

EUTROPHICATION ASSESSMENT IN THE KAVANGO RIVER SYSTEM FROM
RUNDU TO DIVUNDU, NAMIBIA

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ABSTRACT

Eutrophication is one of the most serious problems facing freshwater ecosystems globally. Nutrient enrichment of these freshwater ecosystems results in excessive plant and algal growth that have negative effects on biodiversity and water quality. The present study was conducted at six selected sites from Rundu to Divundu along the Kavango River namely; Rundu, Mashare, Shitemo Irrigation schemes, Quito, Shadikongoro Irrigation systems and Divundu. The overall objective of the study was to assess the level of eutrophication of the Kavango river downstream from Rundu to Divundu in Namibia by assessing concentration levels of Total Nitrogen, Total phosphate and Ortho-phosphate in the water. Water samples were collected in 50 ml plastic bottles from the main flow along the Kavango river gradient. Each site was sampled upstream (Before the site) and downstream (After the site) from Rundu to Divundu. Water samples were collected 3-5 cm below the surface following United States Environmental Protection Agency standards. Sampled water was analysed for Total Nitrogen (N), Total Phosphate (P), Ortho-phosphate using Inductively coupled plasma-atomic emission spectrometry (ICP-AES). Dissolved oxygen was also measured 3-5 cm below the water surface. Simple Linear Regression was used to test the effect of distance on the concentration levels of Total Nitrogen, Total Phosphates and Ortho-phosphate. The Wilcoxon Signed Rank test was used to compare nutrient concentration levels, flow rates and dissolved oxygen before and after sites. To test for compliance with acceptable standards International Water Quality Guidelines (IWQES) and South African Water Quality Guidelines for Aquatic Ecosystems (SAWQG), one Sample Wilcoxon Signed Rank test was used for non-parametric data and one -sample t test was used for parametric data.

There was no significant relationship between concentrations of Total Nitrogen and Total phosphate concentration in the Kavango river and the distance downstream from Rundu to Divundu. However, there was a significant relationship between the concentration of Ortho-phosphate (mg/l) and distance along the Kavango River ($p = 0.028$; $R^2 = 0.42971$). Furthermore, there was no significant difference in concentrations of Total nitrogen, Total phosphate and Ortho-phosphate. The study also revealed no significant difference in flow rate and dissolved oxygen before and after the sampled sites.

Total Nitrogen concentration in the River was significantly lower ($p = 0.001$) than the allowable general standards limit of 0.3mg/l set by US EPA (2000), and lower than the allowable concentration limit of 2.5mg/l as set by South African Water Quality Guidelines for Aquatic Ecosystems, Department of Water Affairs and Forestry (1996) value ($p = 0.001$). Although the observed Total phosphate in the Kavango River were significantly higher ($p = 0.000$) than the allowable general standards Total phosphate concentration limits of (0.1mg/l) set by US EPA (2000), the same Total phosphate concentrations were significantly lower ($p = 0.001$) than the allowable concentration limit of 2.5mg/l as set by South African Water Quality Guidelines for Aquatic Ecosystems, Department of Water Affairs and Forestry (1996). Total Phosphate concentrations of the Kavango River are below the acceptable regional limit, but do not comply with the standards set by the USEPA. However, the concentration of Ortho-phosphate in the Kavango River was significantly lower ($p = 0.002$) than both the allowable concentration limit (0.1 mg/l) as set by South African Water Quality Guidelines for Aquatic Ecosystems, Department of Water Affairs and Forestry (1996) and the allowable standard set by US EPA (2000). This study highlights the need to continually assess the nutrient concentration levels in the

Kavango River to ensure that the nutrient loads are within the set regional and international guidelines, especially in this age where human population as well as the number of irrigation schemes in the area continue to increase.

Keywords: Eutrophication, Kavango, Namibia, Ortho-phosphate, Total Nitrogen, Total Phosphate.

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LIST OF ABBREVIATIONS AND/ OR ACRONYMS

°C	Degrees Celsius
DO	Dissolved Oxygen
i.e.	For example
IQWES	International Quality Water for Ecosystems
GPS	Geographic Position System
KIFI	Kamutjonga Inland Fisheries Institute
Km	Kilo metres
NAMWATER	Namibia Water Cooperation Limited.
NSFAF	Namibia students financial assistance fund
O	Ortho-phosphate
SAWQG	South African Water Quality Guidelines for Aquatic Ecosystems
SPSS	Statistical Software Package for Social Science
-	To
TN	Total Nitrogen
TP	Total Phosphate
US EPA	United States Environmental Protection Agencies

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DEDICATION


This thesis is dedicated to my supervisors, Prof. E.G. Kwembeya and Dr C. Hay in whom I saw passion when it comes to helping students.

DECLARATIONS

I, Ester Ishiwa Haikola, hereby declare that this study is my own work and is a true reflection of my research, and that this work, or any part thereof has not been submitted for a degree at any other institution.

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Ester Haikola		OCTOBER 2022
.....
Student Name	Signature	Date

CHAPTER 1: INTRODUCTION

1.1 Background of the study

Eutrophication is considered to be one of the most serious problems facing freshwater ecosystems globally (Vitousek *et al.*, 1997; Mainstone & Parr, 2002). Eutrophication is defined as excessive plant and algal growth in response to nutrient enrichment (Vushe *et al.*, 2014). The major nutrients that contribute to eutrophication are Total Phosphate, Ortho-phosphate, and Total Nitrogen (ISECA, 2021). In addition, Minnesota Pollution Control Agency (2008) stated that Phosphorus (P) and Nitrogen (N) are the primary nutrients that when in excessive amounts pollute lakes, streams, and wetlands. However, the same study also stated that nitrogen is essential for the production of plant and animal tissue. It is used primarily by plants and animals to synthesize proteins. Nitrogen enters the ecosystem in several chemical forms and also occurs in other dissolved or particulate forms, such as tissues of living and dead organisms, while Phosphorus is a vital nutrient for converting sunlight into usable energy, and is essential to cellular growth and reproduction (Minnesota Pollution Control Agency, 2008).

Under natural conditions, phosphorus is typically scarce in water. It has been reported that phosphorus contributed by human activity is a major cause of excessive algae growth and degraded lake water quality (Minnesota Pollution Control Agency, 2008). Phosphorus also occurs in dissolved organic and inorganic forms or attached to sediment particles. In addition, phosphates, which are the inorganic form of phosphorus, are preferred for plant growth, but other forms can be used when phosphates are unavailable (Minnesota Pollution Control Agency, 2008). However, Phosphorus builds up in the sediments of a lake or a river (Minnesota Pollution Control Agency, 2008). When it remains in the sediments, it is generally not available for use by algae, however, various chemical and biological processes can allow

sediment phosphorus to be released back into the water (Minnesota Pollution Control Agency, 2008).

