2 and S1. Because the water quality parameters related to S3 had low loading and S3 is on the negative side of both PC1 and PC2, as shown in **Figure 4.22**,

S3 is less polluted than all other sites. This suggests that pollutants have less influence on S3 than on S4, S2, and S1. These results suggest that the trend of water pollution, which is caused by pollutants from mining, industrial operations, urban wastewater, geological processes, and human activity, is S4>S2>S1>S3.

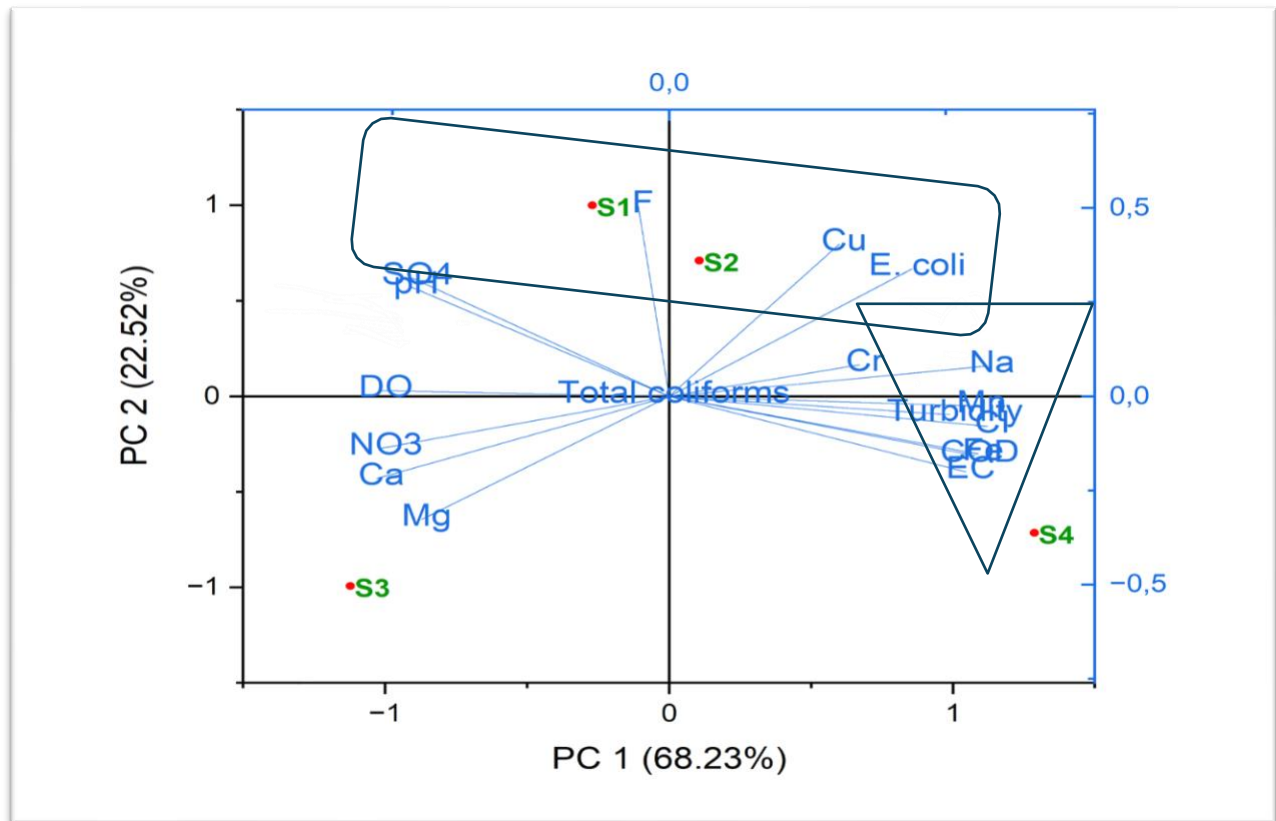


Figure 4.22: Biplot showing the PC loadings and scores of the physicochemical and biological characteristics of water samples collected during the wet season.

4.2.7. Canadian Council of Ministers of the Environment-Water Quality Index (CCME-WQI)
 CCME-WQI was computed to define the Klip River Wetland (KRW) water quality status, for the study’s monitoring sites and seasons (**Table 4.6**). According to the study’s findings, the calculation of CCME-WQI revealed that for both seasons, S1, S2, and S4 recorded values between 0-44, whereas S3 recorded values between 45-64 CCME WQI values.

Table 4.6: CCME-WQI which defines the water quality status of the KRW’s water samples collected during wet and dry seasons, from four monitoring sites

Site	Wet season	CCME-WQI (Panagopoulos <i>et al.</i> , 2022)	Ranking (Panagopoulos <i>et al.</i> , 2022)	Dry season
S1	41,65	0-44	Poor water quality	41,67
S2	39,04	0-44	Poor water quality	37,15

S3	46,43	45-64	Marginal	47,34
S4	36,56	0-44	Poor water quality	36,87
Mean	40,92	-	-	40,76

Figure 4.23 outlines the spatial variations in water quality for both wet and dry seasons, in all the study's monitoring sites, as computed by the CCME-WQI. The findings have revealed that sites, i.e. S1, S2, and S4, are intensively deteriorated and according to the CCME-WQI class, the water quality is poor (Panagopoulos *et al.*, 2022). Dzhanghi and Atangana (2023) also found similar results, where the computation of CCME-WQI showed poor quality. For both wet and dry seasons, the CCME-WQI values for S3 are within the marginal rank. Panagopoulos *et al.*, (2022) allegedly stated that marginal water quality is frequently threatened or impaired and this condition usually departs from natural or desirable levels. Therefore, the study's findings deduce that water quality in the KRW follows this trend, i.e., S3>S1>S2>S4, from marginal to poor water quality, in both seasons. However, the comparison between the seasons shows that dry season water samples are more polluted as compared to wet season, and this is shown by the low mean of CCME WQI for dry season, in contrast with wet season. This is due to rainfall during the wet season, which has the potential to dilute pollutants in water, thus reducing water quality degradation, and the low levels of water during the dry season cause pollutants to become more concentrated (Hossain, 2017 and Ihunwo *et al.*, 2018).

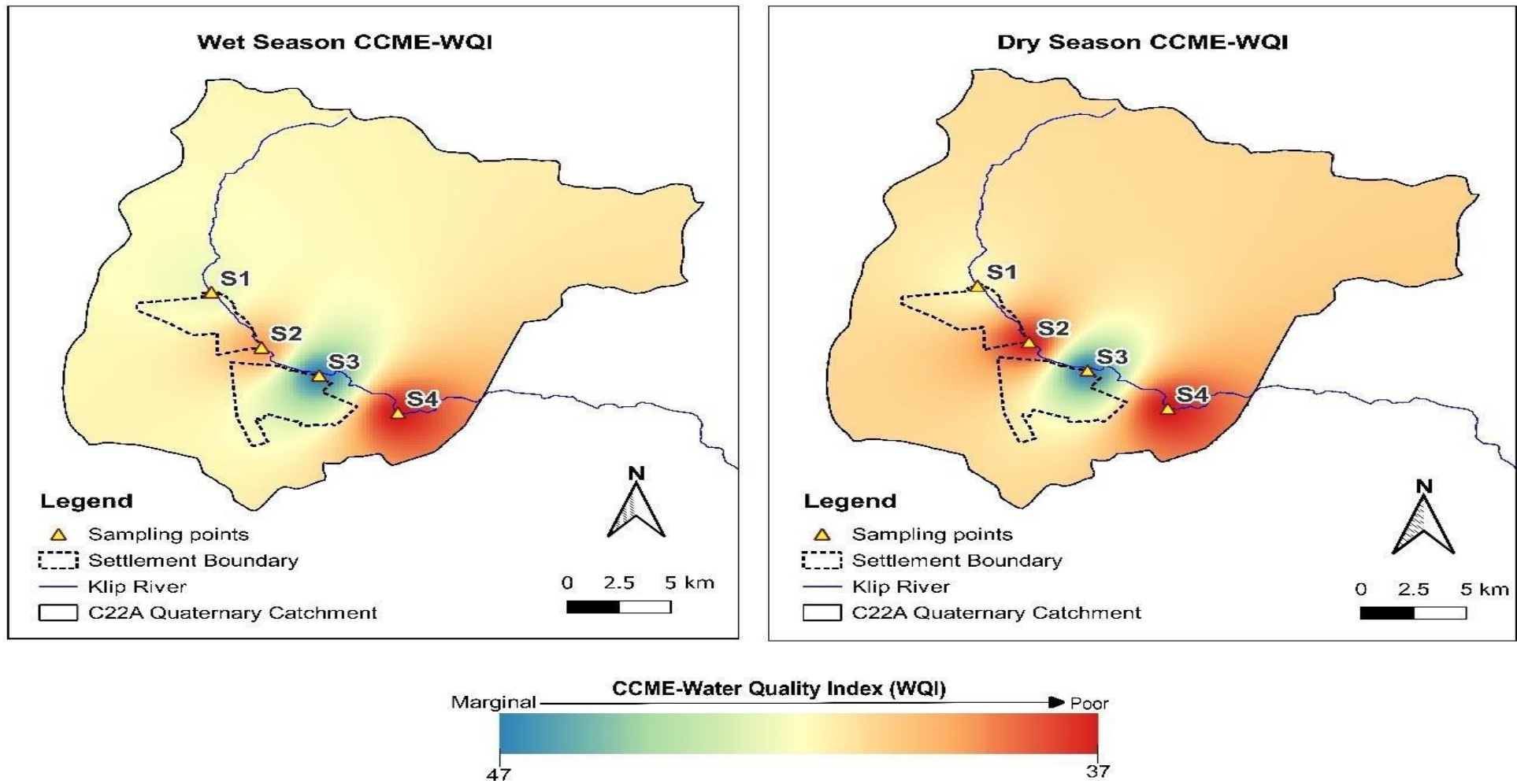


Figure 4.23: The spatial variations of CCME-WQI computed from the physicochemical and biological characteristics of the KRW for wet and dry seasons.

