# EFFECT OF WASTE DISPOSAL ON NITRATE AND PHOSPHATE LEVELS IN RALETING DAM, LESOTHO

**BY**

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# ABSTRACT

Surface water quality in urban areas is consistently declining due to the indiscriminate disposal of both liquid and solid wastes. Identifying waste sources and factors increasing nitrate and phosphate levels in potable water bodies is crucial for water resource managers to mitigate nutrient pollution. This study evaluates the effect of waste disposal on nitrate and phosphate levels in Raleting Dam, located in Mafeteng, Lesotho. Fifty-four water samples were collected from nine sampling locations from March to May 2025. All samples were analysed using a HACH DR6000 spectrophotometer. The results indicated that domestic waste and industrial effluents are the primary contributors of nitrate and phosphate in this reservoir, respectively. Results revealed that all water samples had nitrate concentrations that are within the WHO acceptable contamination threshold of 50 mg/L, with an average value of (4.200 ± 1.083) mg/L. Results also revealed that all samples had phosphate levels exceeding the WHO acceptable contamination threshold of 0.03 mg/L, with an average value of (1.620 ± 0.740) mg/L. Higher nitrate concentration levels were exhibited during the wet season compared to the dry season, yielding mean values of 1.987 mg/L and 1.694 mg/L, respectively. In contrast, higher phosphate concentrations were observed during the dry season, compared to the wet season, yielding the mean values of (1.026 ± 0.114) mg/L and (1.003 ± 0.081) mg/L, respectively. There is, however, no positive correlation between nitrate and phosphate levels, hence suggesting a weak relationship between these two parameters. Historically, nitrate and phosphate levels revealed a gradual increase over time. Extensive investigations are further required around the identified pollution hotspots to ascertain the particular sources and facilitate the implementation of corrective actions. Findings from this study raise awareness among water resource managers and policymakers about the significant harm caused by the indiscriminate disposal of waste in this reservoir. The study can therefore serve as a basis from which local authorities and policymakers can formulate and implement waste management strategies in this area. Future research should explore public perceptions of illegal dumping and involve larger sample sizes over different periods for accurate analysis. Prioritizing physico-chemical parameters in future studies is essential for assessing water quality for domestic use.



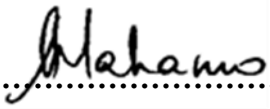
**Keywords**: Raleting Dam, surface water contamination, waste disposal, and nitrate-phosphate concentrations.

## DECLARATION

The work contained in this dissertation was carried out and completed by LEPEKOLA MOETI (201401317) at the National University of Lesotho Water Institute, National University of Lesotho. I hereby declare that this study constitutes my original work and has never been submitted for the award of a degree or diploma to any university. To the best of my knowledge, this dissertation contains no material written by another person except where due reference is made in the dissertation itself.

**Signature**……  …… **Date**……October 2025……

As the candidate's supervisor, I certify the above statement to be correct to my knowledge and have recommended this dissertation for submission.

**Name and Surname**……  …… **Date**……October 2025……

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| | |
|---|---|
| ANOVA | Analysis of Variance |
| DWA | Department of Water Affairs (Lesotho) |
| DWS | Department of Water and Sanitation (South Africa) |
| EPA | Environmental Protection Agency |
| ETC | European Topic Centre |
| DP | Dissolved Phosphorus |
| FAO | Food and Agriculture Organisation |
| GIS | Geographical Information System |
| GPS | Global Positioning System |
| MSW | Municipal Solid Waste |
| NDSO | National Drug Service Organisation |
| NPS | Non-Point Source Pollution |
| NULWI | National University of Lesotho Water Institute |
| PP | Particulate Phosphorus |
| SANS | South African National Standards (South Africa) |
| SD | Standard Deviation |
| SWM | Solid Waste Management |
| SW | Surface Water |
| UNDP | United Nations Development Programme |
| UN | United Nations |
| UNWWD | United Nations World Water Development |
| USA | United States of America |
| US EPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |
| WASCO | Water and Sewerage Company (Lesotho) |
| WHO | World Health Organisation |
| WQ | Water Quality |
| WSPs | Water Safety Plans |

# CHAPTER 1: INTRODUCTION

## 1.1 Background

Surface water is essential for its role in the earth's environment, the global hydrologic cycle, and how it directly affects society through transportation, agriculture, domestic use, and the generation of hydroelectric electricity (Syeed *et al*., 2023). The quantity of freshwater accessible to all living organisms through surface water resources is gradually deteriorating due to the greenhouse effect and human activities (Nweneri *et al*., 2018; Bangani *et al*., 2023). Water quality has a significant impact on the well-being of humans and the overall state of ecosystems.

The increasing decline in water quality stands out as a prevalent and concerning environmental issue, which presents major obstacles to the global community, especially in developing nations grappling with the safety of drinkable or usable water (Custodio *et al*., 2021; Oremo *et al*., 2020). The increasing demand for water supplies poses a serious and pressing threat to water quality (Lin *et al*., 2022; Krishan *et al*., 2023; Kumar, 2018; UNESCO, 2017). As a result, by 2025, over two-thirds of all countries are expected to face water scarcity (FAO, 2024).

Recent studies (Barakat *et al*., 2016; Magna *et al*., 2018; Bangani *et al*., 2023) indicated that the illegal dumping of waste from mining, industrial processes, sewage, household waste, solid waste, land development, and farm drainage into rivers and lakes seriously harms water quality, especially during rainy periods, leading to higher pollution levels. In addition, rapid urbanisation, coupled with advanced technologies and improved living standards, is the principal driver of the rise in waste production (Kurakalva *et al*., 2016; Sultana *et al*., 2021).

The World Bank projected that global solid waste generation would reach between 1.3 billion and 2.2 billion tonnes annually by 2025, with waste collection systems operating at less than 50% efficiency in some regions, leaving large areas vulnerable to contamination (UN Environment, 2017). Studies have demonstrated that water contamination causes health issues, low drinking water quality, depletion of water supply, significant cleanup expenses, and elevated costs for alternative water sources (Harshan *et al*., 2016). In addition, aquatic environment contamination caused by waste disposal is a worldwide issue that could affect people's health (Khan and Ghouri,

2011). Lin *et al*. (2022) reported that around 80 percent of municipal and industrial sewage has been released untreated into water bodies, causing harm to ecosystems and human health.

Issa (2018) found that nutrients (phosphate and nitrate) are among the major frequent contaminants of freshwater worldwide. For that matter, excessive concentrations of these nutrients in aquatic environments may cause aquatic plants, like algae, to grow unnecessarily, inhibiting the growth of other tolerant species. Because of this, when they are carried into the water bodies by surface water runoff, they may change the quality of water (Issa, 2018; EPA, 2015). Concerns about nitrate overexposure have arisen due to its potential negative effects on human and aquatic health (Oremo *et al*., 2019).

According to Yamauchi (2022), waste generation in sub-Saharan African nations is estimated to triple by 2050, increasing from 174 million tonnes in 2016 to 516 million tonnes annually, due to factors including urban population increase, fast urbanisation, the rise of the middle class, changes in production and consumption patterns, and international garbage trafficking and trade. In numerous African nations, the waste collection rate is comparatively low, at under 55%, which raises concerns about the potential for illegal dumping of uncollected refuse (Yamauchi, 2022).

Many people in Sub-Saharan African nations encounter difficulties in getting clean drinking water (WHO, 2017; Szopinska *et al*., 2024). Nigeria and Kenya are among the sub-Saharan African countries that are densely populated, resulting in a detrimental rise in resource usage and waste production, along with a significant decrease in the gathering, handling, and dumping of waste (Selin, 2013; Kumar and Agrawal, 2020). As Amoah and Kosoe (2014) indicated, 810 tonnes of solid garbage are produced every day, which presents significant environmental and public health risks in Ghana.

Seholoholo *et al*. (1998) indicated that about 77,000 tonnes of waste paper and 162,000 tonnes of plastic are produced in Lesotho each year; however, only 1.5% of the paper and 0.6% of the plastic are recovered for recycling. This, in turn, jeopardises water resources. ReNoka (2023) highlighted that plastic pollution is a worldwide catastrophe affecting aquatic ecosystems and human health. UNDP (2021) postulated that rapid urbanisation and increased urban waste generation due to weak

infrastructure often result in poor urban solid waste management. UNDP (2021) further highlighted that approximately 69% of the pollution produced in Lesotho originates from plastic waste that ends up in water bodies.

In most places, contaminated water is the most common and harmful type of environmental pollution. Water pollution is the main contributing factor to the high expenses for water utility corporations like the Water and Sewerage Company (WASCO) in their mandate to provide clean water to the nation (WASCO Strategic Plan, 2020-2025). Raleting Dam is utilised by WASCO for water abstraction for domestic water supply, and it is also an important habitat for aquatic organisms. It also provides ecosystem services to Mafeteng communities and serves as an economic driver through activities such as tourism, weddings, and fisheries.

However, with increasing rural-urban migration, new developments around the dam, encroachment of shacks, agricultural activities upstream, illegal dumping activities in adjacent areas, and sewage discharges into the dam, the water quality of this reservoir can become a major concern for public health and ecological functions. Hence, it is important to understand how waste disposal sites can contribute to higher concentrations of nitrate and phosphate in this reservoir, as such contamination affects both the people living in the urban area and the local ecosystems.

## 1.2 Problem Statement

Raleting Dam, along with Luma Dam, is the key water source for Mafeteng Township. Raleting Dam currently serves as the primary water supply, replacing Raselaba Dam, which has suffered significant siltation, reducing its capacity to about 15% (Motaung and Mahao, 2025; Seboko, 2025; Lesotho Times, 2025; Mochesane, 2025).

The dam is situated downstream from populated areas, and it faces contamination threats from anthropogenic activities like untreated sewage and agricultural runoffs from nearby residential areas, industrial effluents, and rapid development. Consequently, such contamination eventually affects the Raleting's water resources by lowering their quality while also contributing to ecological issues, such as eutrophication.

According to Motaung and Mahao (2025), several incidents of sewage leaking from damaged pipelines and discharging directly into Raleting Dam have recently been reported (Figure 1.1), raising serious concerns about potential contamination. The situation has also been exacerbated by the poor sanitation facilities, while the incidents of contamination alluded to are said to be attributable to the indiscriminate disposal of urban effluents, hence making the dam more vulnerable and putting its water at risk. Therefore, the researcher has deemed it appropriate to conduct a thorough investigation into these issues and work towards addressing them accordingly.

Further, the presence of algal growth at the edges of the dam, as depicted in Figure 1.2, is a clear indication of high levels of nutrients, namely, nitrate and phosphate. In addition, the existence of an illegal dumpsite closer to the dam can significantly influence the concentrations of nitrate and phosphate in this reservoir, and the effect is illustrated in Figure 1.3.

A recent study by Motaung (2020) has shown that in developing nations like Lesotho, inefficient and unsuitable municipal waste management practices can significantly harm the environment and human health. Rising problems, such as overpopulation, changes in consumption patterns, and limited waste disposal facilities (particularly in Lesotho's Lowlands), also raise concerns.

In Lesotho, the improperly planned urban development has led to the indiscriminate disposal of waste materials (including motor car wreckages, paper, plastic, cans, and bottles), and the shortage of the necessary equipment for the collection and transportation of waste has exacerbated the problem (Seholoholo *et al*., 1998). Hence, strong actions need to be taken to improve sanitation and waste management and to ensure compliance with environmental laws. Therefore, this study aims to evaluate the effect of waste disposal on the nitrate and phosphate levels in Raleting Dam.

**Figure 1.1:** Location of Leaking Sewer Line at $29.8^0$ S, $27.4^0$ E (source: Motaung and Mahao, 2025)

**Figure 1.2:** Algal Growth Showing the Eutrophication at the Raleting Dam

**Figure 1.3:** Location of Illegal Dumpsite at Hospital Area Upstream of Raleting Dam

## 1.3 Hypotheses

$H_0$: Nitrate/phosphate levels near waste sites (≤ WHO) Recommended limits.

$H_1$: Nitrate/phosphate levels near waste sites (> WHO) Recommended limits.

## 1.4 Objectives of the Study

The general objective of this study is to evaluate the effect of waste disposal on nitrate and phosphate levels in Raleting Dam.

Our specific objectives are:

i) To determine the levels of nitrate and phosphate near waste disposal sites and across the dam.

ii) To establish the relationship between nitrate and phosphate levels in Raleting Dam.

iii) To identify the potential sources of nitrate and phosphate in Raleting Dam.

iv) To establish trends in levels of nitrate and phosphate using historical data.

## 1.5 Research Questions

This study addresses the following research questions:

i) What are the nitrate and phosphate levels near the waste disposal sites and across the dam?

ii) Is there a link between nitrate and phosphate levels in Raleting Dam?

iii) What are the potential sources of nitrate and phosphate in Raleting Dam?

iv) Does historical data show water quality improving or declining with time?

## 1.6 Significance of the Study

This research provides crucial information to water resource managers, offering insights into the current status of water resources in this dam. This data enables the formulation of effective waste management plans to enhance water quality and ensure safe drinking water for Mafeteng urban communities.

The findings can also assist policymakers by providing evidence-based insights, thus guiding policymakers in developing and revising policies and legal frameworks. This includes aligning the study findings with existing policy objectives, ensuring that policies are informed by scientific evidence. The study's implications extend to creating a reference framework for water resource managers and policymakers to collaborate, ultimately leading to more effective and informed decision-making.

The findings would further help decision makers in establishing measures to combat the effects of improper waste disposal practices near Raleting Dam. It emphasises the link between waste management and public health, calling for better practices to maintain water quality. Therefore, implementing these findings would positively contribute to the sustainability of water resources for drinking and the protection of public health.

## 1.7 Summary

The chapter presented the study by providing a brief introduction to the topic to be studied, as well as presenting the problem statement, hypothesis, and significance. Furthermore, the chapter included the research questions, the study's goal, and the precise objectives that would guide and scope the research.

# CHAPTER 2: LITERATURE REVIEW

## 2.1 Introduction

Surface water quality has emerged as a major environmental issue and a substantial concern for the global population, particularly in developing nations where potable water is scarce (Oremo *et al*., 2020). Because of this, indiscriminate disposal of waste from human activities near water bodies can greatly change their quality, leading to higher levels of nitrate and phosphate that cause eutrophication, which can affect human health and disrupt ecosystems.

This chapter reviews both published and unpublished literature regarding water quality, with a specific focus on the effects of waste disposal on nitrate and phosphate levels in Raleting Dam. It explains the important concepts and terminology related to this research and also provides an outline of the theoretical foundation and conceptual framework, waste disposal, and the impact on surface waters. It also provides a general view of water quality and the elements that influence it. Further, the literature review also examines the levels of nitrate and phosphate in Raleting Dam and identifies the research gaps to justify the study's contributions.

## 2.2 Theoretical Foundation

The study is formulated using the nutrient pollution theory, which encompasses the broader impacts of various pollutants on environmental health. The study specifically emphasises the role of anthropogenic activities in degrading water quality.