In a study done by Dubrovsky *et al.*, (2010), it was reported that although nutrients are essential for plant growth, the over-abundance of nutrients in water can have harmful health and environmental effects. An over-abundance of nutrients—primarily nitrogen and phosphorus—in water starts a process called *eutrophication*. A particular problem facing Southern African Rivers such as Limpopo, Tugela, Maputo and Chobe River is the significant increase in urban runoff and increasingly from overloaded or dysfunctional municipal water treatment plants and unsewered human settlements (De Villiers, 2007). All of these are potentially significant sources of nutrients and other pollutants in the rivers.

Anderson (2006) stated that in societies guided by modern principles of economic growth, it is inevitable that habitats will experience environmental degradation. In addition, Ashton and Braune (1999) found that development and population growth directly affect the availability and quality of freshwater resources. As the human population increases, the impact of migration and urbanisation, industrial growth and agriculture usually have negative effects on the quality of water in rivers receiving return flows (Mmualefe & Torto, 2011). Consequently, the quality of surface water in many countries has decreased over the past few decades (Mattikalli & Richards, 1996). The Kavango River is no exception to the problem of eutrophication (Mmualefe & Torto, 2011).

The Kavango River Basin is shared among three countries namely; Angola at the headwaters, Namibia at the middle-water course, and Botswana at the Okavango Delta (De Villiers, 2007). In addition, the river is called Cubango in Angola, Kavango in Namibia and Okavango in Botswana.

The US EPA (2000) regards agriculture as the leading source of impairment of that nation's rivers and lakes with nutrients ranking second only to siltation as the pollutant most affecting rivers and lakes. There are several irrigation schemes along the Kavango river. The most common irrigation schemes include Musese Irrigation Scheme, Rundu Urban Irrigation Scheme, Kaisosi Irrigation Scheme, Vungu Vungu Irrigation Scheme, Mashare Irrigation Scheme, Shankara Irrigation Scheme, Ndonga Linena Irrigation Scheme, Shitemo Irrigation Scheme, Shadikongoro Irrigation Scheme, Bagani Gardens, and Divundu Prisons Irrigation Scheme. It is, therefore, necessary to study the relationships among population, land-use change and water quality, to increase the understanding of the Kavango River system at a local and regional level. There is a gap in knowledge on the nutrient loads and likelihood of eutrophication along the Kavango River (Mmualefe & Torto, 2011). Tilstone *et al.*, (2012) stated that nutrients such as Total phosphates (TP), Ortho- Phosphate (O) and Total nitrogen (TN) are the main elements that can be measured to determine eutrophication.

1.2 Statement of the problem

Eutrophication has been widely recorded from parts of the Kavango River (McCarthy, 2004). Eutrophication alters the competitive balance between plant species, resulting in the degradation of aquatic plant communities, which provides food, shelter and breeding habitats for a range of animal species (Mainstone & Parr, 2002). However, plants are critically important as green house gases absorbers and as water filters. Additionally, eutrophication can be detrimental to the health of humans and toxic to aquatic animals, kills both invertebrates and fishes, as a result of oxygen depletion. Eutrophication results in the general loss of ecosystem services and has negative impacts on livelihoods of people who depend on the River for survival.

ver the past years, there has been an increase of Irrigation schemes and land use activities along the Kavango River, which could lead to eutrophication (Ortmann, 2012). Therefore, the establishment of numerous irrigation projects along the entire course of the Kavango River section of Namibia prompted the desire to conduct this study. Additionally, local people have recognized that the quality of the water and fish resources is decreasing, and have an interest in understanding how to protect these resources (Jones, 2001)

1.3 Research Objectives

1.3.1 General objective

The overall objective of the present study was to assess the level of eutrophication in the Kavango river downstream from Rundu to Divundu in Namibia by assessing concentration levels of Total Nitrogen, Total phosphate and Ortho-phosphate in the water.

1.3.2 Specific objectives

- a) To determine the relationship between the concentration levels of Total Nitrogen, Total phosphate and Ortho-phosphate and distance along the Kavango river.
- b) To compare the concentration levels of Total Nitrogen, Total phosphate and Ortho-phosphate before and after the selected sites from Rundu to Divundu.
- c) To determine whether there is a significant difference in flow rate before and after the selected sites from Rundu to Divundu.
- d) To determine whether there is a significant difference in Dissolved Oxygen (DO) before and after the selected sites from Rundu to Divundu.
- e) To determine whether the concentration levels of Total Nitrogen, Total phosphate and Ortho-phosphate comply with the effluent standards set by International Water Quality guidelines for Ecosystems (IQWES) (US EPA, 2000) and South African Water Quality

Guidelines for Aquatic Ecosystems (SAWQG) (Department of Water Affairs and Forestry, 1996).

1.4 Null hypotheses

The following null hypotheses (H₀) were tested in the present study:

- a) The distance along the Kavango river from Rundu to Divundu does not influence the concentration levels of Total Nitrogen, Total phosphate and Ortho-phosphate in the water.
- b) There is no significant difference in nutrient levels (Total Nitrogen, Total phosphate and Ortho-phosphate) before and after the selected sampling sites along the Kavango River.
- c) There is no significant difference in flow rate before and after the selected sites from Rundu to Divundu.
- d) There is no significant difference in Dissolved Oxygen (DO) before and after the selected sites from Rundu to Divundu.
- e) There is no significant difference between the concentration levels of Total Nitrogen, Total phosphate and Ortho-phosphate and the allowable concentration limits for nutrients set by international Water Quality guidelines for Ecosystems (IQWES) (US EPA, 2000) and South African Water Quality Guidelines for Aquatic Ecosystems (Department of Water Affairs and Forestry, 1996).

1.5 Significance of the study

The present study provides data on the (Total Nitrogen, Total Phosphate and Ortho-phosphate) indicators available to assess the degree of eutrophication in the Kavango River. High concentrations of nutrients will increase the biomass of the algae (Tilstone *et al.*, 2012), thereby affecting the plant and animal life of the Kavango River system.

The present study also contributes to the understanding of the nutrients which can potentially cause eutrophication in the Namibian freshwater ecosystems. Additionally, studying eutrophication in this river system will provide baseline information for the local government to address the issue of pollution.

1.6 Limitation of the study

The study was limited to six (6) sites, namely Rundu, Mashare, Shitemo, Shadikongoro Irrigation Scheme and Divundu. In addition, short time series of the database (4 days) was also the constraint.