4.3. Objective 2: Assessment of community's perceptions and attitudes on how urbanisation impacts local communities in the vicinity of the Klip River Wetland

To achieve the goal of this objective, a questionnaire tool approach was adopted, in alignment with a research question which intends to contextualise the socio-demographic characteristics of people living in the vicinity of Klip River Wetland (KRW), the drivers of urbanisation within their locality, and how that has impacted their livelihood. The questionnaire included close-ended questions about the socio-demographic characteristics of community residents of Protea Glen (PG) and Lenasia (LENZ). The socio-demographic characteristics of respondents such as gender, age, educational background, and economic status, are outlined. These types of socio-demographic characteristics are considered significant influences of high pollution in wetlands (Ssanyu *et al.*, 2023). Furthermore, drivers of urbanisation in the area were assessed by asking respondents to choose between a variety of factors such as income, education, and health services. The uncertainty option was also included for respondents who consider other factors as contributing elements or who are ignorant about the reason behind the intensification of urbanisation in their community. Through open-ended questions, respondents were able to articulate how urbanisation has influenced life within their communities, and they held varied perceptions and attitudes towards urbanisation. The outcomes of open-ended questions are presented thematically and graphically in the section below.

4.3.1. Socio-demographic characteristics

In this section, the results and discussions on the respondents' gender, age, educational background, and economic status, are shown. Cross-tabulations are presented, to highlight the relationship between these socio-demographic characteristics of respondents.

4.3.1.1 Gender

In this study, the respondents who participated were classified according to their gender. **Figure 4.24** illustrated below shows a gender-based pie chart with proportion of gender that took part in the survey. According to the findings, more males participated (52%) when compared to females (48%). Census (2022) reported that the city of Johannesburg has more males (50.4%) than females (49.6%) and this substantiates male dominance in the study area, i.e. Protea Glen (PG) and Lenasia (LENZ), in the city of Johannesburg. Similar results were observed by Tshililo *et al.*, (2024), in one of the settlements falling under the city of Johannesburg municipality, with 54.5% of males and 45.5% of females engaging in the community survey related to water resources. Moreover, a study by Ssanyu *et al.*, (2023)

which assessed community perceptions of wetlands pollutants also showed similar results with this study. The present study's findings and the recent reviewed literature emphasize as a critical socio-demographic characteristic when assessing urbanisation dynamics within communities. Integrating the existing knowledge with the present study's findings about gender reveals consistency of information, in relation to the research objective, therefore, outlining feedback to the research question and adding more knowledge to community survey research.

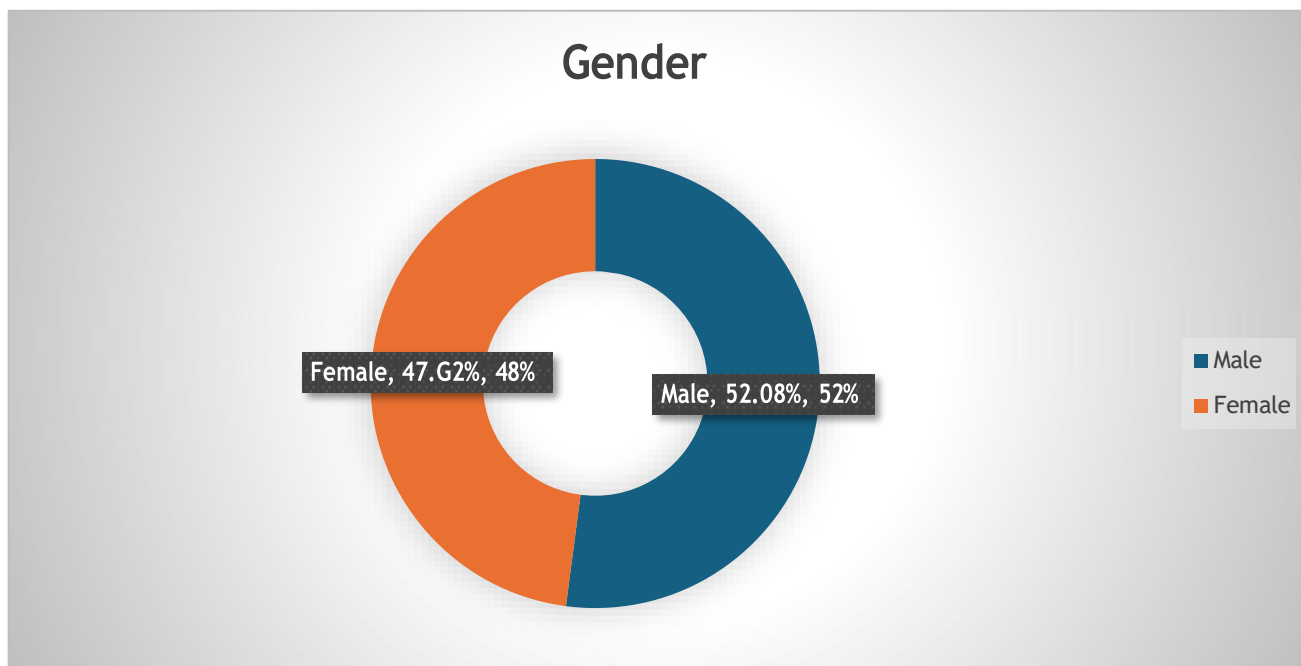


Figure 4.24: A gender-based pie chart showing male dominance over females, in PG and LENZ communities, in the city of Johannesburg municipality.

4.3.1.2 Age

The categories used to characterise the respondent's ages were: 28-39 years old, 40-49 years old, and 50+ years old. According to **Figure 4.25**, respondents who are aged between 40-49 years were dominant in the survey (40%) as compared to other age groups. These results indicate that the age group of 40-49 years is more represented in the community, in contrast with the 28-39 years and 50+ years age groups. According to Census (2011) reports, the dominance of 40-49 years age group, followed by 50+ years age group in the study means that people within this age group are settled in their lives compared to young people between 28-39 age range, who might be in transitional phases such as moving and establishing careers. 50+ years age group people were less active in the survey compared to the 40-49 years age group, this is because they might be in their retirement phase and chances are they might have gone back to stay in the rural areas because they were driven into the urban area by job purposes (Wassem and Talpur, 2021). The reports by Census (2011), in both PG

and LENZ, have shown similar results with the present study whereby there are more 40-49 years age group people than 50+ years age group. Existing knowledge on the subject matter, incorporated with the present findings, culminates to essential and coherent argument that age is one of the main factors that is considered to determine knowledge and experience in diverse situations, in alignment with the research objective which assess community perceptions and attitudes on how urbanisation affects local communities (Githiora *et al.*, 2023; Qobilovna, 2023).

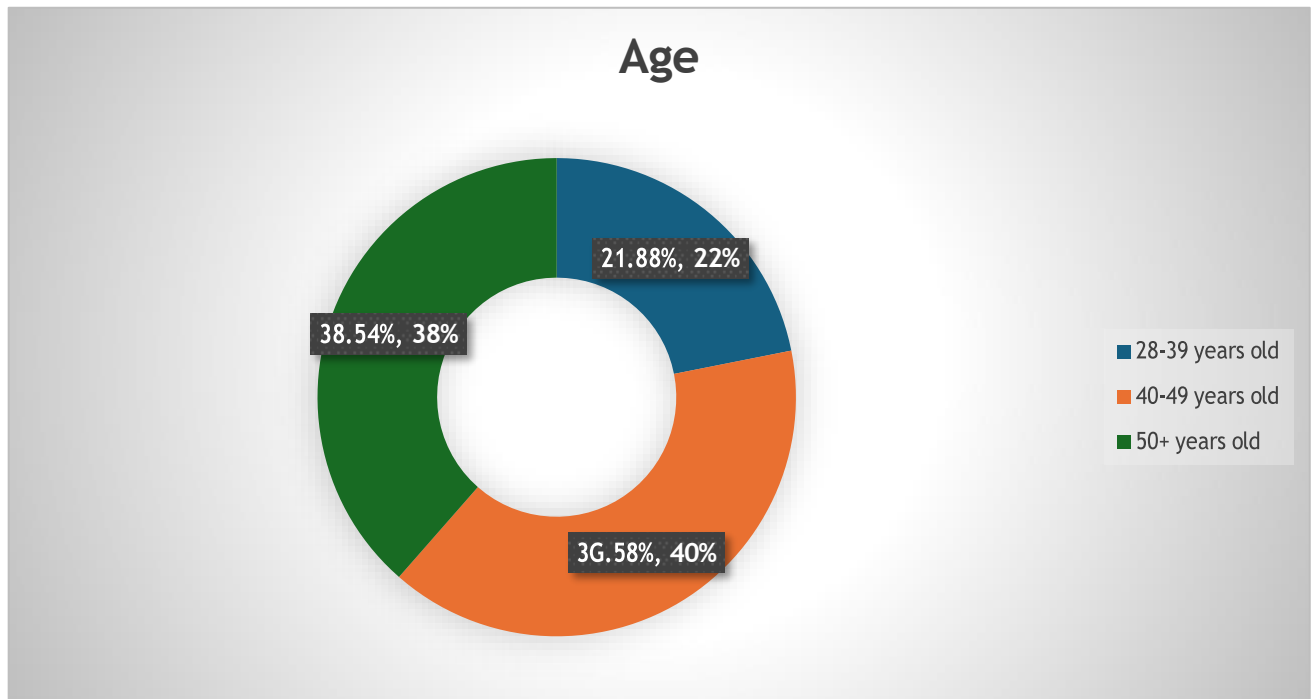


Figure 4.25: Age-based pie chart dominated by middle age group (40-49 years old) of respondents in PG and LENZ communities, in the city of Johannesburg municipality.

4.3.1.3 Educational background

The educational background of respondents in the present study is grouped into three categories, i.e. primary, secondary, and tertiary. As displayed in **Figure 4.26**, the most participated community residents in both Protea Glen (PG) and Lenasia (LENZ) have secondary education as their highest educational level, which is 45% of the sample size. Community residents with no formal education accounted for 3% of the sample size, whereas 16% have primary education as their highest education level, and 36% of the sample size is respondents with tertiary educational level. The findings about the dominance of secondary education in the community survey are consistent with a study by Ssanyu *et al.*, (2023), conducted in the same research discipline with the present study, which evaluates the impacts of urban growth dynamics on wetland degradation. These findings implies that respondents with secondary education have access to information and the time to participate in surveys, unlike those who have primary education or no formal education, due to limited information.

Knowledgeable individuals with tertiary education might have been too busy to engage due to work and career demands. The trends in recent literature and the findings of the present study strengthens the relevancy of the link between educational level and the present study's research objective. This deduce that education is crucial when assessing urbanisation-induced impacts within communities located in the vicinity of wetlands, since it shapes respondents' perspectives and experiences, which makes it essential for understanding the questions presented in the questionnaire document (Zirkel *et al.*, 2015).