Water quality relates to the chemical and biophysical qualities of water, which are assessed according to its intended uses (WHO, 2017). Protected areas effectively conserve biodiversity and sustain ecological health (Xu *et al*., 2022; Dudley and Stolton, 2018). However, due to population density, industrial activity, increased consumption, agricultural production, and urban life, water quality has become a global concern in cities. These factors have resulted in environmental degradation and pollution, which harm life-sustaining water bodies and ultimately threaten human health and social development (Tanor *et al*., 2014).

The scarcity of fresh water is one of the critical challenges facing the world today. Surface water sources such as rivers, dams, lakes, and canals provide approximately one-third of the world's

drinking water supply (FAO, 2024). It is projected that around 25 African nations will face water stress, having less than 1,700 $m^3$ per capita annually, by the year 2025 (Oni and Fasakin, 2016). Chauhan *et al*. (2019) indicate that the decline in potable water quality presents considerable health concerns for a large portion of the population in many developing nations.

Moreover, commercial, industrial, and other human activities generate water pollution *(*Ma *et al*., 2017). With rapid acceleration in urbanisation, there has been a continuous growth in wastewater from industrial output and water contamination (Wu *et al*., 2020; Eneye *et al*., 2025). Further, the presence of nitrogen and phosphorus in aquatic habitats, even in limited amounts, is regarded as a crucial nutrient for algal growth. Therefore, the wastewater, industrial effluents, and household sewage all impact the abundance of these nutrients as phosphates mix with organic nitrogen (Fink *et al*., 2018).

According to Bhat and Qayoom (2021), nutrients such as phosphates and nitrates are prevalent in industrial sewage, which are key factors contributing to eutrophication in aquatic ecosystems. Several freshwater ecosystems worldwide have suffered from eutrophication caused by the discharge of untreated sewage. The growth of algal blooms blocks light from getting to the plants and animals below the surface, making the water less clear and creating a harmful environment that can produce toxins dangerous to many living things.

The industries, agriculture, and domestic wastewater contain organic nitrogen, which negatively impacts aquatic life (Qayoom *et al*., 2020). Therefore, high contents of nitrate intake in water affects the cardiovascular and nervous systems and can lead to gastric cancer (Saleem e*t al*., 2016).

## 2.3 Conceptual Framework Linking Waste and Water Pollution

Rapid economic growth is leading to urbanisation and industrialisation, generating waste that is adversely affecting the environment. “Wastes” are materials that are discarded after use at the end of their intended lifespan. Depending on their source of origin, wastes are classified into: domestic, industrial, agricultural, municipal, and sewage.

Figure 2.1 below provides the link between different sources of waste, their pathways (how they flow into the reservoir), and how they can impact water quality, in particular nitrate and phosphate levels, which can significantly lead to environmental impacts, such as human health and aquatic life.

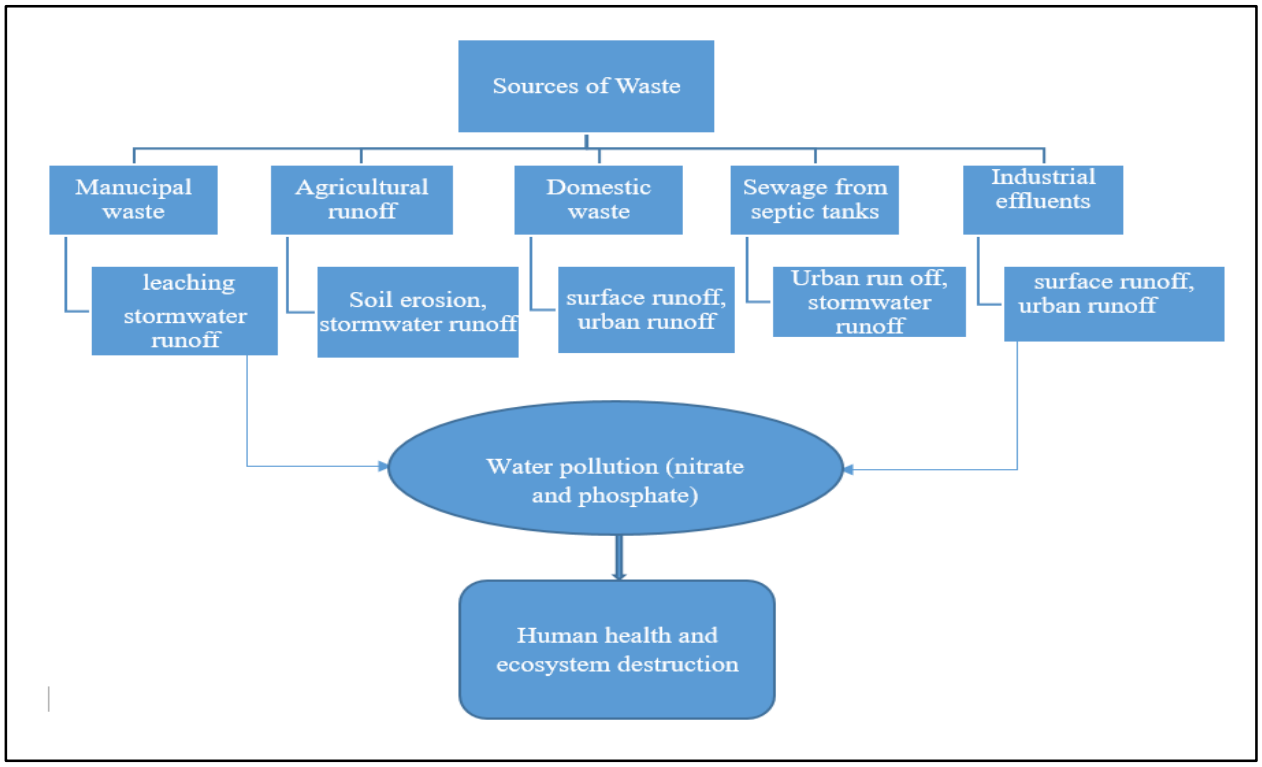


**Figure 2.1:** Conceptual Framework Linking Sources of Waste and Water Pollution

## 2.4 Waste Disposal and Its Effect on the Nitrate and Phosphate in Surface Water

### 2.4.1 Industrial Waste Discharges and Urban Runoff

Industrial effluent is defined as both organic and inorganic contaminants emitted by companies and found in most water sources (Ali and Khan, 2018; Singh *et al*., 2022). The industrial waste contaminates surface and groundwater sources, exacerbating shortages of quality water and threatening both aquatic and terrestrial life with severe health hazards (Howard *et al*., 2016).

In addition, Chowdhary *et al*. (2019) undertook a study focused on the impact of industries on water scarcity and the consequent negative implications for the environment and human health. The investigation revealed that the industrial sector is the primary source of water pollution. The

sectors include distillation, tanning, wood and paper, textiles, processing of food, iron and steel manufacture, and nuclear industries, among others. Industrial production can emit a range of harmful chemicals, including both organic and inorganic substances, toxic solvents, and volatile organic compounds. The discharge of these pollutants into aquatic habitats without adequate cleanup can lead to water contamination.

Gyawali *et al*. (2012) investigated the effects of industrial waste disposal on the U-tapao River's surface water quality in Thailand. The results showed that the water in the U-tapao River, especially near factories, was much more polluted because nearby industries were releasing waste and dirty water without any rules or control. Another study by Sujaul *et al*. (2013) investigated the impact of industrial pollution on the spatial variation of surface water quality. The findings indicated that industrial waste is a significant contributor to pollution, characterised by elevated levels of ammonia-nitrogen.

Chandan *et al*. (2013) conducted a study on identifying the causes, status, and extent of water contamination in the Buriganga River. The findings indicated that both natural processes and human actions, including industrial processes and the use of agrochemicals, have considerably contaminated the river water.

According to Bhat and Qayoom (2021), nutrients such as phosphates and nitrates are prevalent in industrial sewage, which are key factors contributing to eutrophication in aquatic ecosystems. Several freshwater ecosystems worldwide have suffered from eutrophication caused by the discharge of untreated sewage. The growth of algal blooms blocks light from getting to the plants and animals below the surface, making the water less clear and creating a harmful environment that can produce toxins dangerous to many living things.

On the other hand, urban runoff refers to the flow of water, primarily from rainfall or melted snow on impermeable surfaces in urban centres, which does not infiltrate into the ground. Instead, it flows over surfaces and often collects pollutants before entering storm drains, rivers, lakes, or coastal waters (Singh *et al*., 2022; US EPA, 2025). This urban runoff contains contaminants such as soil, pesticides, and fertilisers that originate in urban areas and have an impact on water quality

(Popoola *et al*., 2019; Khaniya *et al*., 2021; Riva *et al*., 2019). These impermeable surfaces in urban settings produce five times more runoff than in wooded areas, and urbanisation can potentially increase the type and volume of contaminants transported to water bodies (Winston *et al*., 2016). In addition, pollutants such as silt, road salt, viruses, germs, hazardous substances from autos, and thermal pollution from non-porous surfaces, such as cemented and paved roads, can harm wildlife and contaminate water supplies (Winston *et al*., 2016).

Furthermore, urban activities directly impact water quality in hydrographic basins, as effluents often enter streams without undergoing any treatment process. The primary contamination pathways involve both direct and indirect exposures to treated and untreated sewage, runoff, air deposition, and pollution. The quality of surface water has been recognised as an important concern in most nations, particularly because of apprehensions over water shortages. To conserve this vital resource, a monitoring program for both surface and groundwater is necessary (Pesce and Wunderlin, 2000; Marques *et al*., 2012).

Wondie (2009) investigated the impact of urban stormwater runoff and domestic waste effluent on the water quality of Lake Tana and local groundwater near Bahirdar, Ethiopia. The study period yielded significant findings. The runoff gathered from regions housing hotels and various commercial establishments exhibits an elevated concentration of nitrogen and phosphorus, which are present in excessive amounts and contribute to the eutrophication of the lake.

### 2.4.2 Domestic Waste

Domestic waste, whether liquid or solid, generated by domestic activities such as cleaning, cooking, disposing of garbage, and bathing, has indirect or direct consequences on human well-being and socioeconomic implications for human well-being (Gutberlet and Uddin, 2017). Wastewater is generated by our daily activities, encompassing food preparation, toileting, bathing, and washing (Milla *et al*., 2012). Further, greywater and backwater flow out from household places with piped water, as well as business premises and residential establishments, such as schools and healthcare institutions (Stuart *et al*., 2011).

Sidabutar *et al*. (2017) studied the effects of anthropogenic activities on the decline of water quality. The study concentrated on how human activities along the riverbank in an urban setting affect raw water quality. The water along the riverbank has been contaminated as a result of human activities, including domestic practices like cooking, bathing, and washing, in addition to dumping and the release of wastewater from households into the river's waters. Further study by Hobbie *et al*. (2017) revealed that pet waste generated from household garbage is a substantial source of nitrogen and phosphorus in urban water.

### 2.4.3 Municipal Solid Waste (Illegal Dumpsite)

Municipal Solid Waste (MSW) is defined as any undesired or wasted substance that is neither a liquid nor in a gaseous state. This umbrella term encompasses a diverse array of materials often disposed of by families, enterprises, and industries (Dehghani *et al*., 2021). The composition includes different types of waste based on where they come from and their features, such as municipal solid waste, industrial waste, hazardous waste, agricultural effluent, electronic waste, mining waste, and organic waste. This waste causes considerable dangers to human health and the environment due to its toxicity, mutagenic characteristics, and carcinogenic potential (Zhu *et al*., 2021).

Indiscriminate dumping of solid waste, particularly unlawful dumping, can cause considerable air and water pollution, land degradation, climate change, and health hazards due to the long-term accumulation of harmful substances. Thus, it endangers human and animal health, environmental sustainability, and economic development (Gebrekidan *et al*., 2024). Nevertheless, significant progress in industrialisation has led to a rapid increase in both the world economy and population (Ally *et al*., 2024).

The increase in human actions associated with life and production has, unfortunately, resulted in a notable rise in both water shortage and contamination (Yang *et al*., 2023). Consequently, nitrogen and various contaminants are present in numerous water resources globally, resulting in an increasing trend of eutrophication (Salem *et al*., 2023).

Letsie (2005) investigated the water quality of the Maqalika Reservoir as a source of potable water for Maseru City, Lesotho. The water quality measurements exceeded the permissible limits, and the contaminants are linked to the dumpsite; hence, a researcher made a recommendation that studies should be conducted to check the link between the dam and the dumpsite as far as water quality is concerned.

Another study by Bangani *et al*. (2023) focused on assessing the impact of solid waste on water quality along the Mthatha River in both rainy and dry seasons. The water quality at the monitoring locations near the indiscriminate disposal sites deteriorated more significantly during monsoonal periods and moderately during low flows. The findings suggested that illegal disposal locations near water bodies adversely affect water quality.

Recently, Raphela *et al*. (2024) studied the impact of improper waste disposal on human well-being and the environment in Umgungundlovu District, KwaZulu-Natal Province, South Africa. The findings revealed ramifications linked to indiscriminate waste disposal, encompassing effects on human health, environmental degradation, and the financial burdens related to cleanup and infrastructure maintenance. The findings also reported that indiscriminate disposal of waste has both short-term and long-term effects that hinder community development.

Njewa *et al*. (2025) studied the effects of dumpsites on air, soil, and water contamination in five selected Southern African countries. The main focus was on the problems and suggestions from five Southern African countries, each facing different issues with landfill pollution due to a mix of environmental, economic, and health factors: South Africa, Zimbabwe, Botswana, Zambia, and Malawi. These findings indicated that landfills and open dump sites pose significant hazards to both surface and groundwater resources. They recommended implementing policies to govern and manage landfills to reduce their environmental impact.

### 2.4.4 Agricultural Runoff

Pesticide residues are introduced into surface waters mostly by agricultural runoff. Common pesticides, such as DEET (N, N-diethyl-meta-toluamide), DDT (dichloro diphenyl trichloroethane), metolachlor, and malathion, have long contaminated water systems (Firozjaee *et*

*al*., 2017). In addition, pesticides exhibit toxicity and can induce harmful effects on living organisms, even in trace quantities (Yadav *et al*., 2022).

Agriculture constitutes 70% of global water usage and is the primary source of non-point source pollution impacting surface waters. Agricultural intensification often results in increased soil erosion, increased salinity, elevated sediment loads in water bodies, and excessive fertiliser applications intended to boost productivity. Agricultural pollution can contaminate water sources (FAO, 2017; FAO, 2021).

Additionally, farmers utilise nutrients in their farmlands through the use of inorganic fertilisers and animal wastes, providing crops with essential nitrogen and phosphorus for agricultural productivity. Plants may not fully absorb nitrates and phosphates, leading to their significant loss from agricultural regions and a negative impact on the quality of downstream water. Therefore, high levels of nitrates and phosphates may leach from agricultural fields into streams during precipitation events and snowmelt. High levels of nitrate and phosphate can also lead to eutrophication in aquatic ecosystems, causing fish mortality and a reduction in biodiversity (US EPA, 2015).