CHAPTER 2: LITERATURE REVIEW

2.1 Eutrophication

Eutrophication happens when a body of water becomes overly enriched with minerals and nutrients that induce excessive growth of plants and algae (Pathak & Pathak, 2012). In addition, this enhances algal growth (algal bloom), reduces dissolved oxygen, and can cause other organisms like fish to die (Patzner & Muller, 2001). When nutrient-rich runoff from the land enters the river, aquatic life blossom and ultimately dies due to high competition, thereby

greatly increasing amounts of organic debris (Bista, 2016). The constant production, decomposition, and sedimentation of biomass caused by adding up of the excess nutrients from the runoff (mostly from the agricultural land) negatively affects underground aquifers (Yen, 1999).

Eutrophication of river systems, resulting from nutrient enrichment, is globally considered to be one of the most serious threats to freshwater ecosystem services such as water quality and biodiversity (De Villiers, 2007). Study done on the overview of the nutrient status of the 20 largest river catchments in South Africa found that nutrient levels exceeding recommended water quality guidelines for plant life are commonly observed in many rivers (De Villiers, 2007). Statistically significant upward trends in dissolved Phosphate levels were found in almost 60% of the rivers evaluated (De Villiers, 2007). On the other hand, a study conducted by Mmualefe & Torto (2011) in the Okavango Delta showed that total nitrogen and phosphorus are generally low with maximum concentrations of 1.7 and 1.6 mg/l, respectively, recorded downstream of the Delta. In the upper catchment of the Limpopo River basin in Botswana nitrate values range from 0, 27 mg/l to 11, 78 mg/l, which are quite high (Mmualefe & Torto, 2011). Additionally, the main sources of nitrogen in rivers include human and animal wastes, industrial pollutants, and non-point-source runoff from agriculture and aquaculture activities. However, in excess amounts, nitrates in water can cause an increase in algal growth, which can rob the water of dissolved oxygen and can eventually lead to the death of some forms of aquatic life (Glibert, 2017; Sutton *et al.*, 2013).

2.1.1 Causes of eutrophication

Patzner & Müller (2001) indicated that under natural circumstances, eutrophication occurs over long periods but is accelerated by human activities such as sewage disposal. The rapid increase in nitrate caused by the application of nutrients and agrochemicals in cultivated area, and

phosphate nutrient levels in standing waters cause extended growth of phytoplanktons. When it rains, fertilizers from cultivated areas run off into the streams and rivers and feed the algae and plankton with nutrients. Sewage water is rich in nutrients, and when it escapes into the environment, it could lead to local eutrophication, particularly given the hyper oligotrophic status of the Okavango Delta ecosystem (Cronberg *et al.*, 1995). Hooda *et al.* (2000) added that animal waste contains phosphate, nitrate, and dissolved solids, as well as harmful pathogens. Phosphorus is necessary for the growth of algae and nitrates provide nutrition for the algae (Pathak & Pathak 2012). Phosphate and Nitrogen are the main nutrients responsible for eutrophication which causes the levels of dissolved oxygen in the water to decrease, resulting in oxygen dead zone- areas in the water where little to no oxygen is present and aquatic life is unable to survive (Hooda *et al.*, 2000). Nonetheless, a study done by Bista (2016) indicated that natural events such as floods and the natural flow of rivers and streams can also wash excess nutrients off the land into the water body contributing to eutrophication.

2.1.2. Consequences of eutrophication

When the freshwater body has eutrophication, consequences such as penetration of light into the water will diminish (Muir, 2012). Also, this occurs because the algae form mats as a result of being produced faster than consumed. In addition, diminished light penetration decreases the productivity of plants in the deeper waters (and hence their production of oxygen). Adeoye *et al.*, (2013) argued that a decrease in photosynthesis results in lower levels of dissolved oxygen, which hinders the respiration of aquatic life. When the abundant algae die and decompose, more oxygen is consumed by those decomposers.

Again, Muir (2012) added that lowered oxygen results in death of fish that need high level of dissolved oxygen (DO). However, the community composition of the water body changes, with fish that can tolerate low DO, such as carp becoming abundant and dominating. Furthermore

increased vegetation may interfere with water flow, the water may become unsuitable for drinking even after treatment and the value of the water may decrease to a point that it would be unsuitable for water sport due to increases in turbidity. Bista (2016) further added that lack of oxygen from the decomposition of dead organisms and photosynthesis causes the water to be hypoxic. A dead zone is created when no organisms can survive in a hypoxic environment. In addition, some algae produce toxins that have harmful effects on other forms of life negatively affecting the ecosystem.

2.2 Nitrogen, Total Phosphorus and Ortho-phosphate .

2.2.1 Nitrogen

Nitrogen is an essential nutrient for all aquatic organisms. The forms of nitrogen generally analyzed from a water sample include ammonium (NH_4), organic nitrogen (Norg), and oxidized nitrogen, which is nitrate (NO_3^-) and nitrite (NO_2^-). (Glibert, 2017; Sutton *et al.*, 2013). Total nitrogen (Tot – N) is a measure of all the forms of nitrogen, dissolved or particulate that are found in the sample. Human and animal wastes, industrial pollution, and non-point-source runoff from agriculture and aquaculture activities are the main sources of nitrogen in rivers. However, excessive quantities of nitrates in water can promote algal development, robbing the water of dissolved oxygen and finally resulting in the demise of certain aquatic species. (Glibert, 2017; Sutton *et al.*, 2013).

According to Roy and Bickerton (2014), Nitrogen occurred in a variety of forms, or species, and the species present can change as they move between the air, water, and soil. Ammonia (NH_3) and Ammonium (NH_4^+) are among the primary forms of nitrogen in natural waters. Ammonia can be toxic to fish. It is also soluble in water and relatively unstable in most environments. Ammonia is easily transformed into nitrate (NO_3^-) in waters that contain

sufficient dissolved oxygen or into nitrogen gas in waters that have no dissolved oxygen (Roy & Bickerton, 2014).

Nitrate (NO_3^-) is another primary form of nitrogen in lakes and streams. Nitrate tends to be very soluble in water and stable over a wide range of environmental conditions. It readily transported in groundwater and streams. An excessive amount of nitrate in drinking water can cause health problems (Roy & Bickerton, 2014). Neelon *et al.*, (2015) added that Nitrogen pollution is caused when some nitrogen compounds like ammonia and nitrous oxide become too abundant. Synthetic fertilizer use can sometimes cause pollution. Another factor is the breakdown of large amounts of animal dung and slurry, which is common in intensive livestock operations. This excess nitrogen can have negative impacts on climate, the natural environment and our health (Neelon *et al.*, 2015).