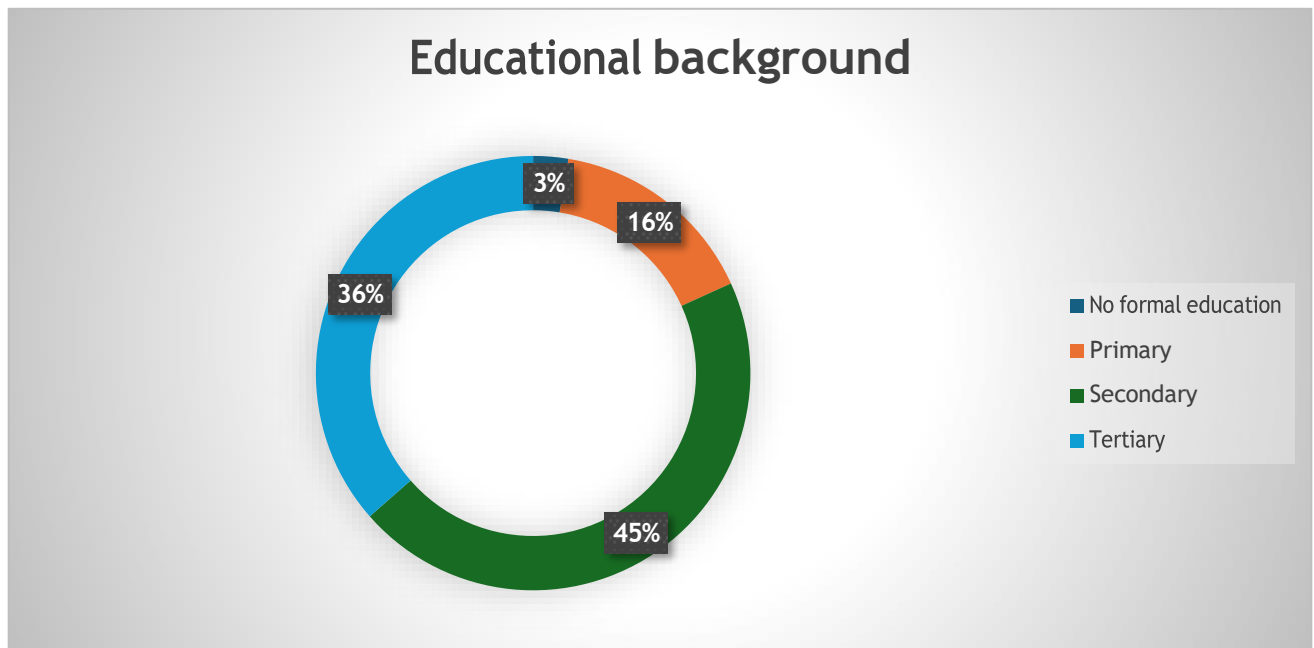


Figure 4.26: A pie chart showing the educational background of respondents in PG and LENZ communities, in the city of Johannesburg municipality.

4.3.1.4 Economic status

In this study, the economic statuses of the participating community residents were assessed based on three categories, i.e. employed, self-employed, and unemployed. This was done to capture the economic dynamics of residents in both Protea Glen (PG) and Lenasia (LENZ). As shown in **Figure 4.27**, employed participated residents were dominant (51%) in the survey, followed by self-employed (27%) residents, and lastly, unemployed (22%) residents. These findings mean that urbanisation shifted the economic aspects within the communities towards wage employment. Reviewed studies highlighted that economic status, which strengthen the integration between the existing knowledge and the present study's, is a socio-demographic which can be incorporated when conducting community survey which examines urban dynamics on natural wetland ecosystem such as Klip River Wetland (KRW), because various studies revealed that resident's economic status are considered significant influencers of high pollution in the ecosystem (Ssanyu *et al.*, 2023). Moreover, Muntaner *et al.*, (2020) outlined

that economic status affects social relationships and behaviours, which in turn affects community engagement and cohesion. This information deduces that it is crucial to fuse economic status when evaluating the impacts of urbanisation on wetlands degradation, because people’s economic standing often shapes their perceptions, and in most cases, individuals who are financially stable may have more access to resources, information, and ways to adapt to changes brought on by urbanisation.

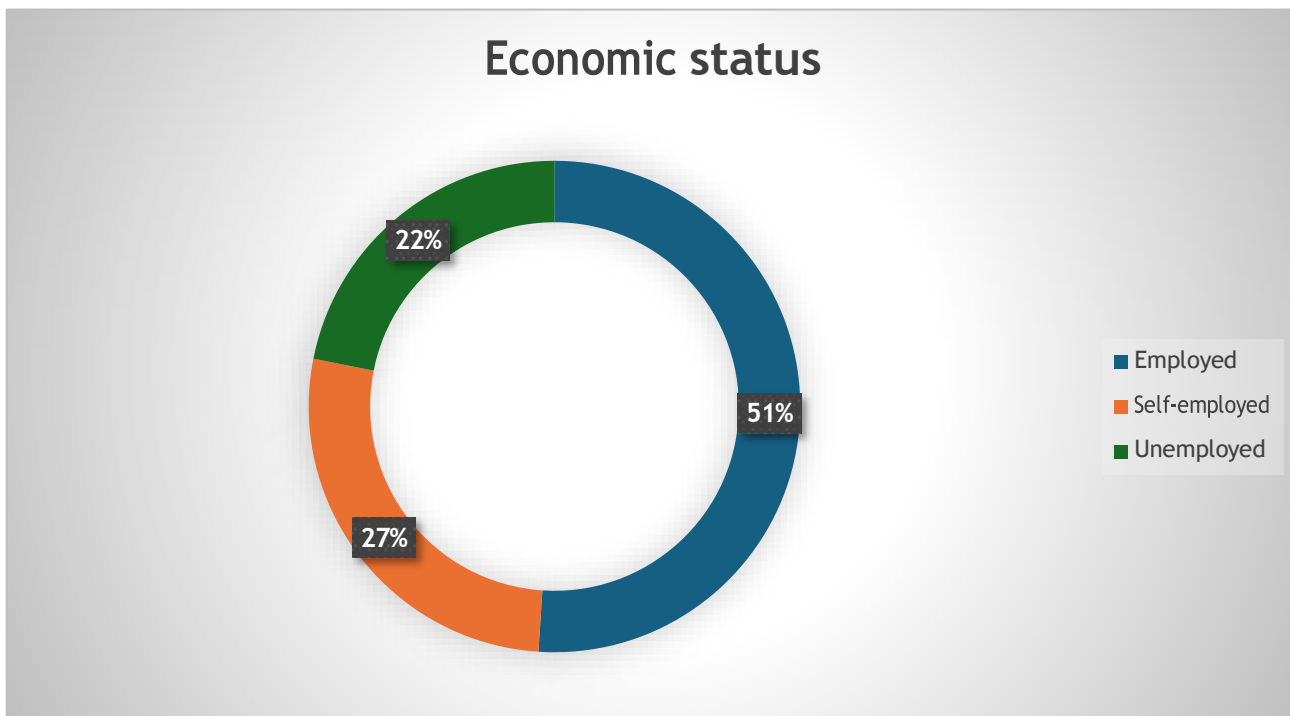


Figure 4.27: A pie chart showing the economic status of respondents in PG and LENZ communities, in the city of Johannesburg municipality.

4.3.1.5 Cross-tabulation of gender and age

The socio-demographic characteristics of participated respondents, i.e. gender, age, educational background, and economic status, were used to generate cross-tabulation that facilitated the comparison between the socio-demographic characteristics in Protea Glen (PG) and Lenasia (LENZ). **Table 4.7** displayed a cross-tabulation between respondents’ gender and age. As outlined, there are more females than males who are aged between 28- 39 years in the community survey. In contrast with the female gender, more males are between 40-49 years and 50+ year groups.

Table 4.7: A cross-tabulation showing a relationship between respondents’ gender and age

Cross-tabulation	28-39 years old	40-49 years old	50+ years old	Total
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Male	19	39	42	100
Female	23	37	32	92
Total	42	76	74	192

4.3.1.6 Cross-tabulation of gender and educational background

The cross-tabulation (**Table 4.8**) depicted the relationship between respondents' gender and educational background. According to the findings, more males had primary and secondary education when compared to females, and more females had tertiary education, with some having no formal education, when compared to the male gender. According to Pekkarinen (2012), this cross-tabulation highlights the interactions between changing gender roles, historical educational access, and the transforming effects of urbanisation. The increasing proportion of women with tertiary education indicates progress in gender equality, whereas the higher proportion of uneducated women may indicate the legacy of previous inequalities in educational opportunities. Overall, the trend suggests a possible positive move toward more educational options for women, particularly as urbanisation continues to change community access to education and social structures (Bataineh, 2019).

Table 4.8: A cross-tabulation showing a relationship between respondents' gender and educational background

Cross-tabulation	Primary	Secondary	Tertiary	No formal education	Total
Male	20	44	34	2	100
Female	10	43	36	3	92
Total	30	87	70	5	192

4.3.1.7 Cross-tabulation of gender and economic status

Table 4.9 represents the cross-tabulation of respondents' gender and employment status. According to the findings, more females were employed than males. Self-employed and unemployed economic statuses were dominant on the male side, in contrast with females. Because more females are employed, this substantiates male dominance and their availability in the community survey, as shown in **Figure 4.24**. These findings reveal that males who are self-employed and unemployed are always available within the communities because most of the self-employed jobs are within the local community.

Table 4.9: A cross-tabulation showing a relationship between respondents' gender and economic status

Cross-tabulation	Employed	Self-employed	Unemployed	Total
Male	48	27	25	100
Female	50	25	17	92
Total	98	52	42	192

4.3.1.8 Cross-tabulation of age and educational background

According to **Table 4.10**, there were no respondents between the 28-39 age group who had primary education as their highest level of education and there were no respondents within this age group who had no formal education. Most of these respondents within the 28-39 age group had tertiary education. More respondents within the 40-49 years age group had secondary education and no respondents didn't have formal education. Within the 50+ age group, most respondents had secondary education as their highest educational level when compared to the ones that had primary, tertiary, and no formal education. These findings suggest that urbanisation and its associated changes in education systems have had a significant impact on the community's educational attainment over time. The results about respondents between the 28-39 age group might be affected by the total number (42) of respondents within this age group, which is less than the total number of respondents who are aged between 40-49 years (76) and 50+ years (74). Although respondents between the 40-49 age group were more than those who are 50+ years old, which makes it not fair enough to compare them, these findings might imply that the 40-49 age group benefited from the expanding urbanisation which granted access to secondary and tertiary education, while the 50+ age group likely reflects the earlier, less urbanised stages of Protea Glen (PG) and Lenasia (LENZ), where secondary and tertiary education were less accessible, and primary education being the only option. This age group might have had economic constraints which prioritised work over education.