**Table 2.1:** Summary Table for Comparison of Nitrate and Phosphate Sources

| Parameter Present | Sources | References |
|---|---|---|
| Nitrate and Phosphate | Industrial effluents | Dehghani *et al*. (2021), Gebrekidan *et al*. (2024), Bhat and Qayoom (2021), Chowdhary *et al*. (2019) |
| | Urban runoff (wastewater) | Singh *et al*. (2022), US EPA (2025), Popoola *et al*. (2019), Khaniya *et al*. (2021), Riva *et al*. (2019), Wondie (2009), Winston *et al*. (2016) |
| | Domestic wastewater (households/residential wastewater) | Stuart *et al*. (2011), Hobbie *et al*. (2017), Sidabutar *et al*. (2017), Milla *et al*. (2012) |
| | Agricultural runoffs (Fertilisers, pesticides) | Firozjaee *et al*. (2017), Yadav *et al*. (2022), EPA (2015), Dehghani *et al*. (2021), FAO (2017 and 2021), Abbott *et al*., 2018, UNEP (2021) |
| | Municipal solid waste | Dehghani *et al*. (2021), Gebrekidan *et al*. (2024), Zhu *et al*. (2021), Letsie (2005), Bangani *et al*. (2023), Njewa *et al*. (2025) |
| Nitrate | Industrial effluents | Stets *et al*. (2015), Liu *et al*. (2022), Qu *et al*. (2025), WHO (2011), Jin *et al*. (2017) |
| Phosphate | Agricultural runoffs (fertilisers from farmland) | Duan *et al*. (2011), Wang *et al*. (2021), Hillary and Kipngetich (2012), USGS (2018), Holman *et al*. (2008), Razman *et al*. (1999), Jin *et al*. (2017), Qu *et al*. (2025 |

## 2.5 Water Quality and Factors Affecting Water Quality

Water quality is defined by its chemical, physical, and biological contents (Makinde *et al*., 2015). The availability of high-quality water is a crucial element in disease prevention and enhancement of quality of life (Sharma *et al*., 2016; Chakroborty *et al*., 2017). Both natural and anthropogenic

factors influence water quality, with geological, hydrological, and climatic elements having the greatest impact (WHO, 2011).

Human actions, such as industrial, urban, and agricultural practices, negatively impact water quality. The increase in consumption and demand exerts pressure on the water resources due to different activities, eventually compromising the water quality. Geology and the impacts of climate change have the potential to exert natural influences.

### 2.5.1 Natural Factors

#### 2.5.1.1 Geology

The field of geology, a discipline under natural science, examines the Earth, other celestial bodies, the rocks that constitute them, and geomorphology, which refers to the processes that induce alterations in those rocks over time. Therefore, water-rock interactions have a substantial influence on water quality. The geology of a region influences the quality of its water supplies. The main types of rocks and soil in a given area usually influence the chemical and physical properties of the water above and below ground; thus, geogenic variables are just as significant as human activities in determining the overall quality of water resources (Baba and Gunduz, 2017).

This area has been the subject of numerous studies; for example, a study on water quality was conducted, collecting 189 samples from 63 monitoring stations to assess water resource quality and its correlation with human health. The results showed that water taken from weathered volcanic rocks, which are mostly used for drinking, has a relatively low pH, high electrical conductivity, and higher levels of trace elements (Baba and Gunduz, 2017).

#### 2.5.1.2 Climatic Change Conditions

Ludwig *et al*. (2007) conducted a global analysis of climate change during the previous century, noting an annual average temperature increase of approximately 1°C in the Arctic and a rise of 2 to 3°C elsewhere. By 2100, the mean global surface temperature is estimated to rise by 1.5 to 5.8°C. We anticipate a wide array of alterations due to rising worldwide temperatures.

These variations in temperature and precipitation patterns are expected to increase the frequency, duration, and intensity of many extreme weather events, including floods, droughts, heat waves, and tornadoes, having a considerable impact on water quality. Climate change impacts practically all nations, particularly developing ones, which are more vulnerable to calamities like catastrophic floods, droughts, storms, and heatwaves due to their insufficient financial resources to implement adaptation strategies for these natural disasters (Ludwig *et al*. 2007).

Climate conditions, such as temperature, have a crucial impact on surface water composition and hydrological dynamics. The European Topic Centre (ETC) Technical Report 2010 indicated that flooding due to intense rainfall might compromise water quality, as substantial water volumes may carry pollutants into aquatic systems and overwhelm stormwater and wastewater infrastructure. Further, the floods might compromise water quality by allowing runoff to collect animal waste, pesticides, and fertilisers as it moves across agricultural lands.

In urban areas, floodwaters laden with toxins and other pollutants may overwhelm sewage systems, resulting in untreated sewage flowing directly into waterways. The presence of bacteria, viruses, and cysts like cryptosporidium in drinking water can lead to outbreaks of diseases spread through water, while higher levels of toxic pollution can have both immediate and long-lasting effects on people and aquatic environments (Van Vliet *et al*., 2023). The combination of elevated surface water temperatures as well as increased nutrient intake from agricultural runoff may exacerbate the occurrence of algal blooms in rivers and lakes, hence negatively impacting ecosystems.

Conversely, droughts can lead to reduced water levels, concentrating pollutants and decreasing the dilution capacity of water bodies, which in turn can exacerbate water quality issues, particularly in terms of increased concentrations of contaminants (Van Vliet *et al*., 2023). Although flooding facilitates immediate ecosystem recovery, it does not indicate an end to deterioration or a reversal of anticipated long-term dry conditions due to elevated temperatures or drought (Ludwig *et al*., 2007). The growing need for water to meet human demands poses an increasingly serious threat to biodiversity in floodplains.

Moazeni *et al*. (2025) did a study to explore climate change by looking at climate and water quality data in the Zayandeh-Rud River area over 14 years. They analysed the data to see how climate change affected water quality and found that the number of freezing days, along with the average, minimum, and maximum temperatures, has risen, while some water quality measures went down during the study. Additionally, Adam *et al*. (2024) carried out a review that looked closely at how climate change affects water quality, assessing what we currently know, pointing out important findings, areas where more research is needed, and what studies should be done next. The review emphasises the importance of considering climate change in water management decisions and highlights opportunities for adaptation and mitigation strategies to protect water resources.

### 2.5.2 Anthropogenic Factors

#### 2.5.2.1 Agricultural Land Use

Non-point sources of contaminants, such as runoff from agricultural and urban areas, represent the predominant contributors to global water quality impairment (Lintern *et al*., 2020; Patterson *et al*., 2013). Additionally, farming activities greatly add to non-point source pollution because using fertilisers and pesticides leads to nitrates and phosphates washing into nearby rivers, which then causes too many nutrients to build up and lowers oxygen levels in the water.

The UNEP (2021) stated that farming methods add too many nutrients, like nitrates and phosphates, to water because of fertiliser and pesticide runoff, which causes problems like eutrophication and algal blooms in water bodies. Moreover, intensive agriculture exacerbates soil erosion, leading to increased sedimentation that degrades water clarity and habitat quality (Tong *et al*., 2020). In sub-Saharan Africa, unsustainable farming practices further amplify these impacts, often linked to limited access to conservation techniques (Ncube *et al*., 2020).

Among the various pollutants in city and farm runoff, phosphorus (P) and nitrogen (N, particularly as nitrate N, $NO_3^-$-N) are some of the most frequently mentioned chemicals that often go over safe limits for protecting water resources (Abbott *et al*., 2018). Higher phosphorus losses from farming areas are linked to increased phosphorus in the soil from years of using fertilisers and manure, with a lot of the phosphorus in farm streams found in solid particles.

In comparison, the nitrogen in agricultural runoff usually comes from dissolved inorganic $NO_3^-$-N and is often linked to fertilised farmland (Stets *et al*., 2015; Liu *et al*., 2022). The variations in source attribution present an issue for water safety preservation because the best management methods will only be effective if they target the proper source. The dynamic nature of human land use complicates water resource protection even more, with urban growth and agricultural intensification being the leading causes of persistent water quality deficiencies around the world (Brooks *et al*., 2016; Paerl *et al*., 2018; Basu *et al*., 2022).

In 2021, Dick-Sagoe *et al*. (2021) studied the impact of smallholder farmers on water contamination in designated rivers and streams in Lesotho. The findings indicate that farmers predominantly apply agrochemicals and fertilisers, including manure, due to a lack of alternative strategies to protect their livelihoods from the adverse effects of climate change. Farmers often neglect the use of agrochemicals and manure slurries, which leach contaminants and pose risks to aquatic environments and human health. The proximity of their farms to water bodies increases the likelihood of water pollution during heavy rainfall.

In addition, Chatanga *et al*. (2019) detected signs of nitrate and phosphate in the Mohokare River in Lesotho, attributing this to significant leaching of agricultural fertilisers and agrochemicals into the region's water bodies. In conclusion, farmers possess insufficient information regarding the application of agrochemicals on their farms since they rely on personal experience rather than receiving the necessary instruction on the use of fertilisers and agrochemicals. Coupled with this challenge are the low levels of formal education among these farmers.

#### 2.5.2.2 Urbanization and Population Growth

Urbanisation is a broad form of land use and land cover change that is spreading quickly around the world (Paul and Meyer, 2001; Muller *et al*., 2019). It entails turning wetlands, pastures, meadows, woodlands, croplands, and other land cover types into commercial, industrial, residential, and transportation uses, hence increasing the number of impermeable surfaces (Tsegaye *et al*., 2006; Khatri and Tyagi, 2014).

MacGregor-Fors (2011) pointed out that urban centres serve many different purposes, including the size of the population, the total number of people, and specific infrastructures like housing, schools, impermeable surfaces, and the level of non-agricultural economic activities, while also mentioning that the terms used can vary around the world. Therefore, impermeable surfaces are observable elements that strongly connect with increases in contaminated runoff sources, lowering water resource quality (McGrane, 2016).

Population growth and urbanisation have increased pressure on both ecosystems and the aquatic environment. Industrial operations have been advanced to satisfy population growth demands, which may result in wastewater and emissions into the environment (Chen *et al*., 2018; Estrada-Revera *et al*., 2022). Moreover, this accelerated growth in urban areas fosters the emergence of urban slums and unregulated communities in numerous growing African cities and towns. Informal communities typically lack adequate sanitation and waste management systems (Kasinja and Tilley, 2018).

The amount of waste generated by each person in these slums may be relatively lower, but the total amount of waste increases because of population growth and urbanisation. Furthermore, it has been discovered that activities associated with urbanisation raise the levels of phosphorus, nitrogen, alkalinity, and overall dissolved solids in surface waters (Boyer *et al*., 2002; Gergel, 2005).

In addition to changing stream shapes and decreasing biodiversity, degraded streams and rivers that drain urbanized landscapes frequently have increased nutrient and pollution levels (Meyer *et al*., 2005). Improperly planned urbanisation or uncontrolled development may cause such changes (Pompeu and Alves, 2005). This trend has been made evident by the research conducted by Hongmei Bu and colleagues on the Jinshui River in China, where they stated that the majority of the water quality measures were significantly impacted by the population (Bu *et al*., 2016).

A study based on a regional perspective found a positive association between human activity and the decline of a river's water quality when looking at how urbanisation and water quality

parameters relate to one another spatially. Additionally, the impact of urbanisation is assessed using urban population density (Zhao *et al*., 2013).

Recently, Liyanda *et al*. (2017) investigated how population increase affects the water quality of natural water resources. The findings revealed that highly populated areas have the poorest water quality, medium-populated areas have average water quality, and less populated areas have less serious water quality issues. Further, population density was identified as a primary contributing variable that needs to be well monitored to prevent the massive decline and deterioration of the aquatic ecosystems.

## 2.6 Nitrate and Phosphate Levels in Surface Water

### 2.6.1 Phosphates

Phosphorus is a crucial nutrient for plant growth; however, excessive concentrations can lead to water quality concerns. It is a crucial component for plant life; however, excess concentrations in water can accelerate eutrophication, resulting in detrimental algal proliferation that adversely affects aquatic organisms (Jin *et al*., 2017). Razman *et al*. (1999) asserted that phosphorus predominantly exists as phosphate in nature, although in aquatic environments, it can manifest in several forms, including soluble reactive phosphate and total phosphorus. Phosphates in water are the principal source of excessive nitrates. USGS (2018) found that phosphorus levels in water can indicate the health of the water body and the aquatic ecosystem.

Moreover, high levels of phosphate and nitrate in aquatic environments are the primary cause of eutrophication (Duan *et al*., 2011; Wang *et al*., 2021; Hillary and Kipngetich, 2012). Phosphorus is a crucial limiting nutrient in aquatic environments; hence, it is critical to study its concentrations in water bodies and their effects on the aquatic ecosystem and species (Holman *et al*., 2008).

Furthermore, eutrophication leads to low oxygen levels in water, which can harm aquatic life since low oxygen levels lead to fish kills. It also causes turbidity in water and shifts in plant and animal populations. The amount of particulate phosphorus (PP) is calculated by subtracting the dissolved phosphorus (DP) from the total phosphorus (TP) (Qu *et al*., 2025). Possible targets for regulation include animal manure, commercial fertilisers, and soil erosion.

### 2.6.2 Nitrates

Nitrates ($NO_3^-$) are a chemical indicator of water quality because high levels are susceptible to causing water to become unsafe for drinking and can harm aquatic life (Qu *et al*., 2025). Nitrate-rich effluents released into receiving waters lower the water quality by promoting the growth of algae. Drinking water with high nitrate levels (MCL = 10 mg/L) might induce baby methemoglobinemia (blue babies), although nitrite concentrations rarely surpass 0.1 mg/L (WHO, 2011). Excess nitrates and phosphorus cause algae to grow rapidly, which can change the types of plants and animals living in the water; this, in turn, leads to the depletion of dissolved oxygen that can be toxic to warm-blooded animals (WHO, 2011).

Nitrate sources include fertilisers, where excessive use of nitrate-based fertilisers results in elevated nitrate levels in water, and improperly treated or untreated sewage contributes nitrates to the environment. Wastes from certain industrial processes, such as textiles, paper, and munitions manufacturing, can release untreated water with nitrates into the environment. Monitoring nitrates in water, methods such as the spectrophotometric method can be used to measure the content of nitrates in water. Color comparators can be employed to select areas with high nitrate concentrations (Jin *et al*., 2017).

## 2.7 Water Quality Requirements

Water quality guidelines are crucial for safeguarding public health and mitigating pollution across many water applications, including potable water, agriculture, industry, recreation, and ecological preservation. This study will concentrate on the objectives of drinking and aquatic habitats. These requirements correspond with public interest and legal frameworks to protect water integrity (EPA, 2012). Currently, the country's water quality standards are in the developmental stage (Fichtner Water and Transportation, 2013); therefore, it depends entirely on the South African water quality standards (SANS 241:2015) and the WHO water quality guidelines for drinking water (WHO, 2011).