Nitrates in water in excess can induce an increase in algal growth, which can deplete dissolved oxygen in the water and eventually lead to the death of some aquatic species. (Mosepele, 2009). In countries such as China, Total Nitrogen concentration has been classified as one of the nutrient to control eutrophication in the water bodies as well as used when it comes to improving water quality (Xu *et al.*, 2014).

There are effluent guideline limits defined by the South African Water Quality Guidelines (SWAWQG) for Aquatic Ecosystems to identify at-risk surface water bodies and safeguard them from eutrophication, which stipulate that Total Nitrogen concentrations in streams and rivers should not exceed 2.5 mg/L (Department of Water Affairs and Forestry, 1996). USE PA (2002) indicated that it should not be more than 0.3 mg/L (Table 1).

2.2.2 Nitrogen Cycle in a Terrestrial Ecosystem

2.2.2.1 Nitrogen cycles between the atmosphere and living things.

According to Bernhard (2010), Nitrogen is one of the primary nutrients critical for the survival of all living organisms. It is a necessary component of many biomolecules, including proteins, DNA, and chlorophyll. Although nitrogen is very abundant in the atmosphere as dinitrogen gas (N_2), it is largely inaccessible in this form to most organisms, making nitrogen a scarce resource and often limiting primary productivity in many ecosystems. Only when nitrogen is converted from dinitrogen gas into ammonia (NH_3) does it become available to primary producers, such as plants (Bernhard, 2010). Nitrogen comes in a variety of forms, including inorganic (e.g., ammonia, nitrate) and organic (e.g., amino and nucleic acids), in addition to N_2 and NH_3 . As organisms use nitrogen for development and, in certain circumstances, energy, it undergoes a variety of transformations in the ecosystem, moving from one form to another. The Nitrogen Cycle, on the other hand, is responsible for this change.

The major transformations of nitrogen are nitrogen fixation, nitrification, denitrification, and ammonification (Figure 1). However, Bernhard (2010) added that the transformation of nitrogen into its many oxidation states is key to productivity in the biosphere and is highly dependent on the activities of a diverse assemblage of microorganisms, such as bacteria, archaea, and fungi. Groffman *et al.*, (2002) added that the nitrogen cycle moves nitrogen through the abiotic and biotic parts of ecosystems. Figure 1 below shows how nitrogen sequences through a terrestrial ecosystem. In addition, Groffman *et al.*, (2002) stressed that nitrogen passes through a similar cycle in aquatic ecosystems.

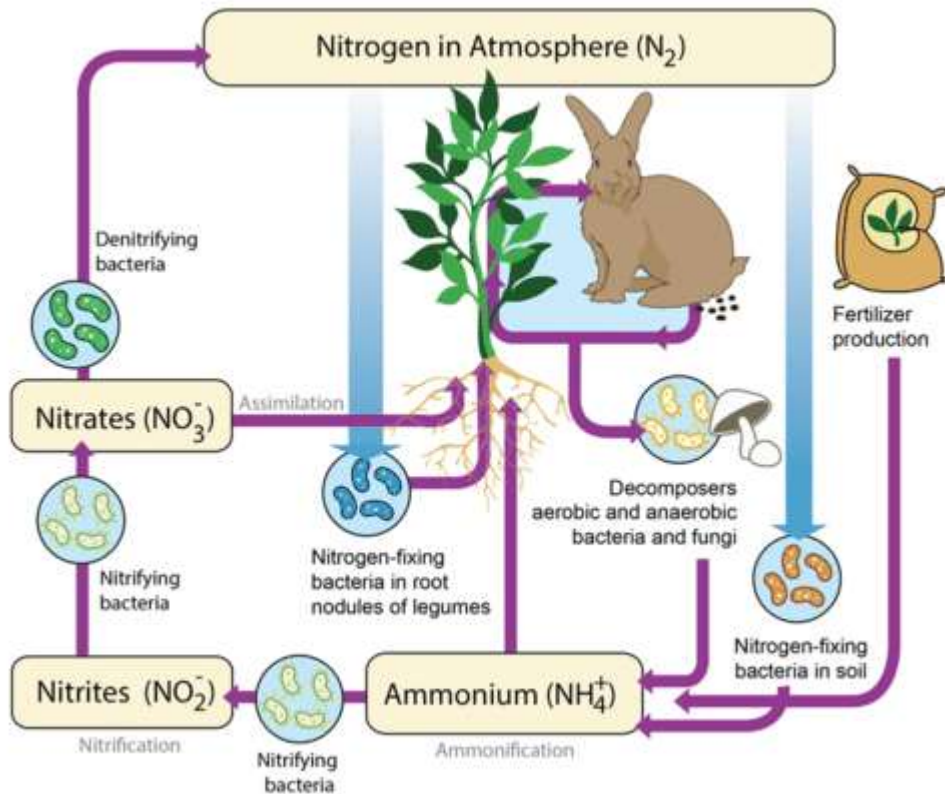


Figure 1: Nitrogen cycle in a terrestrial ecosystem. The Nitrogen cycle assimilations, when plants absorb nitrogen; nitrogen-fixing bacteria that make the Nitrogen available to plants in the form of Nitrates; decomposers that transform nitrogen in dead organisms into ammonium; nitrifying bacteria that turn ammonium into nitrates; and denitrifying bacteria that turn nitrates into gaseous nitrogen (Bernhard, 2010).

2.2.3 Role of Nitrogen in plants and animals

Plants need usable nitrogen for their growth and they acquire it from the soil and/or water they live in (Groffman *et al.*, 2002). Nevertheless, Deacon (1997) stated that nitrogen is the key component of chlorophyll, which facilitates the photosynthesis process in plants. Amino acids, proteins, and DNA all contain nitrogen in large amounts. Plants cannot carry out the metabolic reactions they require to thrive without amino acids, which are the building blocks of proteins. However, nitrogen is also a constituent of ATP (Adenosine Triphosphate), which allows cells to conserve and use the energy released in metabolism (Deacon, 1997).

Furthermore, DNA is the genetic substance that enables plants and animals to reproduce and grow. For their metabolism, growth, and reproduction, animals consume living or dead organic matter containing nitrogen molecules.

2.2.4 Environmental impact of Nitrogen

Despite the rapid increase in yield due to a large increase in human production of nitrogen fertilizers for agricultural output, an increase in reactive nitrogen in the environment has been observed, with evidence of negative impacts (Vitousek, 1997; Howarth, 2004). Due to the presence of excessive environmental Nitrogen, major environmental problems such as acidification of soil and water resources, surface and groundwater contamination, ozone depletion and crop injury, greenhouse gas levels due to N₂O emission, loss of biodiversity in ecosystems, invasion of Nitrogen loving weeds, increased atmospheric haze, and production of airborne particulate matter have developed (Galloway *et al.*, 2002).