Table 4.10: A cross-tabulation showing a relationship between respondents' age and educational background

Cross-tabulation	Primary	Secondary	Tertiary	No formal education	Total
28-39 years old	0	20	22	0	42
40-49 years old	9	39	28	0	76

50+ years old	21	28	20	5	74
Total	30	87	70	5	192

4.3.1.9 Cross-tabulation of age and economic status

Table 4.11 illustrates the cross-tabulation of respondents' age and economic status. As per the results displayed on the table, most of the respondents who are within the 28-39 years and 40-49 years age group are employed. As for the 50+ age group, most respondents were unemployed.

Table 4.11: A cross-tabulation showing the relationship between respondents' age and economic status

Cross-tabulation	Employed	Self-employed	Unemployed	Total
28-39 years old	28	8	6	42
40-49 years old	50	18	8	76
50+ years old	20	26	28	74
Total	98	52	42	192

4.3.1.10: Cross-tabulation of educational background and economic status

A cross-tabulation of respondents' educational background and economic status is shown in **Table 4.12**. Most respondents with primary education as their highest educational level were deemed unemployed. Secondary and tertiary education is attributed to most of the respondents who are employed. The unemployment rate was high for respondents who possessed no formal education.

Table 4.12: A cross-tabulation showing respondents' educational background and economic status

Cross-tabulation	Employed	Self-employed	Unemployed	Total
Primary	12	3	15	30
Secondary	42	30	15	87

Tertiary	44	18	8	70
No formal education	0	1	4	5
Total	98	52	42	192

4.3.2. Drivers of urbanisation

In this study, the drivers of urbanisation in both Protea Glen (PG) and Lenasia (LENZ), were analysed to check what causes rapid urbanisation. Depicted in **Figure 4.28** is a pie chart that categorises the factors intensifying urban growth, and such factors are categorised as follows: Income, education, and health services. Uncertainty is one of the options which respondents selected as they were uncertain about what causes urbanisation in their community. Out of all the drivers of urbanisation which were included in the questionnaire, income is perceived by a significant proportion of participating respondents (83.85%). This means that income is the main influencer of urbanisation in PG and LENZ. Reportedly, migrants are attracted by better economic prospects in the Gauteng province. The high rate of urbanisation in the province is supported by the region's industrialisation, modernisation, and marketisation (Nhamo *et al.*, 2021). Moreover, Ogra and Onatu (2024) reported similar results to the present study, which highlighted that Johannesburg, and its suburban areas are centred on manufacturing sectors, financial and business services, and retail and wholesale trade (Ogra and Onatu, 2024).

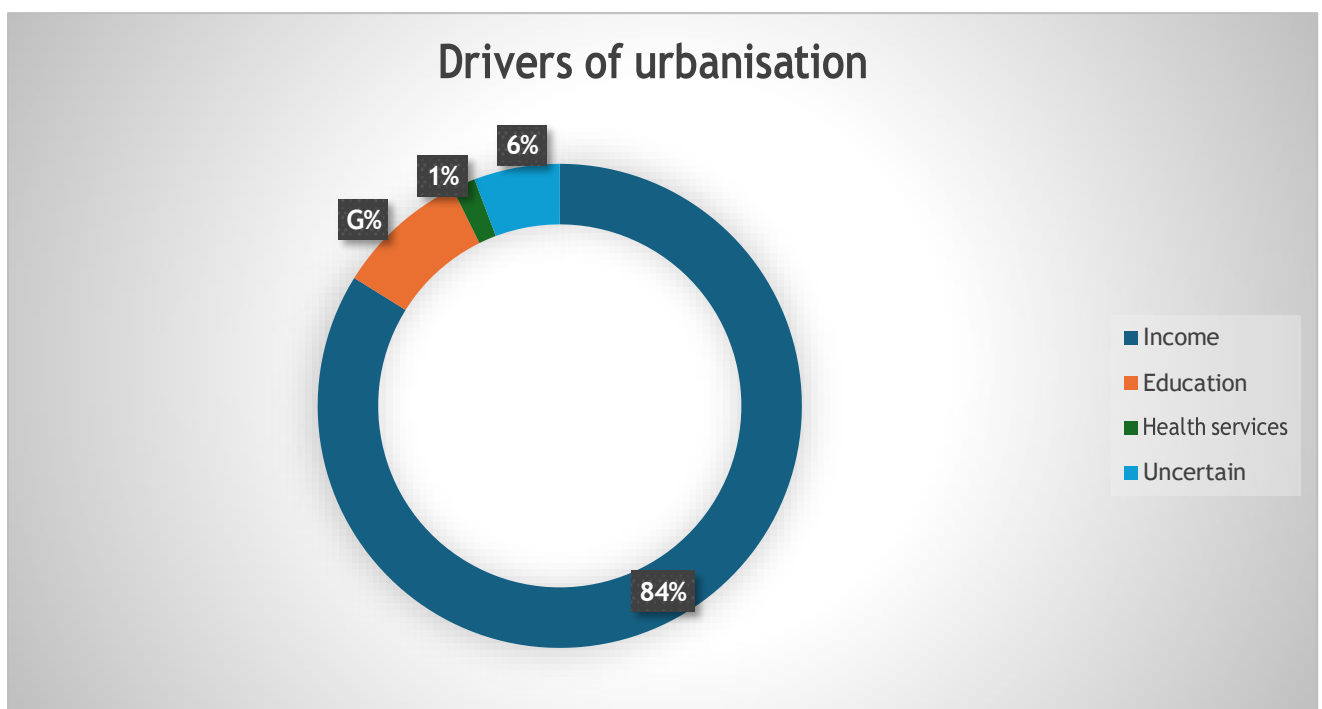


Figure 4.28: A pie chart illustrating the drivers of urbanisation in Protea Glen (PG) and Lenasia (LENZ), in the city of Johannesburg.

4.3.3. Impacts of urbanisation on local communities

The influences of urbanisation on communities, i.e. Protea Glen (PG) and Lenasia (LENZ) were assessed thematically to capture the key themes about how urbanisation has impacted the livelihood of community residents. According to the study’s results, respondents perceived urbanisation-related dynamics in their communities such as infrastructure impact (25%), environmental impact (22%), economic impact (19%), waste impact (17%), social life (10%), energy impact (5%), staple food (2%) and health impact (1%), as displayed on **Figure 4.29**. However, this section discussed the most significant impacts of urbanisation such as infrastructure, environment, economy, and waste impact, which were perceived by a high proportion of respondents.

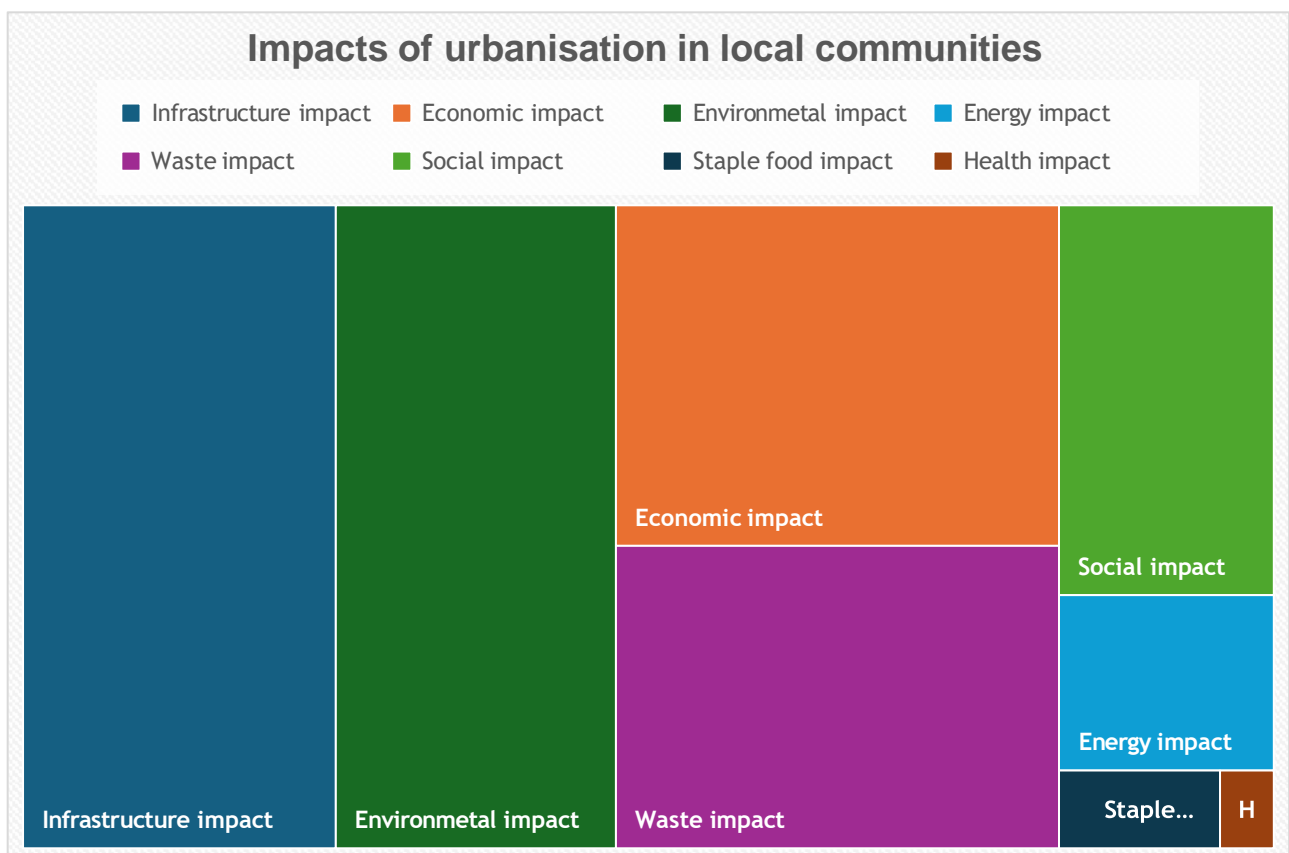


Figure 4.29: A tree graph depicting the impacts of urbanisation in Protea Glen (PG) and Lenasia (LENZ), in terms of main themes generated from open-ended responses.