### 2.7.1 South African National Standard for Drinking Water (SANS 241-1:2015)

The Republic of South Africa governs water quality standards for domestic use via the South African National Standards (SANS:2015). SANS 241 (2015) selected the permissible standards for potable water according to four criteria: microbiological, physical, aesthetic, and chemical. Consequently, water that complies with these guidelines is deemed to present an acceptable health risk for lifelong consumption. The potential dangers linked to these determinants are classified into four groups:

1) Acute health risks
2) Chronic health risks
3) Aesthetic concerns
4) Operational factors

### 2.7.2 Department of Water and Sanitation (DWS) Water Guidelines

South Africa's Department of Water and Sanitation (DWS) is in charge of developing and implementing water policies. The South African Water Quality Guidelines divide water use into four major categories: residential (drinking, cooking, bathing, gardening, and laundry), industrial, agricultural (agriculture, irrigation, and livestock drinking), aquatic ecosystems, and recreational uses. They assess each category based on its fitness for use, classifying it as ideal (100% safe), acceptable, tolerable (for limited periods), unacceptable, or completely unfit.

The water quality parameters should align with or exceed the target requirement for water quality set by DWS to ensure safe usage (DWS, 1996). These guidelines specify microbiological, physical, and chemical determinants, although some elements, such as boron, phosphorus, and nickel, lack national guideline values. In such cases, international standards, such as the WHO water quality standards, are referenced. A risk-based method, which includes Water Safety Plans (WSPs), has been used to ensure safe potable water from its origin to when it's used, moving the focus from just checking at the end to managing risks ahead of time (Dunn *et al.*, 2014; Figueras and Borrego, 2010).

### 2.7.3 World Health Organization (WHO) Drinking Water Guidelines

The WHO provides international standards for drinking water quality, serving as reference points for establishing national standards. However, individual countries have the right to develop their regulations based on specific needs (EPA, 2012). Water quality criteria are defined as permissible levels of substances in water to ensure safe and sustainable use. While some parameters have maximum allowable limits to prevent harm, others require minimum concentrations to support biological functions, such as dissolved oxygen (WHO, 2010).

The WHO has been actively formulating guidelines, but recently, a more inclusive approach involving the formulation of water safety plans (WSPs) has progressed. WSPs acknowledge all elements that may jeopardise the quality of water from its origin to the tap, rather than solely assessing the ultimate drinking water quality (Figueras and Borrego, 2010). Consequently, Water Safety Plans (WSPs) are founded on a holistic risk evaluation methodology to guarantee the provision of safe potable water (Dunn *et al*., 2014).

Therefore, monitoring of surface water quality should be maintained below or within the permissible limit before it reaches the end user, thus ensuring that it complies with the set standards by WHO as well as SANS 241-1:2015 to avoid any harm to human health and aquatic life. According to the WHO's (2010) drinking water quality guidelines, the permitted maximum for nitrate and phosphate levels in surface waters is 50 mg/L and 0.03 mg/L, respectively. However, the SANS 241-1 (2015) has set an acceptable limit for nitrates at 11 mg/L, but does not explicitly specify a maximum allowable limit for phosphates in its specifications.

## 2.8 Research Gap

A review of the literature indicates that there is little to no data on specific freshwater resources, particularly regarding how waste disposal practices influence nitrate and phosphate levels in the Raleting Dam in Lesotho. Hence, this study is intended to fill this gap by evaluating the seasonal variations and trends in nitrate and phosphate concentrations and the effects of waste disposal on nitrate and phosphate concentrations in this reservoir.

Available data for that particular dam primarily comes from newspaper reports (Lesotho Times, 2025). This provides previously unavailable water quality data for Raleting Dam. So monitoring of nitrate and phosphate levels is imperative to gather basic information and have baseline data that would enable policymakers and water managers to develop effective water resources management plans and to protect aquatic life in this area.

When sampling, the researcher looks into cognizance of the evolution of water pollution with seasons to determine how seasonal variations affect the levels of nitrate and phosphate in this reservoir. Hence, proper waste management around this dam is highly encouraged to ensure that water security is maintained.

## 2.9 Summary

The chapter briefly described the theoretical foundation and outlined and reviewed various literature topics that are relevant for addressing the stated research objectives. It can be noted that various studies have highlighted the significant contribution of different waste disposal practices to the nutrient levels in water and the importance of understanding how the natural and anthropogenic factors influence the surface water quality. The chapter further discussed the importance of nitrate and phosphate levels in surface water and how excessive concentrations of nutrients in water bodies can affect the water quality.

The chapter also discussed the water quality standards and guidelines that guide a certain acceptable limit for domestic and aquatic ecosystem purposes. Lastly, the chapter indicated how time is important in the concentrations of nitrates and phosphates in water resources and highlighted the gaps that the study should fill as a way of improving water quality in this reservoir.

# CHAPTER 3: RESEARCH METHODOLOGY

## 3.1 Introduction

This chapter provides a brief description of the study area and outlines the materials and methods, as well as the sampling techniques and tools, to be used in fulfilling the study's goal and objectives. This chapter will be divided into six main sections, such as Section 3.2, which describes the study area; Section 3.3, which discusses the study design; and Section 3.4, which discusses the sampling technique in Section 3.4. Section 3.5 will describe sample size determination. Section 3.6 will delve into the data requirements, while Section 3.7 will discuss steps for achieving each objective of this study. Section 3.8 will deepen the discussion of data collection procedures, while the remainder of Section 3.9 will address laboratory analysis. Furthermore, sections 3.10, 3.11, and 3.12 will discuss data analysis, ethical considerations, and provide a summary of the study's chapter, respectively.

## 3.2 Description of the Study Area

Raleting is a relatively large dam with a surface area of 25 hectares; however, its capacity is very low because of a high siltation rate and the presence of a 4-hectare woodlot that divides the dam into two sections: the upper part and the lower part. However, its upper storage level has seemed to be below 2.5 m deep because fishermen were seen catching small catfish in that shallower part of the dam without using the nests. This dam is located in the northeast part of the Mafeteng township area, which is around 76 km south of the country's capital, Maseru (Tilquin and Lechela, 1995; Lesotho-Geography, 2011).

Moreover, this dam is located at S 29°48'31" / E 27°24'40", approximately 1500 metres above sea level (Lesotho-Geography, 2011). Furthermore, Lesotho recognises this impoundment as a rare natural, water-related environment. It is most likely fed by springs and represents community interactions; for example, villagers in the vicinity use it for animal drinking, fishing, and domestic purposes, such as drinking, washing, and bathing (Tilquin and Lechela, 1995), as shown in Figure 3.1.

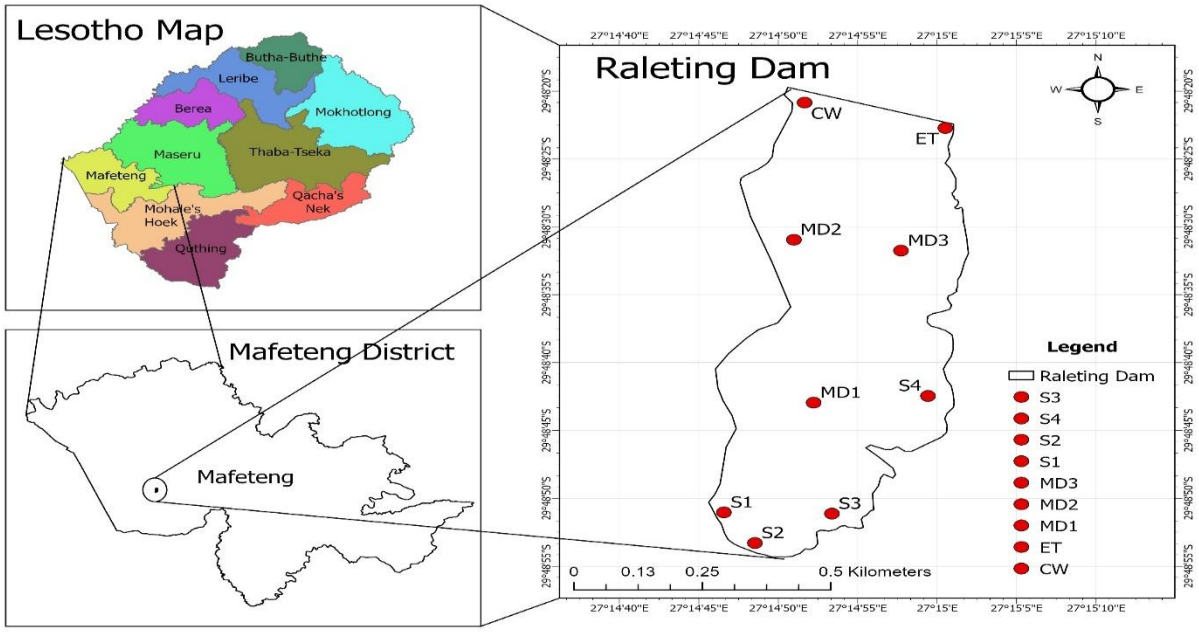


**Figure 3.1:** Map of Sampling Points in Raleting Dam, Mafeteng, Lesotho

## 3.3 Study Design

This study adopted a quantitative research approach that combines field observations and experimental techniques to identify potential sources of waste disposal, determine the best sampling locations for surface water samples, and collect relevant primary data. These methods benefit this study by acquiring more relevant information to address the research questions outlined in the earlier chapters, contributing to an understanding of how waste disposal affects the water quality of Raleting Dam. The sample size was determined by examining existing waste disposal sites and randomly selecting points along the dam (upstream, midstream, and downstream), and water was collected from nine locations (S1-S4, MD1-MD3, CW, ET) using a grab sampling method to gather at least fifty-four water samples over three months (March, April, and May 2025) to ensure the analysis is robust.

## 3.4 Sampling Technique

This study used a grab sampling technique to identify and choose sampling sites, ensuring that the samples accurately represented the Raleting reservoir. This method is simple and can be employed to collect samples from various sites within the dam at different intervals to evaluate fluctuations in nitrate and phosphate concentrations (*Abbasi et al*., 2018).

This technique is better than composite sampling because it lets you take samples from specific places over a set time, allowing for different sampling rates at one location over time (Sunar *et al*., 2018); therefore, this technique is suitable for this study to address the outlined research questions and to collect several water samples at a single point at several times.

When using the grab sampling technique, a large number of samples from a particular site must be collected from a specific site several times (Piniewsk *et al*., 2019). Moreover, grab samples collected over time must accurately reflect the water conditions at the moment of sampling, unlike composite samples, which should represent the water conditions during the period of composite sampling averages (Sunar *et al*., 2018).

## 3.5 Sample Size Determination for a Reservoir

According to Singh and Masuku (2014), sample size determination is the technique of selecting the number of observations to incorporate in a sample. The sample size is a critical aspect of any study or investigation aimed at drawing inferences about the population from a sample. The sample size in a study is generally decided by the expense of data collection and the need for adequate statistical power.

USGS (2018) emphasized that sample size determination for a reservoir depends on the size and homogeneity, as well as the geomorphological characteristics of the water body. If the water body is well-mixed, multiple grab samples from different locations within the water body are necessary to get a better picture of the water quality.

To determine the sample size of Raleting Dam. The field observation was done by the research team at the site to get the overall analysis of the area, such as morphological features, the topography, the existing disposal practices (see Table 3.1 below) upstream, and their pathways into the reservoir before the sampling process. The choice of sampling points was based on the accessibility and consideration of the upstream (baseline/control), which is the inflow streams into the reservoir, midstream (consideration of the air current/mixing occurrence), which is divided into two sections and the downstream to check the quality of water leaving the reservoir

(consideration of settling of water at the downstream), were used to select sampling points, as depicted on the Figure 3.1.

The other factors that were carefully considered were the expected margin of error (confidence interval), confidence level, variability, and statistical power in order to make this research efficient and accurate. The margin of error indicates the range within which the true population parameter is expected to fall. Hence, a smaller margin of error requires a larger sample size. The confidence level reflects how certain the researcher is that the population parameter lies within the margin of error.

Statistical power is the likelihood that the study will detect an effect if there is one. Theoretically, the standard for power is usually 80%, meaning there is an 80% chance of finding a statistically significant result if the hypothesis is true.

According to Memon *et al*. (2020), the choice of the right sample size actually stems from accuracy, generalizability, and efficiency. A well-determined sample size minimizes errors and improves the accuracy of results. The larger sample sizes increase the likelihood that the results can be generalized to the overall population, and hence, the researcher also has to ensure that the sample size is neither too small nor too large, as this helps to manage time and resources efficiently.

Further, in this study, the researcher was comfortable with a margin of error of ±5%, needed a smaller sample than a margin of error of ±2%, and even chose the confidence level of 95% (5% margin of error), which, however, required a smaller sample size to be certain of the results. There was less variability and high homogeneity in samples, which allowed for a smaller sample. Based on this reasoning, the sample size in this study was fifty-four (54), which is considered to be relatively small. Lastly, the sampling frequency of six weeks was chosen based on the research goal and to have representative water quality conditions of the reservoir.

## 3.6 Data requirements

This study relied on both primary and secondary data sources to address the research questions outlined in earlier chapters. The steps for achieving each objective have been presented in Figure 3.2.

### 3.6.1 Field Observation

A preliminary field observation was done to have an overview of the existing situation in the area before embarking on the identification of sampling locations and commencement of the data collection process. Additionally, the objective was to identify potential waste disposal sites and the types of waste disposal practices that are being used in the dam, as these may affect the water quality and assist the researcher in determining the best locations for collecting primary data.

### 3.6.2 Secondary Data

Secondary data was obtained from the Water and Sewerage Company's (WASCO) database for 10 years of water quality monitoring at Raleting Dam (January 2015–December 2024) to identify trends in nitrate and phosphate levels using historical data. This data was typically used to understand the history of nutrient pollution in the reservoir and to see if water quality has improved or declined over time.