2.3 Phosphorus

Phosphorus is a vital mineral for life processes, just as nitrogen is for plants and animals; it is a key component of nucleic acids and phospholipids, and it makes up the supporting components of our bones as calcium phosphate. In aquatic ecosystems, particularly freshwater environments, phosphorus is frequently the limiting nutrient (required for growth) (Fowler *et al.*, 2018). On the other hand, Billah *et al.*, (2019) stated that Phosphorus (P) is a macronutrient that plays essential role in plant growth and participates in many metabolic reactions. Phosphorus occurs in nature as the phosphate ion (PO₄³⁻) (Fowler *et al.*, 2018).

Additionally, Phosphate is one of the main limiting elements for biomass production in terrestrial ecosystems, and the reason for the ongoing eutrophication of continental and coastal waterways is because of extensive utilization of Phosphosphate–fertilizers (Billah *et al.*, 2019). Natural surface runoff occurs when Phosphates are leached from phosphate-containing rock by

weathering, sending phosphates into rivers, lakes, and the ocean, in addition to phosphate runoff caused by human activities (Fowler *et al.*, 2018).

Phosphorus exists in a multitude of forms, or species, according to Roy & Bickerton (2014), and the species present can change as they migrate between the air, water, and soil. However, Roy & Bickerton (2014) added that Phosphorous (containing PO_4^{3-}) are the most common form of phosphorus in natural waters. Despite the fact that phosphates are only moderately soluble and, in comparison to nitrate, are not extremely mobile in soils and groundwater, they are nonetheless important. Phosphates tend to remain attached to soil particles, but erosion can transport considerable amounts of phosphate to streams and lakes (Roy & Bickerton, 2014). According to Mosepele (2009), phosphorus is a critical ingredient for plant and animal growth in water. Its concentrations in clean waters, on the other hand, are typically minimal. It is introduced in a waterbody as a natural element found in rocks and soils and from human activities (Mosepele, 2009).

2.4 Ortho-phosphate

Ortho-phosphate is one phosphorus atoms bonded to four oxygen atoms (Dabkowski & White, 2015). Ortho-phosphate is also known as "phosphate" or "reactive phosphorus" because it is particularly easy to bind with other positive elements and compounds since it has three "extra" electrons that are drawn to protons. Phosphate, which is a required ingredient for most organisms' growth, makes up nearly all of the phosphorus in water (Dabkowski & White, 2015).

Erickson *et al.*, (2017) described Ortho-phosphates as normal phosphates which are composed of one phosphate unit per molecule. The water quality parameter Orth-ophosphate, on the other hand, identifies the amount of readily available phosphate in the water.. It does not include any

phosphate bound to plant or animal tissues (Erickson *et al.*, 2017). In addition, the total Ortho-phosphate test is largely a measure of Ortho-phosphate.

Erickson *et al.*, (2017) stated that in worstcase scenarios, aquatic life can suffocate and die.

According to US EPA guidelines, the difference between Total phosphate measures and total ortho-phosphate measures is that the Total *Ortho-phosphate* test is largely a measure of Ortho-phosphate. Because the sample is not filtered, the procedure measures both dissolved and suspended Ortho-phosphate. The EPA-approved method for measuring total Ortho-phosphate is known as the ascorbic acid method.

The Total Phosphorus test, on the other hand, measures all types of phosphorus in the sample (Ortho-phosphate, condensed phosphate, and organic phosphate). Others measure what is already there as well as what is created when other forms of phosphorus are transformed to Ortho-phosphate through digestion (US EPA, 2000).

South African Water Quality Guidelines for Aquatic Ecosystems stipulate that phosphate levels must not exceed 2.5 mg/l for the protection of aquatic life (Department of Water Affairs and Forestry (1996). While US EPA (2000) stated that to control eutrophication, the USEPA has established a recommended limit of 0.05 mg/L for Total Phosphates in streams that enter lakes and 0.1 mg/L for Total Phosphates in flowing waters (U.S. Environmental Protection Agency, 1986) (Table 1).

Table1: Concentration limits for the water quality parameters of interest as set by the IWQGES and SAWQG.

Parameters	General Standards for IWQGES	General Standards for SAWQG
Total Nitrogen	0.3 mg/l	2.5mg/l
Total Phosphate	0.1mg/l	2.5 mg/l
Ortho-phosphate	0.1mg/l	0.1mg/l

2.5 Nutrient load in the Kavango River

A few studies have been conducted for investigating the water quality of the Kavango River system (Vushe *et al.*, 2014). Mosepele (2009) stated that Total nitrogen and Total phosphorous which include organic phosphorous and inorganic phosphate are typically low in concentration and are difficult to detect accurately by conventional laboratory methods. The water quality of the Kavango River measured in Namibia remains not polluted overall and the river contains low concentrations of nutrients, turbidity and suspended solids (Bethune, 1987; Bethune, 1991; Gronberg *et al.*, 1995; Turton 1999; Hay *et al.*, 2000; Trewby, 2003; Anderson, 2006).

The National data on nutrients indicators in the Kavango river system has shown that the purity of the River indicates that it is extremely deficient in nutrients (Mendelsohn & Obeid , 2004). According to Bethune (1987) stated that the oxidized nitrogen, which is the sum of the nitrate and nitrite, was below detection limits in the first half of 1984. However, the highest concentration was recorded at 0.8 mg/L in May of 2002 (Trewby, 2003), but during the latter half of the same year, it was again too low to be detected. This was double the highest concentration that was recorded during the Limnological Baseline Survey of the Kavango River of 1984 – 1986, which was 0.43mg/L in May 1985 (Bethune, 1987).

Trewby (2003) found that the total phosphorous concentration in the Kavango River is an order of a magnitude lower than the total nitrogen, with its maximum for the entire stretch of the Namibian side being 0.37mg/L compared to the Total Nitrogen being 3.8 mg/L. In 2006, Andersson (2009) found that the phosphorous concentrations were similarly low or even lower than those quoted by Trewby. However, according to Mosepele (2009), this study concentrated on large-scale agricultural farms, and it was clear that there were no substantial differences in phosphorous concentrations between regions above and below these large-scale agricultural projects.