4.3.3.1 Infrastructure Impact

The infrastructure impact brought on by urbanisation in Protea Glen (PG) and Lenasia (LENZ) was perceived by 25% of the respondents who participated. Issues related to infrastructure were driven by traffic congestion, construction, and housing infrastructure, drainage system,

and sanitation problems. Urban growth in PG and LENZ has caused traffic congestion whereby many people are in greater need of mobility. Respondents who perceived traffic congestion said that *“Urbanisation has caused traffic congestion which is normally seen at Jub-Jub and Impala Street between 6 am to 7 am when people are driving to work and school kids are being transported to school”*

Traffic congestion might be attributed to the high volume of vehicles with fewer roads. It can be said that due to urbanisation, there’s a struggle to expand road networks and public transport systems to keep pace with the growing population. Traffic congestion issues in the city of Johannesburg were also reported in a study by Mbhatha *et al.*, (2021). According to Mbhatha *et al.*, (2021), public transportation is contributing to high levels of traffic congestion at various times, and fewer efforts are being made to lessen the constantly increasing problem of traffic. Moreover, infrastructural vandalism such as damaged bridges is also one of the reasons that disrupted traffic flow. Subsequently, respondents stated that *“The bridge for crossing the Klip River, from PG ward 13 to Naledi Ext 2 has been damaged and this has led to traffic congestion as vehicles diverted from using the bridge to using Protea city boundary street.”*

Additionally, traffic congestion in the study area is due to the lack of drainage systems, as respondents mentioned that when it rains heavily, the surface runoff creates a small dam on Boundary Street, downhill PG, and a wide range of vehicles experience mobility issues due to road damages.

Infrastructural aspects such as drainage and sanitation systems are not improved with the growing population in the study area. The drainage and sanitation systems were constructed for a certain number of populations and due to urban expansion and population growth, these systems are overloaded and frequently blocked. Similar results were observed in a study by Vyas-Doorgapersad and Kemp (2020). According to this study, which evaluated PG's service delivery issues, the suburban value is incredibly unsatisfactory because of its filthy streets and constantly leaking sewer lines. Furthermore, it has been noted that governance problems and causative elements are to blame for inadequate sanitation and inadequate sewage facilities.

Rapid house constructions were reported as one of the infrastructure impacts brought on by urbanisation. The findings highlighted that the need for housing is high to meet the demand of the growing population. House infrastructures are expanding and encroaching on the Klip River Wetland (KRW) as depicted in **Figure 4.30**. Ogra and Onat, (2024) allegedly mentioned

similar infrastructural developments. According to the reports, the rapid urban population, the increase in settlements, and the socio-economic opportunities have resulted in considerable urban sprawl in and around the urban fringe areas of Johannesburg metropolitan city (Ogra and Onat, 2024).



Figure 4.30: A photograph displaying the expanding housing infrastructure shifting towards the Klip River Wetland (KRW).

Source: Mabale, 2024.

4.3.3.2 Environmental impact

In the study area, urban growth has an influence on the environment and respondents were aware of issues such as air pollution, deforestation, and climate change. Emissions of greenhouse gases like CO₂, CH₄, and N₂O are linked to climate change (Daramola, 2020). Global warming and an increase in the frequency of heat waves were caused by these emissions, which trapped heat in the atmosphere. As a result, heat waves produced unstable atmospheric conditions that led to intense rainfall and floods. According to reports, respondents stated, *“As the area grew, there have been abnormal temperature fluctuations which are attributed to global warming. The fluctuations in terms of rainfall patterns were observed in 2022. This caused heavy flooding within the KRW (Klip River Wetland), to an extent where the water flow even got into houses located approximately 80m away from the KRW”*.

Nhamo *et al.*, (2021) reported environmental concerns related to air pollution in Gauteng Province and the reports are like the findings of the present study. According to Nhamo *et al.*, (2021), heavy air pollution levels are compounded by rapid urbanisation and Vehicular pollution. These factors result in CO₂ emissions which interact with the environment. The findings reveal that the reported traffic congestion in the present study which is mainly due to infrastructure issues is correlated to air pollution.

4.3.3.3 Economic impact

According to the study's findings, urbanisation resulted in both positive and negative impacts on the livelihood of PG and LENZ residents in the economic aspect. Economic growth due to concentrated businesses, industries, and services, is increasing job opportunities and that is seen as a positive impact of urbanisation within the study area. PG is characterised by economic aspects such as Protea Glen Mall and Builders Superstore (located on the R558 road to Roodeport), Sizwe Shopping Centre on Protea Boulevard, Cashbuild (located on Wild Chestnut Street), etc. The rapidly growing area of LENZ has shopping centres such as Trade Route Mall (located at the intersection of R554 and M10), Food Lover's Market, and Plaza Board Centre (located at M10), etc. Moreover, various industrial activities and other means of generating money are present in the study area. On the other hand, urban growth has led to competition for jobs, cost of living, and gentrification in the study area. The demand for services and housing is high, making it difficult for low-income residents to afford basic needs. There is informal shack settlements located on the outskirts of the Klip River Wetland (KRW) that belong to the low-income residents of LENZ. According to Ogra and Onatu (2024), households earning R3,200 or less per month struggle to obtain home loans and housing demands are similarly limited by ineligibility for credit or affordability capacity. Substantially, respondents said that "*Urbanisation has both negative and positive impacts on our livelihoods. A positive impact is it has led to economic development, but there's competition for jobs and inequalities. However, the ongoing mining activities are causing vibrations and cracks in our houses, and we are forced to buy materials to repair our house infrastructures. Such issues are ripping our finances.*"

4.3.3.4 Waste Impact

Figure 4.31 illustrates one of the major concerns in the study area which is waste dumped in the vicinity of the Klip River Wetland (KRW). Because the study area is experiencing urban growth, the high population of inhabitants caused congested areas and the more people concentrated, solid waste production became high, leading to solid waste management issues. Respondents reported that "*Joburg Municipality has introduced Pikitup dustbins which*

are used to dispose of waste generated from households and the municipality collects the waste dustbins every Monday. However, some people are still dumping directly on open sites.”

Selahle (2020) found similar outcomes in a study concerning waste management challenges. The spatial distribution of unlawful solid waste dumps in Soweto is influenced by several factors, according to this study, including household size, and high population density. Lower levels of education also typically contribute to illegal solid waste dumping. Furthermore, according to Selahle (2020), Pikitup picks up 4,500 tons of waste every week on average, and when Pikitup trucks are not there, locals prefer to dispose of their waste in open, vacant spaces nearby. Based on the primary and secondary results, waste management problems in Soweto-PG and LENZ require regional and local stakeholder involvement because the municipality and its local people are contributing to waste management issues.



Figure 4.31: A photograph of waste dumped in the vicinity of Klip River Wetland (KRW).

Source: Mabale, 2024.

4.4. Objective 3: Evaluation of the factors related to urbanisation in communities that interact with the degradation of the Klip River Wetland

This section highlights the weighted score of the factors related to urbanisation in the study area which were assessed by field observations and augmented with the perceived

urbanisation influences by participating respondents. These study's findings reveal that traffic congestion, drainage and sewage issues, construction, wildfires, mining and industrial activities, and waste, are the most dominant factors which interact with water quality within the wetland.

Table 4.14: Factors related to urbanisation that interact with water quality in the Klip River Wetland

Field observation factors	Scale (0-5)	Weight applied by respondents' data	Weighted score (Scale x Weight applied)
Traffic congestion, drainage and sewage issues, construction	4	0.25, Infrastructure impact (25%)	1
Wildfires	3	0.22, Environmental impact (22%)	0.66
Mining and industrial activities	4	0.19, Economic impact (19%)	0.76
Waste	4	0.17, Waste impact (17%)	0.68
Crime and cultural services	1	0.10, Social life impact (10%)	0.10
Agriculture	1	0.02, Staple food impact (2%)	0.02
Pharmaceuticals	1	0.01, Health impact (1%)	0.01

4.4.1. Traffic congestion

Traffic congestion is a result of the study area's growing population and strong demand for mobility. As a result, more fuel is used, which raises emissions of greenhouse gases (GHGs) such as Carbon dioxide (CO₂), methane (CH₄), and Nitrous oxide (N₂O) (Sitati, 2021). These GHG emissions are linked to climate change (Yoro and Daramola, 2020). According to Ahmed (2021), climate change is associated with heat waves which result in heavy floods, and this is substantial to the present study's results because in the open-ended question section, respondents in Protea Glen (PG) observed heavy floods in 2022 in the KRW. According to Salimi *et al.*, (2021), wetland environments can be impacted by climate change through changes in hydrological patterns, which can alter the chemical composition of the ecosystem. Moreover, Rankoana (2020) highlighted the influence of climate change on water quality. The primary and secondary data deduce that the observed water quality degradation in the KRW might be linked to the perceived traffic congestion.

4.4.2. Drainage and sewage issue

Both field observation and respondents' perception noted drainage and sewage issues in the study area. Similar results were highlighted in a study by Kalembo (2020). It was mentioned that prolonged sewage overflow into the Klip River Wetland (KRW) from the poorly maintained

wastewater drainage system in the Slovo Park informal community has increased COD, thus reducing the quality of the water. This was said to be a result of infrastructure issues within the informal community. Moreover, Mavhungu and Mankga (2024) in research within the city of Johannesburg, also mentioned the significant impact of inadequate infrastructure maintenance. It was reported that infrastructure issues led to raw sewage spills in streets and rivers. This caused water quality degradation which was observed by high levels of *E. coli* and turbidity.

4.4.3. Constructions

Sediments from construction sites have been shown to accumulate in wetlands and deteriorate water quality. This is observed by low pH levels at S4 during the wet season. Zhu *et al.*, (2018) also stated that construction activities such as building houses may result in a quick deterioration of the wetland's pH. Moreover, Zhu *et al.*, (2018) mentioned that suspended particles from constructions may increase Fe and Cl^- . The present study's findings suggest that the perceived housing constructions in the vicinity of the KRW have loaded sediments in the wetland, thus degrading water quality.

4.4.4. Wildfires

Figure 4.32 shows wildfire ashes observed on the outskirts of the Klip River Wetland (KRW). Reportedly, high nutrient levels in this study such as calcium (Ca^{2+}), magnesium (Mg^{2+}), and nitrates (NO_3^-) might be attributed to the observed wildfire ashes, as also stated by Numbere and Obanye *et al.*, (2023), that increased nutrients in wetlands are linked to wildfires. Additionally, Paul *et al.*, (2022) reported that nutrients are one of the chemical water quality parameters which show fluctuations due to wildfires. The findings of the study indicate that nutrients that are associated with wildfire residue and burned ash might be carried into KRW by wind erosion which is normally observed during dry seasons (Yang *et al.*, 2023).



Figure 4.32: A photograph depicting wildfire ashes in the vicinity of the Klip River Wetland (KRW).