## 3.7 Methodology

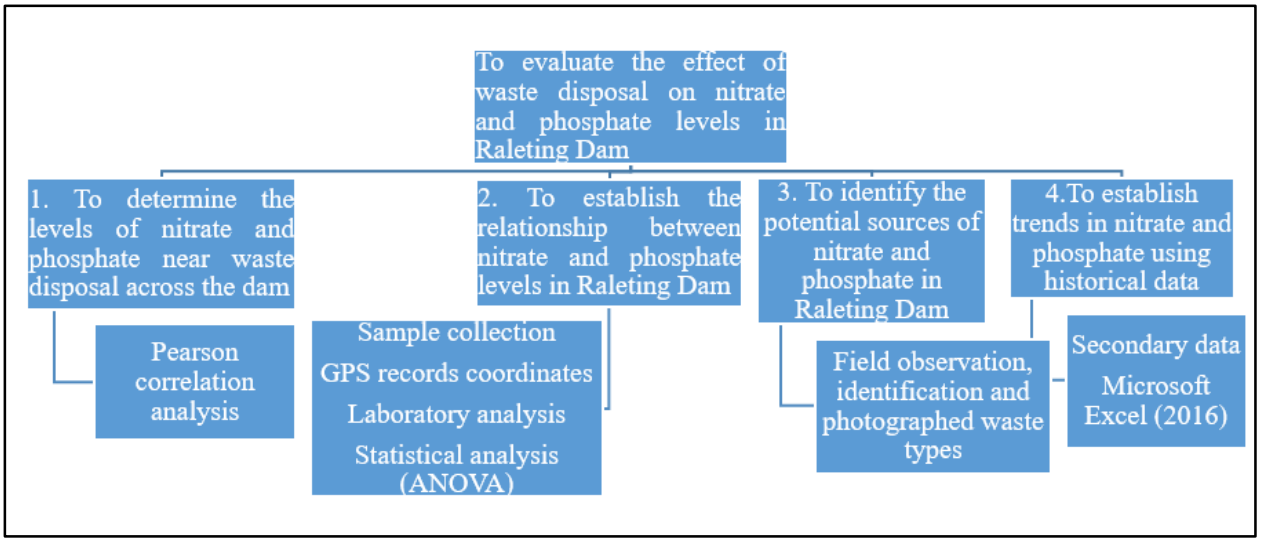


**Figure 3.2:** Flow Chart Showing the Steps to Achieve the Study's Objectives

## 3.8 Data Collection Procedures

### 3.8.1 Location and Descriptions of Sampling Sites

The current study aimed to identify the potential sources of nitrate and phosphate levels in Raleting Dam. Before selecting sampling locations and beginning the data collection process, the study team went to the reservoir to gain an understanding of it. The current characteristics and waste disposal practices were photographed, and the GPS was used to record the coordinates at each sampling location for future reference. Human activities near the Raleting Dam, such as constructing a taxi rank upstream, farming and livestock keeping, new shops and shacks, commercial activities (food and garbage), urban and industrial effluents discharged directly into the reservoir, illegal dumping of solid waste, and upstream inflow streams from waste sites, were used to select sampling sites.

Table 3.1 lists sampling stations S1, S2, S3, S4, MD1, MD2, MD3, CW, and ET with their selection criteria. S1, S2, S3, and S4 are upstream of Raleting Dam, which runs adjacent to waste disposal sites' inflow streams, including illegal dumpsites (solid waste below Hospital Area), hotels and shacks (leaking septic tanks and food waste from shacks near the hotel), industries and supermarkets (effluents and leaking sewer pipelines adjacent to the NDSO), and their locations provide baseline water quality, notably nitrate and phosphate concentrations impacted by waste disposal practices.

The other three sample stations (MD1, MD2, and MD3) are located in the middle of the dam, with MD1 at the top and MD2 and MD3 below the woodlot that separates the reservoir. The selection of waste disposal sites determines their ability to reduce pollution. The CW is located downstream of the dam, close to the WASCO water intake point (where water is taken to be stored in a reservoir before being sent to the treatment plant), to compare nitrate and phosphate levels with data from the 10-year WASCO database to see if water quality has improved or declined. Finally, ET along the spillway serve the same purpose as midstream sampling sites.

**Table 3.1:** Description of Sampling Sites in Raleting Dam[a]

| Sample ID | Description | GPS Coordinates | | Elevation (m) |
|---|---|---|---|---|
| | | **Latitude** (°S) | **Longitude** (°E) | |
| S1 | An illegal dump site of solid waste beneath the Hospital Area | 29.81401 | 27.24601 | 1647 |
| S2 | Effluents from the leaking sewer line and food waste from the nearby hotel and shacks | 29.81489 | 27.24674 | 1634 |
| S3 | Industrial effluents from two leaking septic tanks below and behind NDSO, and urban runoffs | 29.81424 | 27.24825 | 1642 |
| S4 | Domestic effluents from nearby communities (Motse-Mocha, Thabaneng) | 29.81149 | 27.24979 | 1643 |
| MD1 | Mid-point located at the upper part of the dam | 29.81275 | 27.24721 | 1635 |
| MD2 | Mid-point located at the lower part of the dam (NW) | 29.80855 | 27.24749 | 1640 |
| MD3 | Mid-point located at the lower part of the dam (NE) | 29.8099 | 27.24962 | 1640 |
| CW | Sampling point closer to the water abstraction point in the reservoir | 29.80566 | 27.24962 | 1645 |
| ET | Sampling point near the spillway | 29.80624 | 27.25023 | 1649 |

See Figure 3.1.

### 3.8.2 Sample Collection, Storage, and Preservation

To determine the concentrations of nitrates and phosphates near waste disposal sites and across the dam. Surface water samples were collected in March, April, and May 2025. A total of fifty-four (54) water samples were taken upstream, midstream, and downstream from nine sampling sites. Samples were collected at the confluence of the input streams in the dam (upstream),

midstream, and downstream. Generally, six samples were obtained from each location. Samples were collected biweekly for three consecutive months (March, April, and May 2025). Six sampling events were conducted; four occurred during high rainfall in March and April, while two took place during low rainfall in May, illustrating the impact of seasonal variability on nutrient levels. Samples were obtained using a 1L plastic bottle, filled to the brim approximately 30 cm beneath the surface. The sampling vials were securely sealed with a plastic stopper and maintained in a 4 °C cool box for transport to the Department of Water Affairs laboratory for chemical analysis.

Sampling vials were accurately labelled with the sample's ID, date, time of collection, and the collector's name and were rinsed three times with reservoir water before sampling to avoid contamination. The Global Positioning System (GPS) was employed to record the coordinates and elevations, which were then coded in ArcGIS for the visualisation of sampling sites on the region map. Upon delivery to the laboratory, the samples were stored at 4 °C and analysed within 48 hours of collection using the HACH (2019) Method 8039 and Method 8048 for nitrate and phosphate, respectively. The samples were then placed in the Labcon oven at 25 °C for at least one hour to keep them at room temperature, and were tested for nitrate and phosphate using UV-VIS spectrophotometry standard procedure equivalent to US EPA (2018) for drinking water analysis.

Moreover, Muchiri (2021) used this method in a study titled "The Potential Use of Kilibwoni Bubbling Spring Water in Nandi County, Kenya". This method is superior to other methods because it is a pre-programmed testing method with high-speed wavelength scanning capability across the UV-Vis spectrum, resulting in more accurate results and automatically preventing errors. Furthermore, the method provides high sample throughput, high-resolution mass spectrophotometry, and a high level of interference control.

Ten years' historical data were acquired from the Water and Sewerage Company (WASCO) database, starting from January 2015 to December 2024. This data was compared with current data collected during the study period (March 2025-May 2025) to ascertain whether the water quality in this reservoir has improved or deteriorated over time.

## 3.9 Laboratory Analysis

### 3.9.1 Determination of Nitrate

Nitrate ion concentrations were determined using a HACH DR6000 UV-Vis spectrophotometer. The HACH DR6000 spectrophotometer was set up by setting the program to (355 N, Nitrate Reagent HR PP), with a wavelength of 500 nm. A 10 mL sample was put into a sample cell, and one NitraVer 5 nitrate reagent powder pillow was added. The entire mixture was allowed to react for one minute before closing the sample cell and shaking its contents to facilitate dissolution.

A five-minute subsequent reaction time was set until an amber color developed, indicating the presence of nitrate in the water sample. A blank water sample was placed in a separate sample cell for instrument calibration; subsequently, the sample was inserted into the cell holder, and the nitrate concentration measurement was recorded. This procedure is an acceptable version of EPA Method 365.1 (2018) for drinking water analysis, illustrated in Figure 3.3 below.

### 3.9.2 Determination of Phosphate

Phosphate ion concentrations were determined using a HACH DR6000 UV-Vis spectrophotometer. The HACH DR6000 spectrophotometer was set up by selecting the appropriate program at (490 P, total/AH PV TNT), with a wavelength of 880 nm. A 10 mL water sample was put into the sample cell, and one PhosVer 3 powder pillow was introduced into the test vial. The batch was then permitted to react for 30 seconds.

The container was thereafter capped, and the contents were thoroughly mixed. After the 30-second reaction period, the vial was placed into the cell holder. A blank water sample was put in an individual sample cell, and the instrument reading was calibrated to zero (0.00 mg/L $PO_4^{3-}$). A response time of 2 minutes was set, and the sample was subsequently measured within 8 minutes following the expiration of the reaction period. Then recorded the contents in mg/L $PO_4^{3-}$. This procedure is an acceptable version of EPA Method 365.1 (2018) for drinking water analysis, illustrated in Figure 3.3 below.

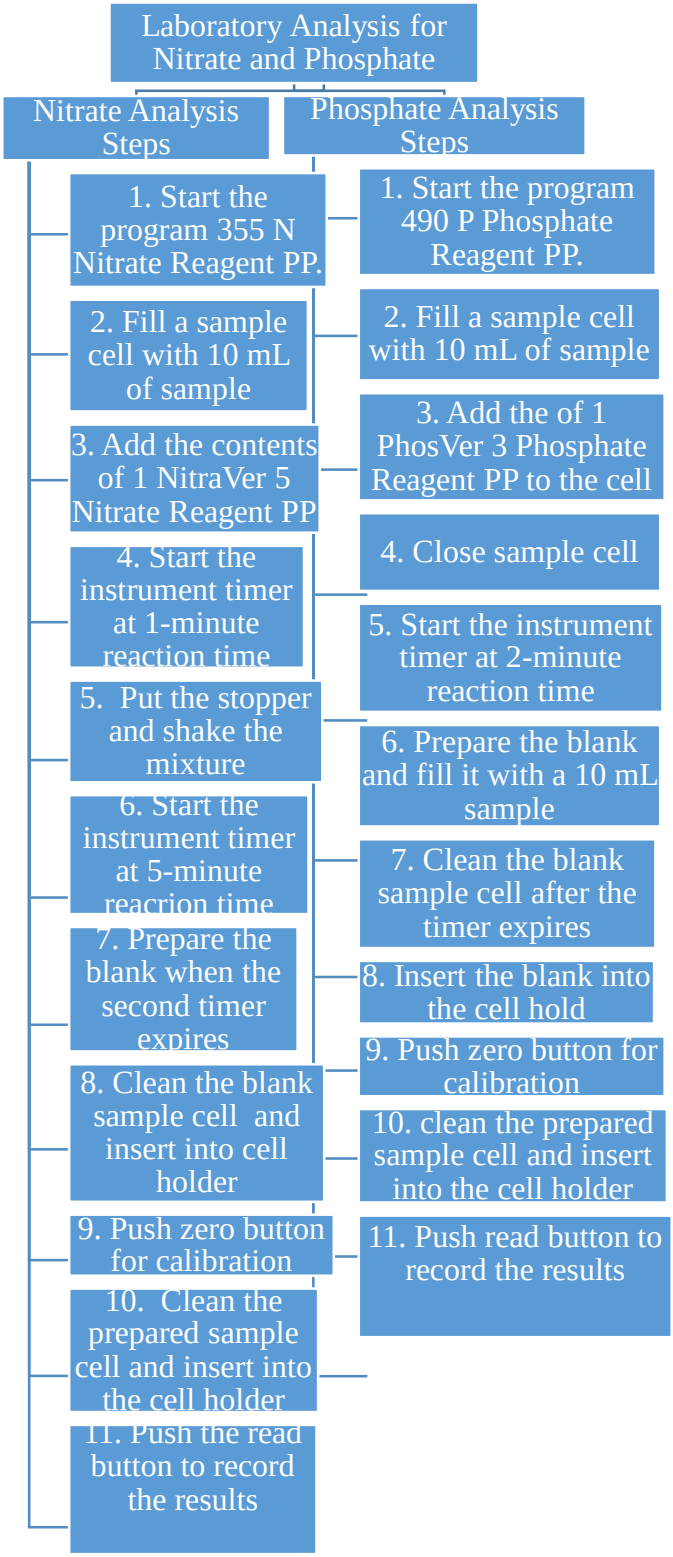


**Figure 3.3:** Flow Chart Showing Laboratory Procedure for Nitrate and Phosphate

## 3.10 Data Analysis

All the data gathered from lab tests for nitrates ($NO_3^-$) and phosphates ($PO_4^{3-}$) were examined using the Statistical Package for Social Sciences (SPSS) software (v.29.0) with a 5% significance level for the analysis (Raphela *et al*., 2024). The analysis of variance (ANOVA) using the General Linear Model (GLM) was used to analyse data, through which the Least Squares Difference (LSD) procedure was used to compare the differences between waste types and seasons.

Pearson correlation analysis was used to see if there was a significant correlation between nitrates and phosphates in water samples (Oremo *et al*., 2020). To analyse the 10-year historical data supplied from the Water and Sewerage Company (WASCO) database, Microsoft Excel (v. 2016) was used to check if there are any trends in nitrate and phosphate levels from January 2015 to December 2024, with a significance level of 0.05. The work was done to determine whether the water quality of this reservoir had improved or declined with time, thereby determining the annual variability in nitrate and phosphate levels.

### 3.10.1 Experimental Model for Data Analysis

The model used for the analysis of the effects of waste types and season on nitrate and phosphate concentrations was presented by the formula below:

$$Y_{ijkl} = \mu + R_i + S_j + \sum_{ijkl}$$

Where Yijkl = dependent variables (nitrate and phosphate concentrations)

$\mu$= Overall mean

$R_i$= $i^{th}$ effect of the waste type i = 1, 2, 3

$S_j$ = $j^{th}$ effect of the season, 1,2

$\sum_{ijkl}$ = random residual error

## 3.11 Ethical Considerations

The National University of Lesotho (NUL) Research Office, in partnership with the NUL Water Institute (NULWI) Office, provided the clearance for the commencement of the study. Authorisation to undertake the study in this reservoir was granted by the Water and Sewerage Company (WASCO), which is the responsible authority for monitoring water quality at Raleting Dam. The local chief also approved access to sampling sites.

## 3.12 Summary

The chapter presented a detailed description of the study area and the research design and explained the chosen approach for the study. The chapter clearly described the sampling technique used, data collection methods and procedures, and the rationale behind their adoption. Additionally, the researcher presented the data analysis methods and obtained ethical clearance.

# CHAPTER 4: RESULTS AND DISCUSSION

## 4.1 Introduction

This chapter presents measured nitrate and phosphate levels in surface water to evaluate waste disposal at Raleting Dam. It analyzes results using statistical methods, aligns with research questions, and compares findings to WHO and SANS standards. Additionally, it summarizes implications for health risks and aquatic life, emphasizing eutrophication effects, and connects findings to previous studies.

## 4.2 Concentrations of Nitrate and Phosphate in Drinking Water

### 4.2.1 Nitrate and Phosphate Concentrations in Surface Water

Table 4.1 below represents the mean and the standard deviation (SD) of nitrate and phosphate levels in surface water. In a short-term study conducted over a period of three months, 9 different sampling sites from Raleting Dam, Mafeteng, were monitored.