Bethune (1987) observed that ortho-phosphate concentrations were higher in the mainline sites. Given that the majority of the study locations are at human access points to the river, this can be attributed to human and livestock wastes as well as laundry detergents. According to Bethune (1991), the nutritional concentration in the mainstream is very low. Total Nitrogen (N) mg/l ranged from 0.1 to 1.5, Phosphate mg/l ranged from 0.01-0.15, and Potassium mg/l ranged from 1-2. Furthermore, the water quality is good and consistent along the river, however it may fluctuate in the backwaters. Furthermore, the nutrient levels were generally low, indicating an unenriched system, but somewhat greater phosphate concentrations were detected at human access locations where cattle manure and detergents may have been present.

A study conducted by Mosopele (2009) on the Kavango river have indicated that the nutrients in the waters of the Kavango River were very low or undetectable. During the wet season, Mosopele (2009) indicated that there was no difference in the undetectable nutrient concentrations in both the mainstream and the backwater of both sites. Total Nitrogen in the mainstream during dry seasons (Low flow) was between 0.02 mg/dm³ -0.5mg/dm³. During wet seasons (High flows) in the mainstream was less than 0.02mg/dm³ -0.2mg/dm³ while total

phosphate in the mainstream during the dry season (low flows) was only less than $0.2\text{mg}/\text{dm}^3$. During wet seasons (High flows) was only less than $0.2\text{mg}/\text{dm}^3$.

However, a slightly higher concentration of Total Nitrogen was recorded in the isolated floodplain pool at Kapako during the dry season (Mosopele, 2009). The total phosphates were also mostly undetectable during the wet season at both sites with a slightly higher concentration in the Kapako floodplain pool during the dry season. Kay *et al.*, (2010) estimated that agriculture was responsible for more than 50% of nitrate and 30–50% of phosphorus pollution in some catchments.

Water quality monitoring studies by Trewby (2003) and Andersson (2006), who sampled suspected highly polluted points on the Kavango River, concluded that the level of pollution was low, and hence the river system was coping with the pollution load. Trewby (2003) suspected that the 300 Ha irrigated commercial agriculture was contributing more nutrient pollution than any other land use.

According to Mosopele (2009), the nutrient richness or trophic level of the Kavango River is therefore classified as oligotrophic in the wet season since all the recorded $\text{NO}_3\text{-N}$ (Nitrate Nitrogen) values were less than $0.3\text{ mg}/\text{dm}^3$ (Massachusetts Water Watch Partnership) in the mainstream and backwater sites. Mosopele (2009), on the other hand, found a small increase in nutrient concentration of less than $0.5\text{ mg}/\text{dm}^3$ in the mainstream of both locations during the dry season, indicating a mesotrophic state.

Spatially, there were no significant differences in temperature, but other parameters showed significant variability that may be attributed to geology, soils, and land cover. However, Mosopele *et al.*, (2018) stressed that the Okavango River Basin water quality is relatively

pristine, which makes sense given the low human development impact in the basin. The basin's wetland vegetation is partially responsible for the waters' pristine, while the substrate of the Kalahari sand also contributes significantly to water quality. Wetlands also have the ability to remove nutrients from surface water, resulting in freshwater.

The Okavango Delta's increased surface water quality has been ascribed to evapotranspiration and chemical precipitation (Mosepele *et al.* 2018). Land-use activities such as mining, agriculture, industrialisation and settlements affect the water's quality. However, agricultural activities in the basin result in low nutrient enrichment because of minimal use of fertilizers, herbicides and pesticides. Water quality studies, on the whole, demonstrate that the waterways are aerated and meet the Environmental Protection Agency's (EPA) guidelines (Mosepele *et al.*, 2018). Also flood plain along the river has an influence on the water quality of the river. Mosopele (2009) found that at areas characterised by the main channel and floodplain with isolated pools and backwaters such as Kapako had very low nutrient concentrations.

Mosopele (2009) stated that the chemical constituents in the backwaters of this stretch of the river were slightly more concentrated especially in the dry season with low flow rates. This is due to gradual drying because of the absence of moving streams in these backwaters. All in all, the pristine of the Kavango River indicates that it is extremely deficient in nutrients (Mendelsohn & Obeid, 2004).

2.6 Irrigation Schemes along the Kavango River

Irrigation projects have been established following the Government's Vision 2030 goal of utilising all arable land by the year 2030 (Liebenberg, 2009). In the Kavango Region, there is potentially unlimited land available for the development of irrigation schemes, but the volume of water remains a limiting factor (Ortman, 2012). According to Liebenberg (2009), the seasonal flow pattern of the Kavango River is the most critical restriction in terms of

establishing locations for the development of future irrigation schemes. The upstream flow of the Cuito River is highly seasonal, whereas the downstream flow is more uniform due to the more steady inflow from the Cuito. The area currently under irrigation is 2197 ha (Liebenberg, 2009). Figure 2 shows the present irrigation schemes and the size and water requirements of each.

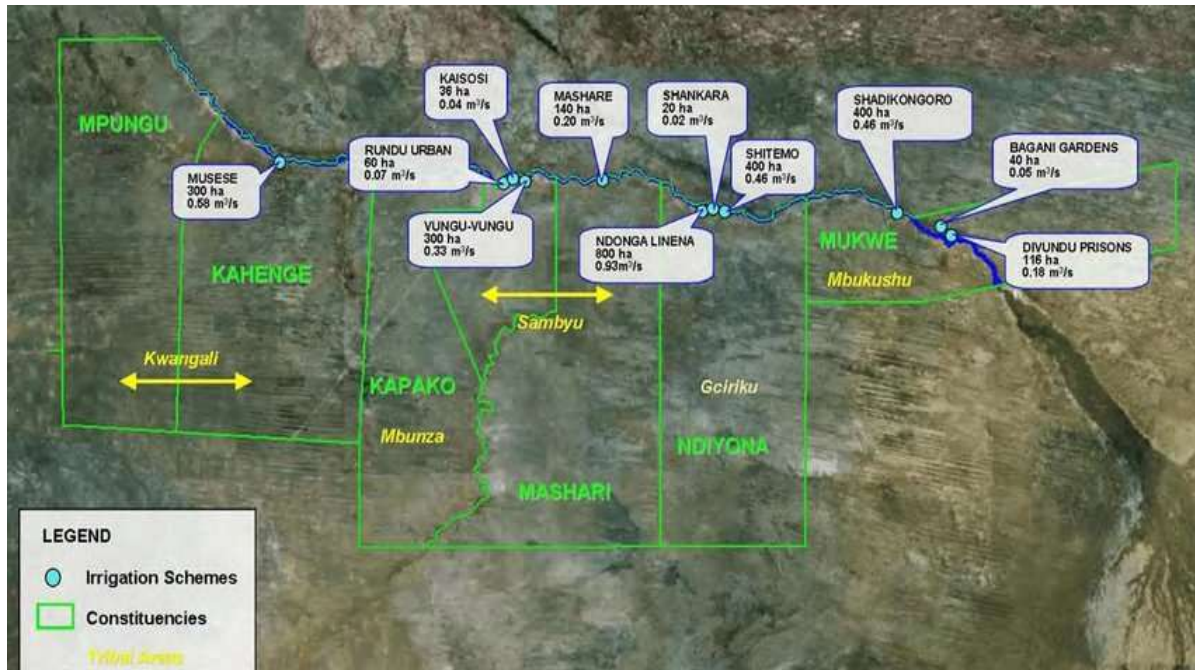


Figure 2: Map indicating the present and future irrigation schemes along the Kavango River
 Source: Liebenberg P, 2009.