Source: Mabale, 2024.

4.4.5. Mining and industrial activities

Field observation and community survey perceived mining activities in the study area. According to Chetty (2021) and Kalembo (2020), one of the biggest dangers to South Africa's water resources is gold mining, despite having been the driving force behind the development of Johannesburg and the nation's economy for more than a century. During mining operations, sulfuric acid is created when pyrite oxidizes, causing Acid Mine Drainage (AMD). Toxic heavy metals such as Manganese (Mn^{2+}) are released from AMD, and have the potential to flow into nearby wetlands, thus posing a threat to aquatic life (Plante *et al.*, 2021). This substantiates the impact of Mn^{2+} recorded in the present study. In addition, Kalembo (2020) also stated that these harmful elements are released into KRW by runoff from the Central Rand Goldfield, lowering the quality of the water.

4.4.6. Waste

During the period of the study, waste was observed along the outskirts of the Klip River Wetland (KRW), and the findings from the open-ended questions validated these results. According to Mekonnen *et al.*, (2020) solid waste which is generated as the urban population increases, has interactions with wetlands water quality. Waste solids are characterised by toxicants such as heavy metals, which raise COD levels in nearby wetlands. This finding is

like a report by Malambana and Visco, (2021), who stated that urbanisation increased waste production within communities, thus decreasing water quality.

4.5. Summary

This chapter highlighted the integration of the present study's findings with the existing knowledge about the impacts of urbanisation on wetland degradation. The research objectives used to attain the study aim has answered research questions which intended to have an overview of the relationship between the physicochemical and biological characteristics of Klip River Wetland's (KRW) water quality, the possible pollutants that are most prevalent in the wetland due to urbanisation, and the water quality status. The information regarding trends on socio-demographic characteristics of people living in the vicinity of KRW, the drivers of urbanisation within their locality, and how that has impacted their livelihood, has been contextualised. The chapter also revealed factors that are influencing the physicochemical and biological regimes of KRW, and how are they linked to wetland degradation.

CHAPTER 5: SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1. Introduction

This chapter provided a concise summary of the study by highlighting key points, research aims, methodology, findings, and the study's contribution to the body of science relating to how urban growth intensifies the demand of socioeconomic needs which are linked to water quality degradation in the Klip River Wetland (KRW). In this chapter, the conclusion of the study brought together the findings on the status of KRW's water quality, the socioeconomic dynamics of people residing in Protea Glen (PG) and Lenasia (LENZ) communities and the implications of the findings, emphasizing the broader context of the study. Subsequently, this chapter, in a feasible manner, recommended possible ways for mitigating hazards that are brought on by urbanisation of the wetlands' water quality, considering the Sustainable Development Goals (SDGs).

5.2. Summary of the study

The study aimed at evaluating the impacts of urbanisation on Klip River Wetland (KRW) degradation in Johannesburg South. The aim was attained by three objectives, i.e. physicochemical and biological characteristics of water quality of the KRW (objective 1), assessment of community's perceptions and attitudes on how urbanisation impacts local communities, i.e. Protea Glen (PG) and Lenasia (LENZ), in the vicinity of the KRW (objective 2) and an evaluation of factors related to urbanisation in these communities which interact with the degradation of the KRW (objective 3).

To address objective 1, a quantitative data approach was utilised, whereby water samples were collected from four monitoring sites in KRW, within the upper Klip River Catchment (KRC), during wet and dry seasons. The water samples were analysed for 18 water quality parameters, i.e. physical, chemical, and biological characteristics of the wetland's water. To be able to assess how these water quality parameters affect each other, Pearson's correlation was utilized, and Principal Component Analysis (PCA) tracked the possible source of pollution, which is linked to urbanisation. The Canadian Council of Ministers of the Environment-Water Quality Index (CCME-WQI) was used to determine and conclude the water quality status of the KRW, from the assessed 18 water quality parameters. This type of WQI was chosen because it supports decision-making, providing information to guide water quality policies and it incorporates multiple water quality parameters, thus it is recently used

in water quality research in South Africa and other parts of the world. To address objective 2, a community survey in PG and LENZ was conducted in the form of questionnaires which were structured to get information about the respondents' sociodemographic characteristics and socioeconomic dynamics which highlighted the influences of urbanisation within the study area. For objective 3, field observations were augmented with the extracted proportion (%) of respondents who articulated factors that have the potential to affect water quality, from the open-ended responses which were analysed thematically, and presented the results in a quantitative form (percentages). This was done to limit biases and to validate the results of the study. Subsequently, secondary data was also integrated to deduce the impact of urbanisation on KRW. The laboratory analysis revealed a significant water quality degradation, as seen by the CCME-WQI, which highlighted spatial variations in water quality that follow this trend: S3>S1>S2>S4 (from marginal to poor water quality), in both wet and dry seasons. The physicochemical and biological characteristics of KRW showed water pollution within the KRW, which is attributed to water quality parameters such as pH, turbidity, dissolved oxygen (DO), chemical oxygen demand (COD), nitrate (NO_3^-), magnesium (Mg^{2+}), calcium (Ca^{2+}), manganese (Mn^{2+}), *Escherichia coli* (*E. coli*) and total coliforms, which exceeded the South African Water Quality Guidelines (SAWQGs) and the Klip River Catchment's (KRCs) In-stream Water Quality Guidelines (ISWQGs). The multivariate statistics have shown the correlations between the water quality parameters, and potential sources of pollution such as weathering of rocks and mineral dissolution, and organic waste.

From the community survey, key results on the sociodemographic characteristics of participated respondents were outlined, i.e. male dominance (52%) in the survey, a significant percentage of age ranging from 40-49 years (40%), a secondary education level (45%), 51% respondents were employed and the 84% reported income as the main driver of urbanisation in the study area. Urbanisation has significantly impacted infrastructure (25%), environment (22%), economy (19%) and waste (17%) in the study area. From these main themes (infrastructure, environment, economy, and solid waste production), factors such as traffic congestion, drainage and sewage issues, constructions, industrial and mining activities, wildfires, and organic waste, were integrated to support the field observations.

5.3. Conclusion

The findings of this study conclude that Johannesburg is the economic hub in South Africa, and it has led to rapid urbanisation, whereby people migrate from rural areas to Johannesburg and its suburban areas, i.e. Protea Glen (PG) in Soweto and Lenasia (LENZ), and others, for better opportunities. Urbanisation in these areas has influenced socioeconomic dynamics and

natural processes which interacted with water quality in the Klip River Wetlands (KRW). Although urbanisation has a positive impact on the economy, mining, and industrial activities, in terms of income generation, it puts pressure on KRW's water quality. The water quality degradation within the KRW is due to infrastructure issues which result in factors that interact with water quality, such as traffic congestion, drainage and sewage spills, and construction. Environmental degradation such as wildfires, mining, and industries which are the drivers of the economy, all have an impact on water degradation within the KRW. Moreover, the findings deduce that increased surface runoff loads sediments from construction activities and organic waste into the KRW, thus increasing the COD in water. High counts of *E. coli* are attributed to drainage and sewage issues. Wildfires are one of the factors that degrade the wetland's water quality by releasing Polycyclic Aromatic Hydrocarbons (PAHs) which interact with water quality parameters. Pearson's correlation and Principal Component Analysis (PCA) suggest that the physicochemical and biological characteristics showed a relationship with each other, and although some of the parameters did not exceed the guidelines, they influence each other, and they have revealed the common source of pollution, which is substantial to the key factors observed within PG and LENZ. The CCME-WQI and PCA revealed the wetland's water quality degradation following this trend: S3>S1>S2>S4, from marginal to poor, in both wet and dry seasons. This study concludes that urbanisation intensifies factors that continue to degrade KRW's wetlands and their ecological services. Moreover, this deduces that the status of the KRW's water quality is poor and toxic for domestic water uses such as drinking, bathing, laundry, and gardening which may include water for fishponds, which are recognized by the SAWQGs published by DWAF (1996).

5.4. Recommendations and future work

The study indicated that urbanisation, while a sign of economic growth, can adversely degrade water quality in wetlands. Factors such as traffic congestion, construction, industrial and mining activities, wildfires, and improper organic waste disposal are the significant factors that degrade KRW's water quality in urban areas, i.e., Protea Glen (PG) and Lenasia (LENZ), in the city of Johannesburg. Therefore, this part of the study recommends feasible actions for mitigating the threat posed by urbanisation-induced factors on the KRW's water quality. This study promotes better public transit networks as well as the use of short-distance walking and cycling as alternate modes of transportation. Bringing congestion pricing into effect in places where traffic contributes significantly to pollution of the air and water would help reduce traffic congestion. To reduce mining and industrial pollution, buffer zones should be established along the KRW. Incentives for recycling and waste segregation at the household and industrial

levels should be implemented by strengthening waste management infrastructures and awareness. When building house infrastructure, sustainable urban design should be included. For example, rain gardens and permeable pavements can help manage stormwater and lessen runoff that carries sediments from building sites. To lessen the likelihood of wildfires, fire protection initiatives, and improved land management should be encouraged. Furthermore, the reforestation and land restoration policies in fire-prone areas must be reinforced.

This study suggests that future research should be done with a long-term goal of evaluating the cumulative effects of urbanisation on the KRW and interdisciplinary research that brings together public health specialists, environmental scientists, and urban planners to evaluate the broad impact of urbanisation on water quality and suggest integrated solutions. Technological advancements like remote sensing and machine learning models should be used to track changes in land use and land cover that could impact water quality. Finally, studies conducted at the local level should be conducted to comprehend the significance of wetlands and assess ways that urbanisation impacts wetlands' water quality in various socioeconomic and geographic contexts.

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APPENDICES

Appendix 1: Ethical clearance certificate



University of Limpopo
Department of Research Administration and Development
Private Bag X1106, Sovenga, 0727, South Africa
Tel: (015) 268 3935, Fax: (015) 268 2306, Email: tukiso.sewapa@ul.ac.za

TURFLOOP RESEARCH ETHICS COMMITTEE
ETHICS CLEARANCE CERTIFICATE

MEETING: 04 December 2023

PROJECT NUMBER: TREC/1759/2023: PG

PROJECT:

Title: An Evaluation of the Impacts of Urbanisation on Klip River Wetland Degradation, Johannesburg South
Researcher: LK Mabale
Supervisor: Dr RT Akanbi
Co-Supervisor/s: Dr JM Letsoalo
Ms MG Montwedi
School: Agriculture and Environmental Sciences
Degree: Master of Science in Geography

PROF D MAPOSA
CHAIRPERSON: TURFLOOP RESEARCH ETHICS COMMITTEE

The Turfloop Research Ethics Committee (TREC) is registered with the National Health Research Ethics Council, Registration Number: **REC-0310111-031**

Note:

- i) This Ethics Clearance Certificate will be valid for one (1) year, as from the abovementioned date. Application for annual renewal (or annual review) need to be received by TREC one month before lapse of this period.
- ii) Should any departure be contemplated from the research procedure as approved, the researcher(s) must re-submit the protocol to the committee, together with the Application for Amendment form.
- iii) PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES.