For nitrate concentration, the results showed a range of 0.10-14.50 mg/L, with an average mean value of 1.8893 mg/L and a standard deviation of 2.11618 mg/L, indicating a greater variability in nitrate concentrations among sampling sites. The increase in nitrate could be linked to farming activities, such as the use of fertilized from the farmlands upstream of the reservoir. These findings are comparable to those of Mamum *et al*. (2024), who found that nitrate-rich fertilisers and animal manure from farming operations were the cause of comparatively high nitrate levels.

Contrary to the nitrate concentrations, phosphate levels ranged between 0.27 and 2.84 mg/L, with a mean contamination value of 1.0109 mg/L and a standard deviation of 0.48000 mg/L, suggesting a smaller variation in phosphate concentrations among the sampling sites.

**Table 4.1:** Nutrient Concentrations in Surface Water

| Descriptive Statistics | Nitrate (mg/L) | Phosphate (mg/L) |
|---|---|---|
| Mean | 1.8893 | 1.0109 |
| SD | 2.11618 | 0.48000 |
| CV% | 4.478 | 0.230 |
| Minimum | 0.10 | 0.27 |
| Maximum | 14.50 | 2.84 |

SD = standard deviation; CV (%) = coefficient of variation; Number of samples =54

### 4.2.2 Effect of Season on Nitrate Levels in Surface Water

Table 4.2 shows the differences in average nitrate ($NO_3^-$) levels in surface water samples taken from nine (9) locations during both the wet and dry seasons from March 2025 to May 2025. These results showed that nitrate levels were higher in the wet season, averaging (1.987 ± 0.502) mg/L, compared to (1.694 ± 0.355) mg/L in the dry season ($p > 0.05$), suggesting that seasonal changes had little effect on nitrate concentration (Table 4.2). The coefficient of determination ($R^2$) value of 0.551 shows that 55% of the changes in nitrate concentration are explained by the seasons, while the remaining 45% might be influenced by other factors or unexpected situations.

This increase in nitrate during the wet season could be attributed to the heavy downpours that occurred in Mafeteng township during the wet season (March and April 2025). This indicates that runoff has the potential to transport pollutants into water bodies during heavy rainfall. These findings, however, are in agreement with the results of Barco *et al*. (2008), who reported higher nitrate concentrations during the rainy season in the upper Arroyo Seco watershed in California, USA, especially following storms preceded by dry intervals.

These results were expected, especially during high rainfall. This is particularly true for agricultural activities, such as the application of animal wastes and fertilisers, which require water to transport them from one place to another. Relevant studies by Nhapi (2009) revealed that runoff from field crops in the UNCA was a significant contributor to the amount of nitrate washed into Lake Chivero. Sardessai and Sundar (2007) also found higher nitrate concentrations during the monsoon season due to runoff.

**Table 4.2:** ANOVA Results for the Effects of Season on Nitrate Levels in Surface Water

| Season | Mean ± SE | 95% Confidence level | |
|---|---|---|---|
| | | Minimum | Maximum |
| Dry | 1.694[a] ± 0.502 | 0.686 | 2.703 |
| Wet | 1.987[a] ± 0.355 | 1.274 | 2.700 |

[ab] Significant difference in nitrate levels between wet and dry seasons ($p<0.05$, $R^2$ = 0.551, Adjusted $R^2$ =0.449).

[a] Insignificant difference in nitrate levels between wet and dry seasons ($p>0.05$, $R^2$=0.551, Adjusted $R^2$ =0.449).

### 4.2.3 Effects of Waste Types on Nitrate Levels in Surface Water

Nitrate ($NO_3^-$) levels in surface water from nine different types of waste are presented in Table 4.3. The highest amount of nitrate was found at the domestic waste site (S4), with an average of 4.200 mg/L, while the dumpsite (S1) had the lowest average of 1.083 mg/L. This suggests that domestic waste, like soap and waste from uncovered toilets in nearby homes, is likely the main reason for the higher nitrate levels at the domestic site (S4), as shown in Figure 4.1. These results match what Nyamangara *et al*. (2008) found below residential areas.

Wondie (2009), who reported increased nitrate concentration in monitoring sites near households, also observed similar results. The massive increase in nitrate concentration at this site (S4) is an indication that the presence of small urban farming activities, both livestock rearing and crop production within and near the residential sites, could be the major contributors to nitrate pollution in Raleting Dam. Oremo *et al*. (2020) also agreed with these findings and said that the nitrate levels found in all the water samples likely came from human activities, like farming with fertilisers and wastewater being released directly into the environment during runoff.

Moreover, Midstream-1 was found to have the second-highest levels of nitrate ($NO_3^-$), with a mean value of 2.150 mg/L, and it was detected just downstream of a leaking septic tank (S3) (Figure 4.2) and food waste near the hotel, as well as from urban sweepers. The high levels of nitrate found in these waste types near industries, downstream from farmland, and next to leaking septic tanks are seen as the main reasons for nitrate pollution in Raleting Dam. A recent study by Gao *et al*.

(2024) reported that agricultural runoff and domestic sewage discharge (Figure 4.1) were the predominant contributors to pollutant loads, and in particular nitrogen loads.

These findings also match those from Chatanga *et al*. (2019), who found that higher levels of nutrients like nitrate and phosphate in the Mohokare River were due to runoff from farms, urban areas, sewage ponds, and the textile industry in Maseru. Even though there is no big difference between the types of waste ($p>0.05$), the small rise in average nitrate levels found downstream from where waste is disposed suggests that these methods might be significantly adding to nitrate pollution in this reservoir. If left unaddressed, this accumulation could put water resources at risk.

Furthermore, the denitrification process that might have occurred during the study period could account for the nitrate fluctuations observed within different types of waste. Similarly, Kiirikki *et al*. (2006) found that higher levels of nutrients like nitrate, averaging ($2.07 \pm 0.01$) mg/L, were caused by human activities from homes, farming, and city sources.

Based on the results, the null hypothesis ($H_0$), which states that nitrate levels near waste sites are less than or equal to the WHO recommended limits ($\leq$ WHO), has been accepted, while the alternative hypothesis ($H_1$), which states that nitrate levels near waste types exceed the WHO recommended limits (> WHO), has been rejected. In the same way, Sa'id and Mahmud (2013) found that nitrate levels from all the places they tested were lower than the highest allowed limit for drinking water set by WHO (2010) at 50 mg/L and also below the South African National Standard (SANS 241:2015) limit of 11 mg/L or less.

**Table 4.3:** ANOVA Results for the Effects of Waste Types on Nitrate Levels in Surface Water

| Number | Waste Type | Sample ID | Mean ± SE | Minimum | Maximum |
|---|---|---|---|---|---|
| 1 | Dumpsite | S1 | 0.083 [a] ± 0.848 | -0.624 | 2.790 |
| 2 | Sewage at the hotel site | S2 | 2.103[a] ± 0.848 | 0.396 | 3.810 |
| 3 | Industrial site | S3 | 1.883[a] ± 0.848 | 0.176 | 3.590 |
| 4 | Domestic site | S4 | 4.200[a] ± 0.848 | 2.493 | 5.907 |
| 5 | Mid-stream1 | MD1 | 2.150[a] ± 0.848 | 0.443 | 3.857 |
| 6 | Mid-stream2 | MD2 | 1.100[a] ± 0.848 | -0.607 | 2.807 |
| 7 | Mid-stream3 | MD3 | 1.483[a] ± 0.848 | -0.224 | 3.190 |
| 8 | Abstraction site | CW | 1.633[a] ± 0.848 | -0.074 | 3.340 |
| 9 | Exit point | ET | 1.367[a] ± 0.848 | -0.340 | 3.074 |

[ab] Significant difference in phosphate levels between wet and dry seasons ($p<0.05$, $R^2 = 0.551$, Adjusted $R^2 = 0.449$).

[a] Insignificant difference in nitrate levels between wet and dry seasons ($p>0.05$, $R^2 = 0.551$, Adjusted $R^2 = 0.449$).

**Figure 4.1:** Domestic Wastewater Upstream of Residential Areas and Agricultural Effluents (S4)

**Figure 4.2:** Urban Runoff and Industrial Effluents Upstream of Site (S3)

### 4.2.4 Effects of Season on Phosphate Levels in Surface Water

Table 4.4 below represents the mean concentrations of phosphate during both wet and dry seasons for the period of three months (March-May 2025). Unlike nitrates ($NO_3^-$), which were found in greater amounts during the wet season than the dry season (Table 4.2), phosphate levels appeared to be marginally higher in the dry season compared to the wet season (Table 4.4), with an average mean of (1.026 ± 0.114) mg/L and an average mean of (1.003 ± 0.081) mg/L. The coefficient of determination ($R^2$) value of 0.417 shows that 42% of the changes in phosphate concentrations were caused by the independent variables (season and waste type), while the other 58% were due to different factors or unexpected situations.

The low phosphate concentration seen in the wet season rather than the dry season can be attributed to the dilution effect from the high-intensity rainfall observed in March and April 2025 (Table 4.4). Similar results were also observed by Suteja and Purwiyanto (2018), who reported the lowest phosphate concentration during the wet season, attributing it to significant water dilution in the river.

The results also indicated that phosphate levels in all water samples stayed the same throughout the seasons, which is higher than the 0.05 level of significance, suggesting that seasonal variations in this area did not have a major impact on phosphate concentrations (Table 4.4). However, the farming done by small urban farmers and the wastewater from sewer pipes that flowed into the reservoir did not show much change in phosphate levels during both the rainy and dry seasons (Table 4.4). A similar study by Sardessai and Sundar (2007) reported that phosphate concentration observed during river runoff was not significantly different from that recorded from the mouth of estuaries during low flows.

**Table 4.4:** ANOVA Results for the Effects of Season on Phosphate Levels in Surface Water

| Season | Mean ± SE | 95% confidence level | |
|---|---|---|---|
| | | Minimum | Maximum |
| Dry | 1.026[a] ± 0.114 | 0.797 | 1.255 |
| Wet | 1.003[a] ± 0.081 | 0.841 | 1.165 |

[ab] Significant difference in phosphate levels between wet and dry seasons ($p>0.05$, $R^2 = 0.417$, Adjusted $R^2 = 0.141$).

[a] Insignificant difference in phosphate levels between wet and dry seasons ($p<0.05$, $R^2 = 0.417$, Adjusted $R^2 = 0.141$).

### 4.2.5 Effects of Waste Types on Phosphate Levels in Surface Water

Analysis of water quality data was also used for evaluating the effects of different waste types on phosphate levels in water samples, and the results are presented in Table 4.5. The waste types, such as the industrial site (S3) and the hotel sewage site (S2) (Figure 4.3), had the highest average phosphate levels at 1.620 ± 1.198 mg/L, which is located just below the level from industrial discharge (Figure 1.1), while the dumpsite (S1) had a lower average phosphate level of 0.740 mg/L, located downstream from the illegal dumpsite (Figure 1.3). The results showed no major differences in phosphate levels in any of the water samples, indicating that the leaking septic tank at the hotel site (S2) and the industrial discharge site (S3) could be the main sources of phosphate pollution in this reservoir.

These results are in line with those recorded by Wondie (2009), who reported that the highest phosphate concentration was from industrial, urban runoffs, and domestic waste, possibly due to sewer pipes. There are noticeable differences in phosphate levels from various types of waste (Table 4.5) that are likely due to farming activities, such as animal raising and crop growing, happening upstream of the reservoir, which could be the main reason for the higher phosphate levels in this reservoir. Additionally, the increase in algae and other water plants (Figure 1.2) suggests that dumping household waste and farming activities upstream may be leading to more growth of these plants and algae, which lowers the levels of dissolved oxygen.

Overall, the phosphate levels in all water samples are above the safe limit of 0.03 mg/L set by the WHO (2010), with an average level of (1.620 ± 0.740) mg/L (Table 4.6). Based on the results, the null hypothesis ($H_0$), which states that phosphate levels near waste sites are less than or equal to the WHO recommended limits (≤ WHO), has been rejected, while the alternative hypothesis ($H_1$), which states that phosphate levels near waste types exceed the WHO recommended limits (> WHO), has been accepted. Similarly, Sa'id and Mahmud (2013) reported that phosphate concentrations from all water samples exceeded the maximum contamination level according to the WHO (2010) water quality standards set for drinking water at a level of 0.03 mg/L.

**Figure 4.3:** Sewage from Leaking Pipelines beneath the Hotel Upstream of Site (S2)

**Table 4.5:** ANOVA Results for the Effects of Waste Types on Phosphate Levels in Surface Water

| Number | Waste type | Sample ID | Mean ± SE | Minimum | Maximum |
|---|---|---|---|---|---|
| 1 | Dumpsite | S1 | $0.740^{a} \pm 0.181$ | 0.376 | 1.104 |
| 2 | Sewage at the hotel site | S2 | $1.198^{a} \pm 0.181$ | 0.834 | 1.563 |
| 3 | Industrial site | S3 | $1.620^{a} \pm 0.181$ | 1.256 | 1.984 |
| 4 | Domestic site | S4 | $0.755^{a} \pm 0.181$ | 0.391 | 1.119 |
| 5 | Mid-stream1 | MD1 | $1.067^{a} \pm 0.181$ | 0.702 | 1.431 |
| 6 | Mid-stream2 | MD2 | $0.863^{a} \pm 0.181$ | 0.499 | 1.228 |
| 7 | Mid-stream3 | MD3 | $0.963^{a} \pm 0.181$ | 0.599 | 1.328 |
| 8 | Abstraction site | CW | $0.973^{a} \pm 0.181$ | 0.609 | 1.338 |
| 9 | Exit point | ET | $0.862^{a} \pm 0.181$ | 0.463 | 1.261 |

[ab] Significant difference in phosphate levels between wet and dry seasons ($p>0.05$, $R^2 = 0.417$, Adjusted $R^2 = 0.141$).

[a] Insignificant difference in phosphate levels between wet and dry seasons ($p<0.05$, $R^2 = 0.417$, Adjusted $R^2 = 0.141$).

## 4.3 The Relationship between Nitrate and Phosphate Levels in Surface Water

Table 4.6 and Figure 4.4 explore the correlation between nitrate and phosphate levels in surface water. Hence, the Pearson correlation test was employed to determine an association between specified parameters. The correlation coefficient (r-value) was used to assess the relationship between the specified parameters at a 5% probability level ($\alpha = 0.05$).

The results from testing the quality of surface water ($NO_3^-$, $PO_4^{3-}$) were used to look at the relationship between these nutrients in the water. The correlation coefficient (r) values vary from -1 to +1; hence, r = 0 indicates no correlation between two variables, whereas r = -1 and r = +1 represent a perfect negative and perfect positive link, respectively. Strong correlation coefficients are defined as $r > 0.7$, whereas values between 0.3 and 0.7 indicate moderate correlation and a weak positive linear association between 0 and 0.3 (Ratner, 2009).