2.7 Indicators (Dissolved Oxygen and Flow rate)

2.7.1 Dissolved oxygen

Refers to the amount of oxygen dissolved in water and is related to photosynthesis by water plants and aeration as well as decomposition. It is important to organisms living in the water (Masopele, 2009). Additionally, along the river, areas where there are rapids/ waterfalls, ventilation increases resulting in a higher concentration of oxygen in the water (Masopele, 2009).

Dissolved oxygen (DO) (expressed in mg/l) is the concentration of oxygen that is dissolved in water. Oxygen is introduced into the water through photosynthesis by plants and phytoplankton or via diffusion from atmospheric air and through aeration during turbulent mixing (Breitburg, 1990; Sanford *et al.*, 1990). The presence of pollutants in the water may either suppress oxygen production or kill plants and phytoplankton, hence the relevance of DO as an indirect measure of pollution (Engle *et al.*, 1999). Byproducts from sewage effluents, runoff from livestock waste, food waste, decomposing plants, and animals may also reduce dissolved oxygen in the water (Rabalais & Turner, 2001; Rabalais *et al.*, 2001).

In the Okavango Delta concentrations of DO are generally higher than the minimum (2.4 mg/l) required by aquatic life (Koukal *et al.*, 2004). Measurements made between 2005 and 2009 during flooded seasons showed that a majority of sampling points had mean dissolved oxygen values between 2.7 and 5.5 mg/l (Mmualefe, 2010). Masamba and Mazvimavi (2008) reported DO values between 1.85 and 8.81 mg/l from July to November 2005 along the Thamalakane-Boteti River. Low DO in the water was attributed to the decomposition of organic matter or anthropogenic introduction of oxygen-consuming material (such as livestock waste).

This indicator is one of the most important water quality parameters, as it is an essential element for the maintenance of healthy rivers. For living, most aquatic plants and animals require a particular amount of oxygen dissolved in water. Trewby (2003) found that in both the winter (July) and summer (August), the DO concentration in the Mupini floodplain was greater than in the rest of the river system (December). The averages were 8.6 and 7.8 mg l⁻¹, respectively.

The dissolved oxygen concentration measured within a season at the mainstream and channel sites was more or less the same throughout the length of the river during the Limnological Baseline Survey of the Kavango River in 1984–86, with the exception that below the Popa

Rapids, the DO concentration increased slightly due to aeration. From March (5.8 - 8.1 mg l⁻¹) to October (7.1 – 9.4 mg l⁻¹) the oxygen concentrations increased. (Bethune,1987).

Hocutt (1997) indicated that the dissolved oxygen throughout the flowing waters of the Kavango is generally high and near saturation conditions. In contrast, studies by Cronberg *et al.*, 1996 stated that the DO content of the water was substantially below saturation and therefore reflected stagnant conditions throughout the wetland. According to the 1998 report on the Transboundary Diagnostic Analyses of the Kavango River, these variations in results probably reflect the relative stages of flood progression in the specific areas of study. The levels of oxygen decreased with increasing flow.

In the floodplain pools, the oxygen levels are higher by day than at night due to photosynthesis and decrease with depth in isolated backwaters due to decomposition (Bethune, 1991 - Kavango River Wetlands). The study of Anderson, 2006, indicated that dissolved oxygen levels were elevated at sampling sites below the Cuito River confluence with the Kavango River. It seems that the Cuito has a diluting effect and carries less dissolved solids and less dissolved oxygen than the mainstream before the confluence.

2.7.2 Flow rate

Mosopele (2009) stated that fast flows over rapids increase aeration and thus the concentration of oxygen in the water. However, in slow-moving water, organic material decomposes more quickly, resulting in higher nutrient concentrations. In addition, many rivers turn green with low flows, and turbidity levels are low. Because of soil erosion, turbidity in most rivers rises following rainfall and flooding (Mosopele, 2009). Decomposition of organic material occurs more quickly in slow-flowing water, and nutrient content rises (Mosopele, 2009)

CHAPTER 3: MATERIALS AND METHODS

3.1 Description of the study area

The Kavango River originates in the central highlands (approx. 1700 m a.s.l.) of Angola, where it is known as Rio Cubango (Smit 1991). The river is shared by three countries, Angola, Namibia and Botswana, and covers an area of about 192 500 square kilometers, which include three urban centers namely; Menongue, Rundu and Maun (Mendelsohn and El Obied 2004). In Angola, the river is called Rio Cubango, whereas in Namibia, the river is called Kavango, attributed to the Kavango regions through which it flows. Kavango Regions (Kavango East and west) are among the 14th regions designated for purposes of administration and political representation. The borders of the region have changed twice in recent years as has its name. The name “Kavango” was used for several decades by the previous government in 1992, and was changed to “Okavango” and then back again to “Kavango” in 1998 (Mendelsohn & El Obied 2004). In Botswana, however, the river is known as the Okavango River/Delta.

The Kavango river flows in a south-easterly direction, entering Namibia at Katwitwi and forms the border between Namibia and Angola before turning south towards into Botswana (Hay *et al.*, 2000). The steepest gradient of the Kavango River is in the upper reaches, levelling off as the river enters Namibia, where it creates large flood- plains with sandy substrates and rocky outcrops, with abundant aquatic vegetation (Hay *et al.*, 2000). After a distance of 460 km within Namibia, the river enters Botswana where it evaporates in the swamps of the Okavango Delta (Hay *et al.*, 2000).

According to Mendelsohn and El Obied (2004), the river transports around 9.4 cubic kilometers of water into the fan-shaped, vast Okavango Delta. Every year, the Delta waters nourish a unique freshwater marsh that is rich in species. It is known as the largest fresh water wetland in southern Africa, and is also a World Heritage Site (Mendelsohn & El Obied 2004).

Chonguiça & Molefi (2014) stated that the Delta is renowned for its abundance of plant and animal life.