Finding solutions for Africa

Appendix 2: Letter to conduct study in the Klip River Wetland and communities in the vicinity of the wetland



University of Limpopo

School of Agricultural and Environmental Sciences

Private Bag X1106, Sovenga, 0727,

South Africa

Tel: (015) 268 2202 / 3464

Web: <http://www.ul.ac.za>

25/06/2024

Stakeholders

Johannesburg City Parks

PERMISSION TO CONDUCT STUDY

Mr KL Mabale with student number [REDACTED] is a full-time MSc student in the Department of Geography and Environmental Sciences, School of Agriculture and Environmental Sciences, in the Faculty of Science and Agriculture, University of Limpopo. The above-mentioned student as part of his degree requirement is conducting research titled "*An evaluation of the impacts of urbanisation on Klip River wetland degradation, Johannesburg South*". The student has been given all

necessary approval and ethical clearance (TREC/1759/2023: PG) to conduct the research by the University of Limpopo Ethics Committee.

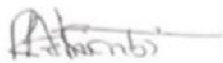
This letter serves as a formal request for your permission to accord the student the opportunity and approval to collect his research samples and all necessary data from city of Johannesburg municipality, along the Klip River Wetland and communities in the vicinity of the wetland.

All necessary consent, precautions and protocols will be followed to protect the privacy and data collected from respondents. All data collected will be kept strictly confidential and will only be used for the purposes of this research.

Your support in this matter will be greatly appreciated.

Thank you for your consideration, and I look forward to your positive response.

Sincerely,



Dr RT Akanbi (Supervisor)

Dr JM Letsoalo (Co-Supervisor)

Ms M Montwedi (Co-Supervisor)

Appendix 3: Permission for conducting research in Klip River Wetland and communities in the vicinity of the wetland



Johannesburg City Parks and Zoo (NPC)

City Parks House P O Box 2824 Tel +27(0) 11 712 6600
40 De Korte Street Johannesburg Fax +27(0) 11 403 4495
Braamfontein 2000 www.jhbcityparksandzoo.com

27/06/24

Name: KL Mabale

Salutation: Mr

Institution & Department: University of Limpopo, Faculty of Science and Agriculture

Email address: katlegolennonmabale@gmail.com

Re: Permission to access and collect data at Klip River Wetland

Dear Mr Mabale

Kindly note that your request has been granted to access and collect data at Klip River Wetland.

Please note however that, we would also like you to adhere and note the following:

- i. The information collected is used for research purposes.
- ii. No payment will be due to you for undertaking the research in our facilities.
- iii. You will be required to make available a copy of your research report to the Johannesburg City Parks and Zoo.
- iv. You will be required to observe all the company's rules and regulations all times.
- v. Johannesburg City Parks and Zoo shall not be responsible for any loss or injury during your research.
- vi. You will provide your own protective clothing equipment suitable for areas you will visit.
- vii. Johannesburg City Parks and Zoo will not be liable for any loss or damages as a result of this initiative.

Yours sincerely

p.p. 

Ms. Ayanda Roji
Johannesburg City Parks and Zoo
Senior Manager: EER Department

Directors: Thenjiwe Mjoli (Chairperson), Rabone Moripe, Andile Jabavu, Mbulelo Fihla,
Peter Kgama, Yongama Zigebe, Ayanda Hlatshwayo, Winnie Ntongwana,
Lucky Fani, John Madela, Yongama Nyalambisa
Thanduxolo Mendrew (Managing Director), Floyd Rikhotso (Chief Financial Officer),
Ayanda Shongwe (Company Secretary)

Reg No: 2000/028782/08

Appendix 4: Colilert-18 51-well Quanti-tray most probable number (MPN) table used for enumeration of Escherichia coli (E. coli) and total coliforms

51-Well Quanti-Tray MPN Table

No. of wells giving positive reaction per 100 ml sample	Most Probable Number	95% Confidence Lower	Limits Upper
0	<1	0.0	3.7
1	1.0	0.3	5.6
2	2.0	0.6	7.3
3	3.1	1.1	9.0
4	4.2	1.7	10.7
5	5.3	2.3	12.3
6	6.4	3.0	13.9
7	7.5	3.7	15.5
8	8.7	4.5	17.1
9	9.9	5.3	18.8
10	11.1	6.1	20.5
11	12.4	7.0	22.1
12	13.7	7.9	23.9
13	15.0	8.8	25.7
14	16.4	9.8	27.5
15	17.8	10.8	29.4
16	19.2	11.9	31.3
17	20.7	13.0	33.3
18	22.2	14.1	35.2
19	23.8	15.3	37.3
20	25.4	16.5	39.4
21	27.1	17.7	41.6
22	28.8	19.0	43.9
23	30.6	20.4	46.3
24	32.4	21.8	48.7
25	34.4	23.3	51.2
26	36.4	24.7	53.9
27	38.4	26.4	56.6
28	40.6	28.0	59.5
29	42.9	29.7	62.5
30	45.3	31.5	65.6
31	47.8	33.4	69.0
32	50.4	35.4	72.5
33	53.1	37.5	76.2
34	56.0	39.7	80.1
35	59.1	42.0	84.4
36	62.4	44.6	88.8
37	65.9	47.2	93.7
38	69.7	50.0	99.0
39	73.8	53.1	104.8
40	78.2	56.4	111.2
41	83.1	59.9	118.3
42	88.5	63.9	126.2
43	94.5	68.2	135.4
44	101.3	73.1	146.0
45	109.1	78.6	158.7
46	118.4	85.0	174.5
47	129.8	92.7	195.0
48	144.5	102.3	224.1
49	165.2	115.2	272.2
50	200.5	135.8	387.6
51	> 200.5	146.1	infinite

Source: Taube *et al.*, (2022).

Appendix 5: In-stream Water Quality Guidelines for Klip River Catchment

In-stream Water Quality Guidelines for the Klip Catchment

Effective: June 2003

Variables	Measured as	Ideal Catchment Background	Acceptable Management Target	Tolerable Interim Target	Unacceptable
Physical					
Conductivity	mS/m	< 80	80 - 100	100 - 150	> 150
Dissolved Oxygen (O ₂)	mg/l O ₂		> 6.0	5.0 - 6.0	< 5.0
pH	pH units	6.0 - 9.0			< 6.0; > 9.0
Suspended Solids	mg/l	< 20	20 - 30	30 - 55	> 55
Organic					
Chemical Oxygen Demand (COD)	mg/l	< 15	15 - 30	30 - 40	> 40
Macro Elements					
Aluminium (Al)	mg/l		< 0.3	0.3 - 0.5	> 0.5
Ammonium (NH ₄ as N)	mg/l	< 0.5	0.5 - 1.5	1.5 - 4.0	> 4.0
Chloride (Cl)	mg/l	< 50	50 - 75	75 - 100	> 100
Fluoride (F)	mg/l	< 0.19	0.19 - 0.70	0.70 - 1.00	> 1.00
Iron (Fe)	mg/l	< 0.5	0.5 - 1.0	1.0 - 1.5	> 1.5
Magnesium (Mg)	mg/l	< 8	8 - 30	30 - 70	> 70
Manganese (Mn)	mg/l	< 1	1 - 2	2 - 4	> 4
Nitrate (NO ₃ as N)	mg/l	< 2	2 - 4	4 - 7	> 7
Phosphate (PO ₄ as P)	mg/l	< 0.2	0.2 - 0.5	0.5 - 1.0	> 1.0
Sodium (Na)	mg/l	< 50	50 - 80	80 - 100	> 100
Sulphate (SO ₄)	mg/l	< 200	200 - 350	350 - 500	> 500
Bacteriological					
<i>E.coli</i>	counts/100ml	< 130	130 - 200	200 - 400	> 400
Faecal coliforms	counts/100ml	< 1,000	1,000 - 5,000	5,000 - 10,000	> 10,000
Biological					
<i>Daphnia</i>	% survival	> 95	95 - 90	90 - 80	< 80

Appendix 5: Canadian Council of Ministers of the Environment-Water Quality Index (CCME-WQI) classes

CCME WQI	Ranking	Water quality characteristics
95-100	Excellent	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.
80-94	Good	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
65-79	Fair	Water quality is usually protected but occasionally threatened or impaired; conditions usually depart from natural or

		desirable levels.
45-64	Marginal	Water quality is frequently threatened or impaired; conditions usually depart from natural or desirable levels.
0-44	Poor	Water quality is always threatened or impaired; conditions usually depart from natural or desirable levels.

Source: Panagopoulos *et al.*, (2022).

Appendix 6: Community survey



University of Limpopo

School of Agricultural and Environmental Sciences
Private Bag X1106, Sovenga, 0727,
South Africa Tel: (015) 268 2202 / 3464

Dear Participants,

My name is Katlego Lennon Mabale, a postgraduate student in the Department of Geography and Environmental Studies, University of Limpopo. I am conducting research titled “An evaluation of the impacts of urbanisation on Klip River Wetland degradation, Johannesburg South.” This study seeks to evaluate physicochemical and biological characteristics of water quality of the Klip River Wetland, assess the community’s perceptions and attitudes on how urbanisation impacts local communities in the vicinity of the Klip River Wetland (KRW) and evaluate factors related to urbanisation in these communities which interact with the degradation of the KRW.

Your identity and other personal information will not be disclosed to third parties or

included in the final draft of the report. The information you submit will be kept private and protected. To ensure that I have all the pertinent information and can double-check its accuracy, I will also record our conversation with your permission. The questionnaire will take 10-20 minutes to complete.

Your patience and time will be highly appreciated.

Should you have any queries regarding the study, do not hesitate to contact me or my

study leaders:

Researcher: Mr. KL Mabale, Email: katlegolennonmabale@gmail.com

Supervisors: Dr. R Akanbi, Email: remilekuntakanbi@gmail.com
Prof. JM Letsoalo, Email: Josephine.letsoalo@ul.ac.za
Ms. MG Montwedi, Email: masego.montwedi@ul.ac.za

COMMUNITY SURVEY

Questionnaire
no.....