The Pearson correlation of 0.025 (r = 0.025) is very close to zero, indicating almost no linear relationship between nitrate and phosphate, as well as a very weak positive relationship (Table 4.6). Additionally, the relationship is insignificant (P = 0.857; hence, P > 0.05), suggesting that there is no strong evidence of a relationship between nitrate and phosphate in this reservoir during the study period.

This implies that managing one pollutant might not significantly affect the other. It further indicates that sources and processes affecting nitrate and phosphate, such as agricultural runoff, wastewater discharge, or industrial activities, vary independently or are influenced by different environmental factors. This knowledge is crucial for targeted water quality management strategies. For example, focusing on nitrate reduction might not reduce phosphate levels, thus necessitating separate management approaches for each parameter.

Tarus (2017) observed similar results, reporting a positive, insignificant correlation between nitrate and phosphate. The nitrate and phosphate in this area originate from domestic wastes, municipal solid waste, industrial wastewater from leaking sewer lines (Figure 1.1), and agricultural activities upstream of the reservoir.

However, these results obtained are in contrast with several studies that have been undertaken. For example, a study by Oremo *et al*. (2020) reported a strong positive relationship (r = 0.942, p = 0.000), implying that both nitrate and phosphate originate from similar sources or are influenced by the same factors, such as agriculture. This also indicated that nitrate and phosphate have similar factors affecting their levels in this reservoir.

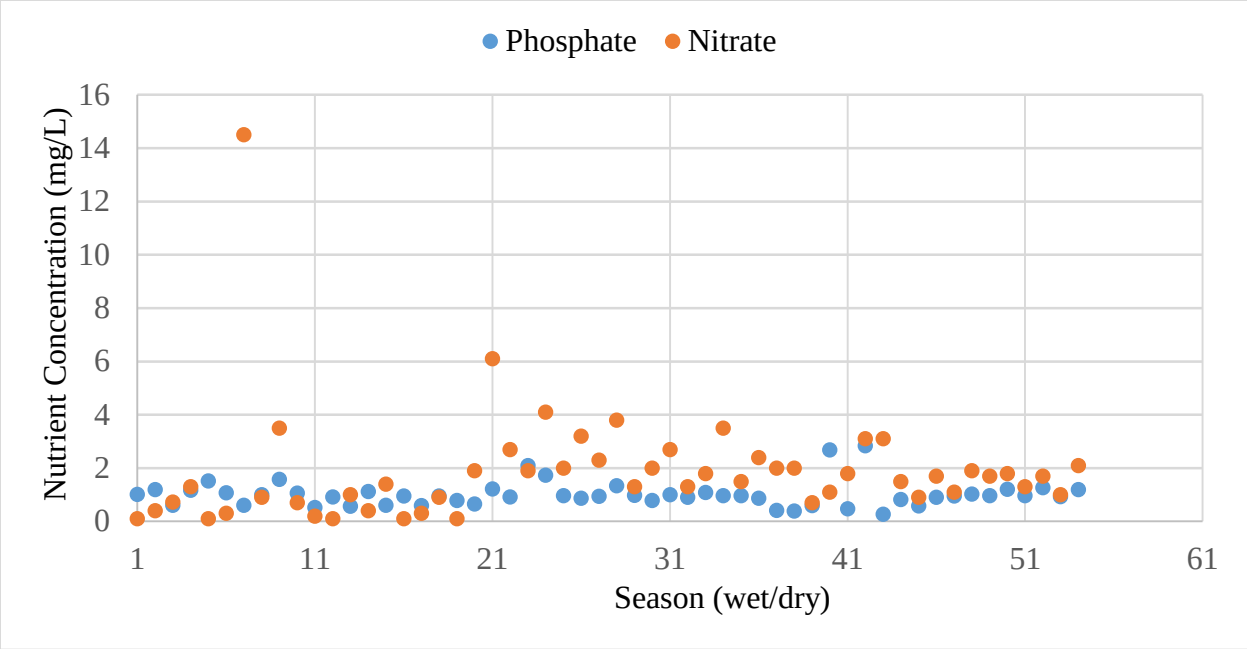


**Figure 4.4:** Scatter Plot for Nitrate-Phosphate Correlation

**Table 4.6:** Relationship between Nitrate and Phosphate Levels in Surface Water

| | | **Nitrate** | **Phosphate** |
|---|---|---|---|
| Nitrate | Pearson Correlation (r) | 1 | 0.025 |
| | Sig. (2-tailed) (p) | | 0.857[a] |
| Phosphate | Pearson Correlation (r) | 0.025 | 1 |
| | Sig. (2-tailed) (p) | 0.857[a] | |
| | N | 54 | 54 |

[ab] Significant difference in phosphate levels between wet and dry seasons ($p>0.05$)

[a] Insignificant difference in phosphate levels between wet and dry seasons ($p<0.05$)

## 4.4 Annual Trend Analysis on Nitrate and Phosphate Levels in Surface Water (Jan 2015- Dec 2024)

Microsoft Excel (V. 2016) was used to analyse the yearly trends in nitrate and phosphate levels collected from two designated monitoring stations, namely TW2 and TW3, where TW2 is defined as the monitoring station located at the treatment plant site, whereas TW3 is another monitoring station at the distribution site, in which water samples were taken for laboratory analysis before

consumption during the study period (Jan 2015–Dec 2024), and the findings from historical water quality analyses are shown in Figure 4.5 (nitrate concentration) and Figure 4.6 (phosphate concentration) below.

Nitrate concentrations at TW2 (treatment plant) and TW3 (distribution site) were lower from 2015 to 2016, with TW2 starting slightly lower (Figure 4.5). Both stations showed increased nitrate levels over time, with TW2 increasing steadily from 2016 to 2018 and TW3 exhibiting fluctuations. From 2017, TW3's concentrations exceeded those of TW2, peaking notably in 2023. Overall, both stations display upward nitrate trends, but TW3 increases more rapidly. TW2 peaked around 2022-2023 but remained below TW3 from 2018 onward, with a slight decline in 2024. In 2019, the findings revealed that there was no monitoring in terms of nitrate content for both stations, and in 2020 for TW3, suggesting possible gaps in monitoring.

In contrast, phosphate concentrations at both monitoring stations (TW2 and TW3) increased from 2015 to 2024, with TW2 consistently higher than TW3, particularly in most years (Figure 4.6). Initial levels in 2015 and 2016 were low; in 2017, TW2 spiked to approximately 8 mg/L, while TW3 rose to about 5 mg/L. From 2018 to 2021, both stations showed moderate levels between 4 and 7 mg/L, with TW2 slightly elevated. In 2022, both stations experienced a decrease, but TW2 surged to 13.36 mg/L in 2023, while TW3 increased less dramatically. Phosphate concentrations declined in 2024 for both stations, with a monitoring gap for TW3 in 2018.

However, both nitrate and phosphate levels were highest and increased more sharply at station TW3 (the distribution site), while a similar sharp increase was seen at station TW2 (the treatment plant) in 2023, suggesting that waste from homes and farming, like livestock and crop production, might be significant causes of nutrient pollution in this reservoir. Kabenge *et al*. (2016) reported similar results, indicating an increasing trend in both nitrate and phosphate concentrations over time (1990-2011).

Also, the yearly changes and sudden spikes in nitrate and phosphate levels indicate that land use, like farming and household waste, plays a role. In addition, the variations in rainfall can cause runoff, which has the potential to transport pollutants like fertilizers and pesticides from the

upstream urban farming into the reservoir, thus diluting or concentrating nitrate and phosphate levels. Further, these variations in rainfall can be highlighted in Figure 4.7 below. These results align with the US EPA (2025) data, which reported that agricultural runoff was found to be the main contributing factor in water contamination, in particular nitrate and phosphate, during the runoff.

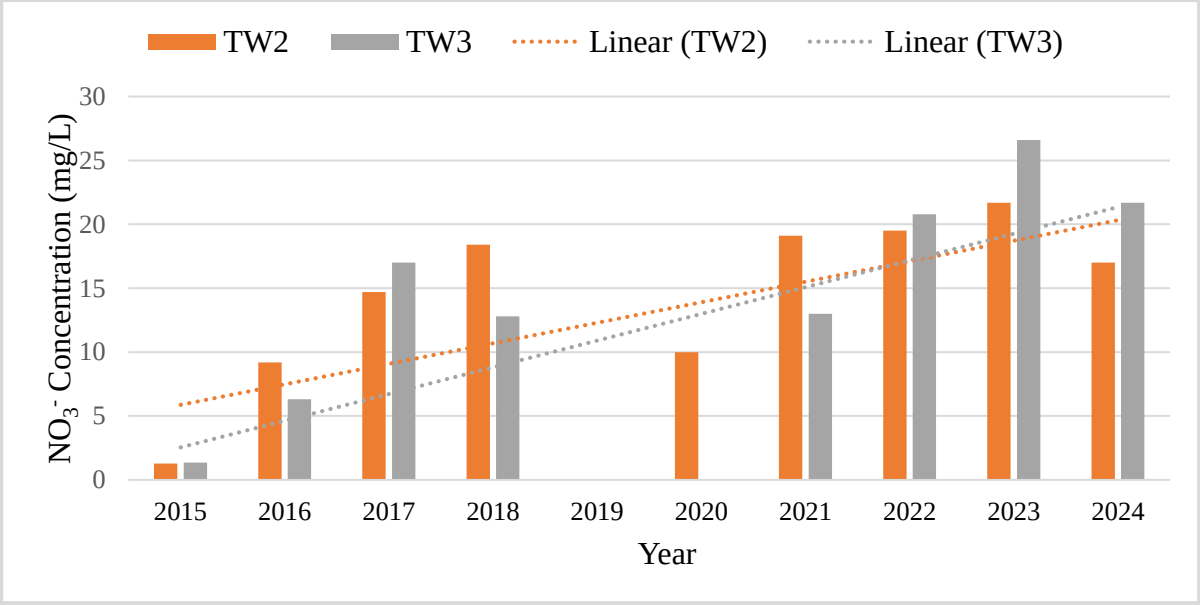


**Figure 4.5:** Annual Trend Analysis in Nitrate Levels in Surface Water

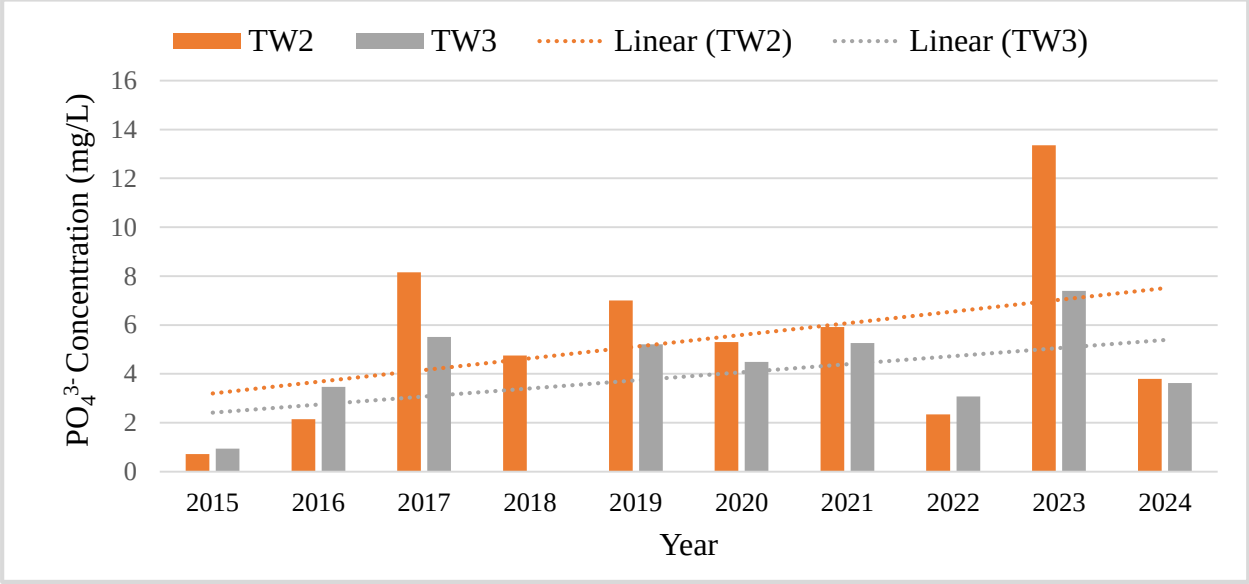


**Figure 4.6:** Annual Trend Analysis of Phosphate Levels in Surface Water

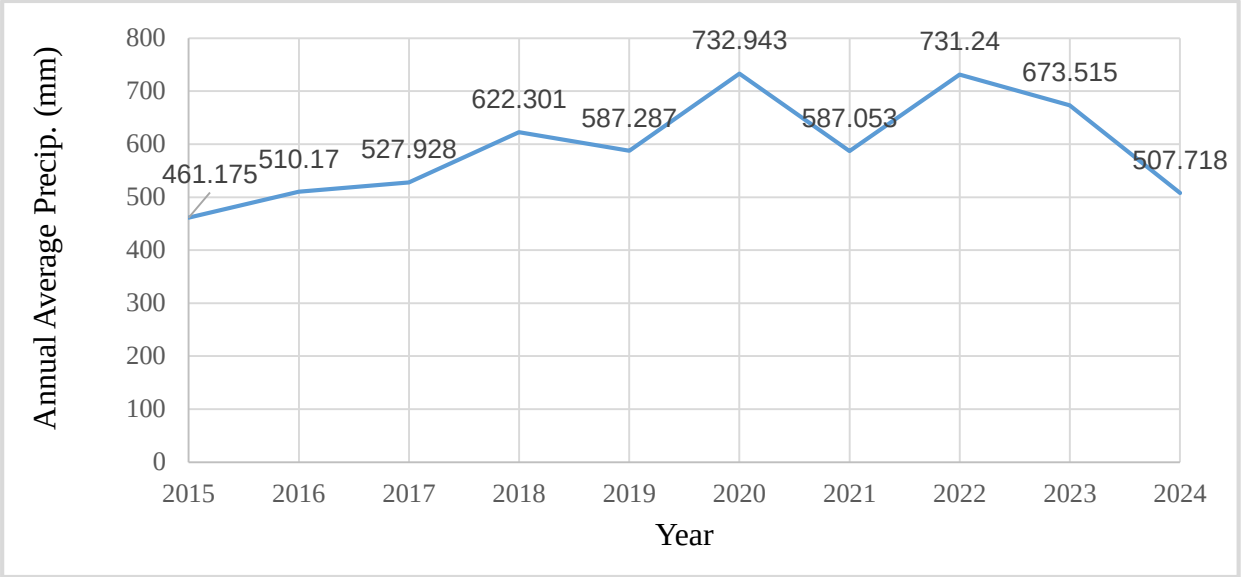


**Figure 4.7:** Annual Average Precipitation Observed During Study Period (Jan 2015- Dec 2024)

## 4.5 Limitations of the Study

There are certain limitations in historical data; for example, the availability of comprehensive historical data on nitrate and phosphate levels before waste disposal interventions might be limited, affecting trend analysis. The data collected might not be reliable because it was not monitored regularly. Hence, a year-round regular monitoring of water quality is highly encouraged to ensure the availability of data.

The historical water quality data comes from three different dams, namely Raselaba, Luma, and Raleting, which could affect how well we can understand the water quality in the Raleting Dam over time. Therefore, the specific water data, such as water quality data for Raleting Dam, is strongly needed to have a true water quality status and to develop specific water management strategies.

However, the researcher is aware that some waste disposal practices have mixed up several wastes due to the current activities, which may influence the conclusions or the findings of what type of waste has more influence on the elevated nitrate and phosphate in this reservoir. This study, therefore, focused only on the most dominant waste disposal practices observed during field

reconnaissance in the study area. Future studies should categorise and quantify the amount of pollutants before they enter the reservoir.

Furthermore, the study only captured a snapshot of conditions over three months (March-May 2025), with a sample size of 54 during the wet (a portion of the wet season) and the dry (a small portion of the dry season) conditions. Therefore, future research work should consider including full seasonal monitoring for thorough analysis.

Waste accumulation in the Raleting Dam was not modeled due to limited timeframes and budget constraints. Therefore, further studies should consider modeling of Raleting water quality for the provision of future projections and source sufficient financial resources to ease monitoring.

In spite of these limitations, the researcher used a thorough approach to collect water samples not just from the dam but also closer to the entry points of waste disposal sites for validation of current results against historical data and to check for variations in nitrate and phosphate contents in Raleting Dam.

## 4.6 Summary

The chapter presented findings addressing the research questions, comparing waste types against WHO and SANS safety standards, and identifying levels of concern for consumption. It highlighted implications of elevated nitrate and phosphate levels on health and water quality at Raleting Dam, explored trends in concentrations over time, and identified agricultural runoff, sewage, industrial effluents, domestic wastewater, and illegal dumpsite as contamination sources, while also comparing results with previous studies. Lastly, the limitations of the study were also identified and given solutions.

# CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Introduction

The chapter presents and concludes the key findings. It further discusses the implications and offers suggestions for future management actions to avoid the cumulative loading of nutrients in water bodies. It further addresses the impact of varying nitrate and phosphate levels on the reservoir's ecosystems, with particular focus on eutrophication. Furthermore, it suggests recommendations, including measures to mitigate the negative impacts, such as controlling the nutrient input sources and conducting future studies for thorough analysis.

## 5.2 Conclusions

This study aimed to evaluate the effect of nitrate and phosphate levels in Raleting Dam. The waste disposal investigated, such as domestic waste, industrial effluents, and agricultural activities, poses a threat to the surrounding environment and is a principal source of nutrient pollution in this reservoir. The analysis shows that the levels of chemicals, like phosphate, in all water samples are higher than the safe limit set by the WHO (2010) during the study period, especially downstream from where waste is disposed of. This raises a concern about the potential negative impacts on aquatic life and public health. This suggests that the water is highly polluted and is unsuitable for domestic use in terms of phosphate content.

Unlike phosphate, nitrate concentrations in all sampled water were within the permissible threshold established by the WHO, suggesting that the reservoir is less polluted in terms of nitrate concentrations for the study period. The primary reason for low nitrate levels is likely the absence of significant agricultural runoff, refuse dump runoff, or excessive fertilizer usage from urban farming, which are common sources of nitrate pollution. The findings also suggest that the reservoir's ecosystem may effectively process or dilute any nitrate inputs. Unlike phosphate, nitrate pollution is linked to the nitrogen used in fertilizers. Thus, the low nitrate level suggests a limited human impact.

The results showed that household waste and industrial waste are the main causes of nitrate and phosphate levels, indicating that household waste, which includes human waste and waste from urban farming, adds nitrate and phosphate through sewage and surface runoff. Additionally,

industrial waste from chemical processes, like those in pharmaceuticals and cosmetics, directly releases phosphate compounds into the water. These pollutants, when in excess, can lead to eutrophication and other water quality issues, impacting aquatic ecosystems and human health.

The dumpsite showed a relatively low amount of both nitrate and phosphate, suggesting that the illegal dumpsite did not contribute much; it does not fully decompose to release a measurable amount of leachate (see Figure 1.3). Although the contamination from this disposal site (illegal dump designated as S1) is minimal, it is significant due to the ongoing neglect of illegal dumping surrounding the reservoir, which can build up and could lead to greater adverse impacts in the future. This issue may intensify, leading to increased water scarcity, which will complicate human consumption and hinder the survival of aquatic ecosystems. It should not be ignored that water is a limited resource, particularly in the Mafeteng district (Sekaleli and Sebusi, 2013); thus, effective control of the indiscriminate disposal of waste should be regulated.

The amount of nitrate in sampled water was greater in the wet season because of rainfall transporting residential waste into the reservoir from urban and agricultural effluents, but phosphate levels were higher in the dry season as a result of industrial effluent entering the reservoir via urban runoff. The situation shows that changes in the seasons affect the amounts of nitrate and phosphate in a reservoir because of different sources of runoff and waste. This runoff carries nitrates from sources like fertilisers used in agriculture and from residential waste, which includes nitrogen-rich materials.

Conversely, higher phosphate levels in the dry season may result from increased concentration due to reduced water volume and increased weathering of phosphate-containing minerals during low-flow conditions. These excessive nutrient concentrations can stimulate algae growth, referred to as algal blooms, which can deplete oxygen in water bodies.

The results indicated a very small positive relationship ($r = 0.025$) between nitrate and phosphate levels, with a high p-value (0.857), meaning that the amounts of nitrate and phosphate in this reservoir did not rely on whether the levels of either nutrient went up or down during the study. This implies that waste disposal practices during this period did not strongly influence the levels

of these nutrients. Hence, there could be other factors that contribute to the weak association in this study.

The observed increase in nitrate and phosphate levels at monitoring stations TW2 and TW3 over the past decade indicates a gradual decline in the water quality of this reservoir. The decline is likely due to increased nutrient pollution, potentially from agricultural runoff, wastewater discharge, or urban runoff, which can lead to eutrophication and harmful algal blooms.

## 5.3 Recommendations

Based on the general conclusions drawn, the recommendations are outlined as follows:

1. Sustainable farming methods and waste management strategies should be undertaken as the long-term plans to prevent phosphate loading into aquatic ecosystems and its impact on the domestic water supply system in Mafeteng urban.

2. Once more, the government should urgently implement conservation measures as a long-term strategy to safeguard the reservoir for the benefit of aquatic life and public health, as this can trap pollutants from entering the reservoir. Hence, it is strongly recommended that the government urgently (short-term plan) enforce the environmental laws and ensure compliance with existing regulations to prevent illegal dumping of waste around this reservoir.

3. Urban council should ensure the provision of sufficient waste bins in proximity to the communities and commercial markets, as one of the long-term plans to avoid indiscriminate dumping. The additional waste bins can play a pivotal role in preventing illegal dumping and contamination of water resources.

4. It is also highly recommended that waste pickers should make frequent collections of waste as an ongoing management strategy to avoid the cumulative loading of waste or to avoid a similar situation as shown in Figure 1.3.

5. Moreover, environmental officers should on yearly provide environmental education to communities, industries, street vendors, and business owners annually about proper ways to dispose of waste and the importance of protecting water resources free from contamination.

6. Furthermore, institutional collaboration should be done quarterly to ensure stakeholders develop collective decisions and shared ideas on how they can mitigate the indiscriminate disposal of waste.

7. The study's findings raise awareness among water resource managers and policymakers about the significant harm caused by the indiscriminate disposal of waste in this reservoir, so that they may develop long-term waste management plans to prevent illegal dumping of waste.

8. Consequently, the study can act as a long-term guideline for educating local authorities and policymakers about probable pollution sources and formulating waste management strategies to mitigate waste generation in this area.

9. Future research should be conducted to comprehend public perceptions regarding illegal waste dumping. Since the present study occurred for a short timeframe of three months, with a sample size of fifty-four, it is strongly recommended that future studies should consider making a full year-round monitoring for comprehensive analysis.

10. Further, research should focus on evaluating seasonal physicochemical parameters, including temperature, total dissolved solids (TDS), electrical conductivity (EC), pH, turbidity (NTU), dissolved oxygen (DO), biological oxygen demand (BOD), and chemical oxygen demand (COD), which are essential for determining the water quality status of water bodies.

## 5.4 Summary

The chapter summarised the main findings, and conclusions were drawn based on the key findings and the recommendations for strengthening environmental laws to control the cumulative loading of nutrients.

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# APPENDICES

## Appendix 1: Data Collection Tools

Tools used in this Study (see section 3.8.2)

| Number | Equipment/Tools | Usability |
|---|---|---|
| 1. | 1L Plastic bottle | To collect water samples |
| 2. | Surface water analysis form | To record data in the Laboratory |
| 3. | GPS | To record coordinates and elevations at each station |
| 4. | Boat (Local boat) | To ease access for midstream sites for sample collection |
| 5. | Cooler box | Storage of samples taken in the field |
| 6. | Biobase Refrigerator | Storage of samples in the laboratory |
| 7. | Labcon Oven | Incubation of samples before analysis (at room temperature) |
| 8. | Sample cell | To keep samples ready for analysis |
| 9. | 10 mL measuring cylinder | To measure samples for analysis |
| 10. | Canon camera | Capture images for documentation. |
| 11. | HACH DR6000 UV-VIS Spectrophotometer | For the determination of nutrient concentrations |
| 12. | Paper towel | To wipe out the sample cell before inserting it into the cell holder |

## Appendix 2: Laboratory Analysis Results

Weekly water quality data collected in March 2025

| Sampling locations | Parameters (mg/L) | | | |
|---|---|---|---|---|
| | Week 1 | | Week 3 | |
| | $NO_3^-$ | $PO_4^{3-}$ | $NO_3^-$ | $PO_4^{3-}$ |
| Illegal dumpsite (S1) | 0.1 | 1.01 | 0.4 | 1.2 |
| Sewage near hotel (S2) | 0.72 | 0.61 | 1.3 | 1.17 |
| Industrial effluents (S3) | 0.1 | 1.52 | 0.3 | 1.07 |
| Domestic effluents and agricultural runoff (S4) | 14.5 | 0.61 | 0.9 | 1 |
| Midstream 1 at the upper part of the dam (MD1) | 3.5 | 1.58 | 0.7 | 1.06 |
| Midstream 2 at the lower part of the dam NW (MD2) | 0.2 | 0.52 | 0.1 | 0.92 |
| Midstream 3 at the lower part of the dam NE (MD3) | 1 | 0.57 | 0.4 | 1.12 |
| Abstraction point (CW) | 1.4 | 0.6 | 0.1 | 0.95 |
| Exit point (ET) | 0.3 | 0.59 | 0.9 | 0.95 |

## Appendix 3: Laboratory Analysis Results

Weekly water quality data collected in April 2025

| Sampling locations | Parameters (mg/L) | | | |
|---|---|---|---|---|
| | W5 | | W7 | |
| | $NO_3^-$ | $PO_4^{3-}$ | $NO_3^-$ | $PO_4^{3-}$ |
| Illegal dumpsite (S1) | 0.1 | 0.78 | 1.9 | 0.65 |
| Sewage near hotel (S2) | 6.1 | 1.22 | 2.7 | 0.92 |
| Industrial effluents (S3) | 1.9 | 2.09 | 4.1 | 1.73 |
| Domestic effluents and agricultural runoff (S4) | 2 | 0.96 | 3.2 | 0.87 |
| Midstream 1 at the upper part of the dam (MD1) | 2.3 | 0.94 | 3.8 | 1.34 |
| Midstream 2 at the lower part of the dam NW (MD2) | 1.3 | 0.98 | 2 | 0.79 |
| Midstream 3 at the lower part of the dam NE (MD3) | 2.7 | 1 | 1.3 | 0.91 |
| Abstraction point (CW) | 1.8 | 1.09 | 3.5 | 0.96 |
| Exit point (ET) | 1.5 | 0.97 | 2.4 | 0.87 |

## Appendix 4: Laboratory Analysis Results

Weekly water quality data collected in May 2025

| Sampling locations | Parameters (mg/L) | | | |
|---|---|---|---|---|
| | W9 | | W11 | |
| | $NO_3^-$ | $PO_4^{3-}$ | $NO_3^-$ | $PO_4^{3-}$ |
| Illegal dumpsite (S1) | 2 | 0.41 | 2 | 0.39 |
| Sewage near hotel (S2) | 0.7 | 0.59 | 1.1 | 2.68 |
| Industrial effluents (S3) | 1.8 | 0.47 | 3.1 | 2.84 |
| Domestic effluents and agricultural runoff (S4) | 3.1 | 0.27 | 1.5 | 0.82 |
| Midstream 1 at the upper part of the dam (MD1) | 0.9 | 0.58 | 1.7 | 0.9 |
| Midstream 2 at the lower part of the dam NW (MD2) | 1.1 | 0.95 | 1.9 | 1.02 |
| Midstream 3 at the lower part of the dam NE (MD3) | 1.7 | 0.97 | 1.8 | 1.21 |
| Abstraction point (CW) | 1.3 | 0.97 | 1.7 | 1.27 |
| Exit point (ET) | 1 | 0.93 | 2.1 | 1.2 |

## Appendix 5: Summary Table for Nitrate

Average weekly water quality data from Raleting Dam

| Weekly Statistical Summary for Nitrate Levels in Surface Water (mg/L) | | | |
|---|---|---|---|
| Week | Mean ± SE | Minimum | Maximum |
| W1 | 2.424 ± 0.699 | 1.019 | 3.830 |
| W3 | 0.567 ± 0.699 | -0.839 | 1.972 |
| W5 | 2.700 ± 0.699 | 1.295 | 4.105 |
| W7 | 2.256 ± 0.699 | 0.850 | 3.661 |
| W9 | 1.800 ± 0.699 | 0.395 | 3.205 |
| W11 | 1.589 ± 0.699 | 0.184 | 2.994 |

## Appendix 6: Summary Table for Phosphate

Average weekly water quality data from Raleting Dam

| Weekly Statistical Summary for Phosphate Levels in Surface Water | | | |
|---|---|---|---|
| Week | Mean ± SE | Minimum | Maximum |
| W1 | 1.086 ± 0.164 | 0.755 | 1.416 |
| W3 | 0.809 ± 0.164 | 0.479 | 1.139 |
| W5 | 1.129 ± 0.164 | 0.799 | 1.459 |
| W7 | 0.990 ± 0.164 | 0.660 | 1.320 |
| W9 | 1.006 ± 0.164 | 0.675 | 1.336 |
| W11 | 1.047 ± 0.164 | 0.716 | 1.377 |