Date of
interview.....

Community perceptions and attitudes on how urbanisation impacts the local community.

Close-ended questions

A- Sociodemographic characteristics

1. What is your gender?

Gender	Tick
Male	
Female	

2. How old are you?

Age group	Tick
28-39 years old	
40-49 years old	
50+ years old	

3. What is your highest educational level?

Educational level	Tick
Primary	
Secondary	

Tertiary

No formal
education

4. What is your economic status?

Economic status Tick

Employed

Self-employed

Unemployed

5. What are the drivers of urbanisation in your area?

Drivers of urbanisation Tick

Income

Education

**Health
services**

Uncertain

Open-ended question

6. Kindly explain how urbanisation has impacted on your local community.

Answer:

.....

.....

.....

.....

.....

.....

.....

Appendix 7: Field observations

Field observations
Factors interacting with water quality Tick
Traffic congestion
Mining and industries
Agriculture
Waste
Construction
Wildfires

Appendix 8: Triplicate data set for physicochemical parameters: pH, electrical conductivity (EC), turbidity, dissolved oxygen (DO) and chemical oxygen demand (COD)

Season	Site	Replicate	pH	EC (μ S/cm)	Turbidity (NTU)	DO (mg/L)	COD (mg/L)
Wet	S1	R1	7.74	40.10	3.27	7.20	47.00
Wet	S1	R2	7.20	39.20	2.44	7.10	48.00
Wet	S1	R3	7.02	41.30	2.19	6.90	56.00
Wet	S2	R1	6.14	66.10	60.40	4.40	222.00
Wet	S2	R2	5.96	60.30	37.80	3.20	234.00
Wet	S2	R3	5.92	59.40	64.40	3.70	256.00
Wet	S3	R1	6.91	30.10	2.51	7.40	26.00
Wet	S3	R2	7.02	31.60	2.47	8.10	35.00
Wet	S3	R3	7.04	30.30	2.29	7.80	24.00
Wet	S4	R1	5.55	73.50	70.20	1.30	610.00
Wet	S4	R2	5.77	68.30	58.60	1.10	556.00
Wet	S4	R3	5.66	70.10	78.30	2.10	702.00
Dry	S1	R1	7.68	40.00	1.58	6.70	7.00
Dry	S1	R2	7.45	43.10	1.32	7.10	7.00

Dry	S1	R3	7.89	42.60	2.54	6.90	8.00
Dry	S2	R1	7.73	42.10	37.30	1.80	79.00
Dry	S2	R2	7.71	46.30	38.90	2.10	81.00
Dry	S2	R3	7.62	45.6	43.2	2.3	76
Dry	S3	R1	7.76	41.4	2.85	7.1	0
Dry	S3	R2	7.54	39.0	2.34	7.5	3
Dry	S3	R3	7.64	40.5	1.6	7.8	8
Dry	S4	R1	7.58	67.7	47.3	0.6	195
Dry	S4	R2	7.32	71.3	50.7	1.2	206
Dry	S4	R3	7.21	69.1	48.6	0.9	213

Appendix 9: Descriptive statistics of physicochemical characteristics: pH, electrical conductivity (EC), turbidity, dissolved oxygen (DO) and chemical oxygen demand (COD)

		Mean	Standard Deviation	Minimum	Maximum
pH	Wet	6,52	0,77	5,66	7,32
	Dry	7,59	0,15	7,37	7,68
EC	Wet	50,86	18,57	30,66	70,63
	Dry	49,06	13,66	40,30	69,37
Turbidity	Wet	32,07	34,65	2,42	69,03
	Dry	23,19	24,70	1,81	48,87
DO	Wet	5,03	2,93	1,50	7,76
	Dry	4,34	3,33	0,90	7,47
COD	Wet	234,67	275,14	28,33	622,67
	Dry	73,59	93,96	3,67	204,67

Appendix 10: Descriptive statistics chemical paramters (anions and cations): chloride (Cl⁻), fluoride (F⁻), nitrate (NO₃⁻), and sulphate (SO₄²⁻), cations such as magnesium (Mg²⁺), calcium (Ca²⁺), sodium (Na⁺)

		Mean	Standard Deviation	Minimum	Maximum
Cl ⁻	Wet	43,51	14,12	34,32	64,54
	Dry	44,88	16,56	29,11	68,18
F ⁻	Wet	0,23	0,05	0,16	0,30
	Dry	0,26	0,00	0,25	0,26
NO ₃ ⁻	Wet	3,28	2,71	0,13	6,60
	Dry	2,12	2,50	0,02	5,22
SO ₄ ²⁻	Wet	81,04	8,40	70,23	90,08
	Dry	67,69	36,67	14,11	97,02
Mg ²⁺	Wet	26,46	13,64	17,06	46,72
	Dry	27,76	9,33	21,57	41,63
Ca ²⁺	Wet	48,00	13,50	33,87	66,19
	Dry	47,37	9,07	39,84	60,34
Na ⁺	Wet	35,42	16,89	14,65	55,71
	Dry	37,72	18,26	14,65	59,34

Appendix 11: Descriptive statistics of heavy metals: chromium (Cr), copper (Cu), iron (Fe) and manganese (Mn)

		Mean	Standard Deviation	Minimum	Maximum
Cr	Wet	0,007	0,006	0,001	0,013
	Dry	0,003	0,001	0,002	0,003
	Total	0,005	0,005	0,001	0,013
Cu	Wet	0,004	0,002	0,001	0,006
	Dry	0,002	0,001	0,000	0,003
	Total	0,003	0,002	0,000	0,006
Fe	Wet	0,002	0,002	0,000	0,004
	Dry	0,037	0,047	0,000	0,104
	Total	0,019	0,036	0,000	0,104
Mn ²⁺	Wet	0,002	0,001	0,001	0,003
	Dry	0,120	0,080	0,038	0,227
	Total	0,061	0,082	0,001	0,227

Appendix 12: Descriptive statistics of biological parameters: Escherichia coli (E. coli) and total coliforms

		Mean	Standard Deviation	Minimum	Maximum
<i>E. coli</i>	Wet	153,50	95,00	11,00	201,00
	Dry	156,75	88,50	24,00	201,00
Total coliforms	Wet	201,00	0,00	201,00	201,00
	Dry	201,00	0,00	201,00	201,00

Appendix 13: Pearson's correlation of water quality parameters for wet season

	pH	EC	Turbidity	DO	COD	Cl	F
pH	1						
EC	-.93	1					
Turbidity	-.98*	.98*	1				
DO	.96*	-.99*	-.99*	1			
COD	-.91	.90	.91	-.96	1		
Cl ⁻	-.78	.78	.77	-.86	.97*	1	
F ⁻	-.82	.93	.87	-.94	.95	.92	1
NO ₃ ⁻	.53	-.75	-.63	.74	-.78	-.83	-.93
SO ₄ ²⁻	.97*	-.84	-.91	.92	-.94	-.87	-.80
Mg ²⁺	.47	-.77	-.62	.69	-.60	-.55	-.82
Ca ²⁺	.56	-.80	-.67	.77	-.76	-.77	-.93
Na ⁺	-.78	.93	-.85	-.92	.90	.86	.99**
Cr	.84	-.60	-.75	.66	-.60	-.45	-.38
Cu	.29	-.54	-.45	.39	-.14	.04	-.36
Fe	.29	.01	-.12	.16	-.38	-.48	-.10
Mn ²⁺	-.16	.04	.15	.02	-.25	-.48	-.33
<i>E. coli</i>	-.41	.73	.57	-.62	.50	.43	.75
Total coliforms	. ^b	. ^b	. ^b	. ^b	. ^b	. ^b	. ^b

	NO ₃	SO ₄	Mg	Ca	Na	Cr	Cu	Fe	Mn ²⁺	<i>E. coli</i>	Total coliforms
1											
.54	1										
.89	.35	1									
.97*	.52	.95*	1								
-.94	-.73	-.88	-.96*	1							
0.00	.83	-.05	.02	-.31	1						
.33	.04	.72	.48	-.45	.04	1					
-.04	.52	-.46	-.17	.02	.46	-.83	1				
.59	.01	.27	.47	-.31	-.51	-.42	.30	1			
-.82	-.26	-.99**	-.90	.82	.09	-.80	.58	-.17	1		
.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	1	
.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	1
.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b

*. Correlation is significant at the 0.05 level (2-tailed).

** . Correlation is significant at the 0.01 level (2-tailed).

b. Cannot be computed because at least one of the variables is constant.

Appendix 14: Pearson's correlation of water quality parameters for dry season

	pH	EC	Turbidity	DO	COD	Cl	F	NO ₃	SO ₄	Mg	Ca	Na	Cr	Cu	Fe
pH	1														
EC	-.97*	1													
Turbidity	-.63	.78	1												
DO	.62	-.77	-1.00**	1											
COD	-.89	.97*	.91	-.91	1										
Cl ⁻	-.89	.97*	.81	-.82	.96*	1									
F ⁻	.67	-.49	-.11	.05	.38	-.26	1								
NO ₃ ⁻	.47	-.67	-.93	.95*	-.80	-.78	-.23	1							
SO ₄ ²⁻	.98*	-.96*	-.73	.71	-.93	-.87	.68	.52	1						
Mg ²⁺	.22	-.44	-.65	.70	-.53	-.64	-.57	.88	.21	1					
Ca ²⁺	.45	-.65	-.78	.83	-.73	-.81	-.35	.95	.45	.97*	1				
Na ⁺	-.72	.85	.77	-.81	.86	.95*	.05	-.86	-.68	-.84	-.94	1			
Cr	-.55	.56	.10	-.15	.40	.64	0.00	-.27	-.38	-.48	-.53	.70	1		
Cu	-.04	.20	.22	-.29	.21	.43	.69	-.56	.07	-.87	-.78	.68	.69	1	
Fe	-.91	.98*	.88	-.88	1.00**	.97*	-.38	-.79	-.93	-.54	-.74	.88	.46	.24	1
Mn ²⁺	-.85	.92	.67	-.70	.87	.97*	-.18	-.71	-.79	-.66	-.81	.96*	.80	.56	.90
<i>E. coli</i>	-.23	.43	.57	-.63	.50	.64	.58	-.83	-.18	-.99**	-.95*	.84	.58	.93	.51
Total coliforms	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b	.b

Mn ²⁺	<i>E. coli</i>	Total coliforms
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1	1	
.69		
	.p	.p

- *. Correlation is significant at the 0.05 level (2-tailed).
- ** . Correlation is significant at the 0.01 level (2-tailed).
- b. Cannot be computed because at least one of the variables is constant.