A study done by Mendelsohn & El Obied (2004) reported that more of the Kavango's water flowing through Namibia and Botswana has been drained from catchment areas in Angola. Namibia thus contributes almost no water to the Kavango river. The Kavango floodplain system in Namibia consists of the main river, standing backwaters, swamps and floodplains covered by water only parts of the year (Hay *et al.*, 2000). Chonguiça & Molefi (2014) indicated that the floodplains sustain the river in the dry season and also store floodwaters that would otherwise increase flooding downstream. The water-covered areas vary considerably between the dry and rainy seasons. Hay *et al.*, (2000) stated that the floodplains are complicated ecosystems where terrestrial and aquatic elements are closely interlinked. In addition, the fish communities are usually diverse, and their population dynamics, migration patterns, habitat use and production rates are poorly known.

Hocutt *et al.*, (1994) divided the river into four zones according to habitat (see figure 3). Zone 1 stretches from Katwitwi to Kasivi and is characterized by shallow water with sandy and rocky substrates. Zone 2 (see figure 3), which stretches from Kasivi to Mbambi, is characterized by developed floodplains with large oxbow lakes and backwater habitats. Zone 3 (see figure 3) is from Mbambi to Popa Falls, and is characterized by many rapids and a substratum of sand and gravel with large boulders. Zone 4 (see figure 3), which stretches from Popa Falls to the Namibia/Botswana border, forms the beginning of the Okavango Delta panhandle and features large flood- plains (Hay *et al.*, 2000). Several tributaries join the Kavango from the north. The Cuito River is the major tributary entering Okavango at Katere, approximately 100 km from Rundu (Hay *et al.*, 2000). Indeed, for seven months of the year the Cuito contributes more water than the Kavango (Mendelsohn & El Obied 2004). Hay *et al.*, (2000) stated that the water

flow of the Cuito nearly doubles the annual flow of the Kavango, thus playing a major role for the fish population downstream. The only southern tributary of any significance is the Omuramba Omatako, which drains the northeastern parts of Namibia. Although certain sections of this system sometimes are water filled, it only rarely reaches the Kavango River (Hay *et al.*, 2000).

The annual flood in the Namibian portion of the Kavango starts during December, reaches its peak in March - April and recedes during May. However, the intensity, timing and duration of the flood depends on the rainfall in Angola. Summer rainfall in the catchment area (an estimated 115,000 km²) is the primary source of inflow into the river (Hay *et al.*, 2000).. The annual discharge of the Kavango at Rundu is between 5,000 and 6,000 million m³ (Hay *et al.*, 2000). This runoff is increased by the inflow from the Cuito River so that the annual discharge in the Kavango at Mukwe has nearly doubled to over 10,000 million m³. Mukwe has a nearly two-fold larger water discharge in cubic meters per second than Rundu. The water discharge at Rundu and Mukwe is highest in April (Hay *et al.*, 2000).

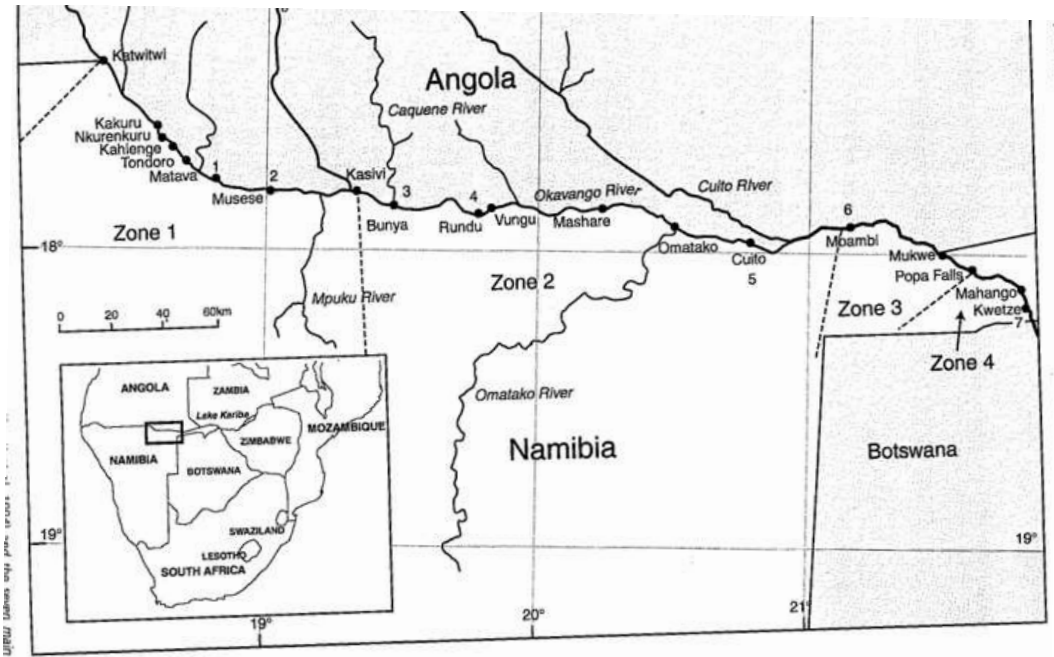


Figure 3: The Kavango River with the four zones (according to Hocutt *et al.*,1994) and the seven sampling localities (according to Hay *et al.*,2000).

The study area covered a 194.3 km long section of the Kavango River from Rundu to Divundu. Water sampling was conducted along the Kavango River in the north-eastern part of the country. This portion of the river included the Cuito's primary tributary's confluence, as well as five other sites from west to east, including irrigation systems and towns. The six selected sites are Rundu, Mashare Irrigation Scheme, Cuito, Shitemo Irrigation Scheme, Shadikongoro Irrigation Scheme and Divundu (Figure 4). Each site was sampled upstream (Before the site) and downstream (After the site) from Rundu to Divundu.

Table 2: The distance before and after each sampled site along the Kavango River and Geo-referenced points.

Site Name	Distance (Km)	Geo-referenced points
1. Before Rundu	0	S17.89235 E019.73504
2. After Rundu	7.5	S17.87116 E019.80344
3. Before Mashare	43.5	S17.89409 E020.14966
4. After Mashare	53	S17.89409 E02.26354
5. Before Shitemo	74.1	S17.95381 E020.56447
6. After Shitemo	81.4	S17.98446 E020.50218
7. Before Quito	104.2	S18.02403 E020.77746
8. After Quito	108.2	S18.03136 E020.80012
9. Before Shadikongoro	164.58	S17.98974 E021.34014
10. After Shadilongoro	174.3	S18.02242 E021.42005
11. Before Divundu	179.8	S18.05197 E021.44297
12. After Divundu	194.3	S18.10897 E021.55790

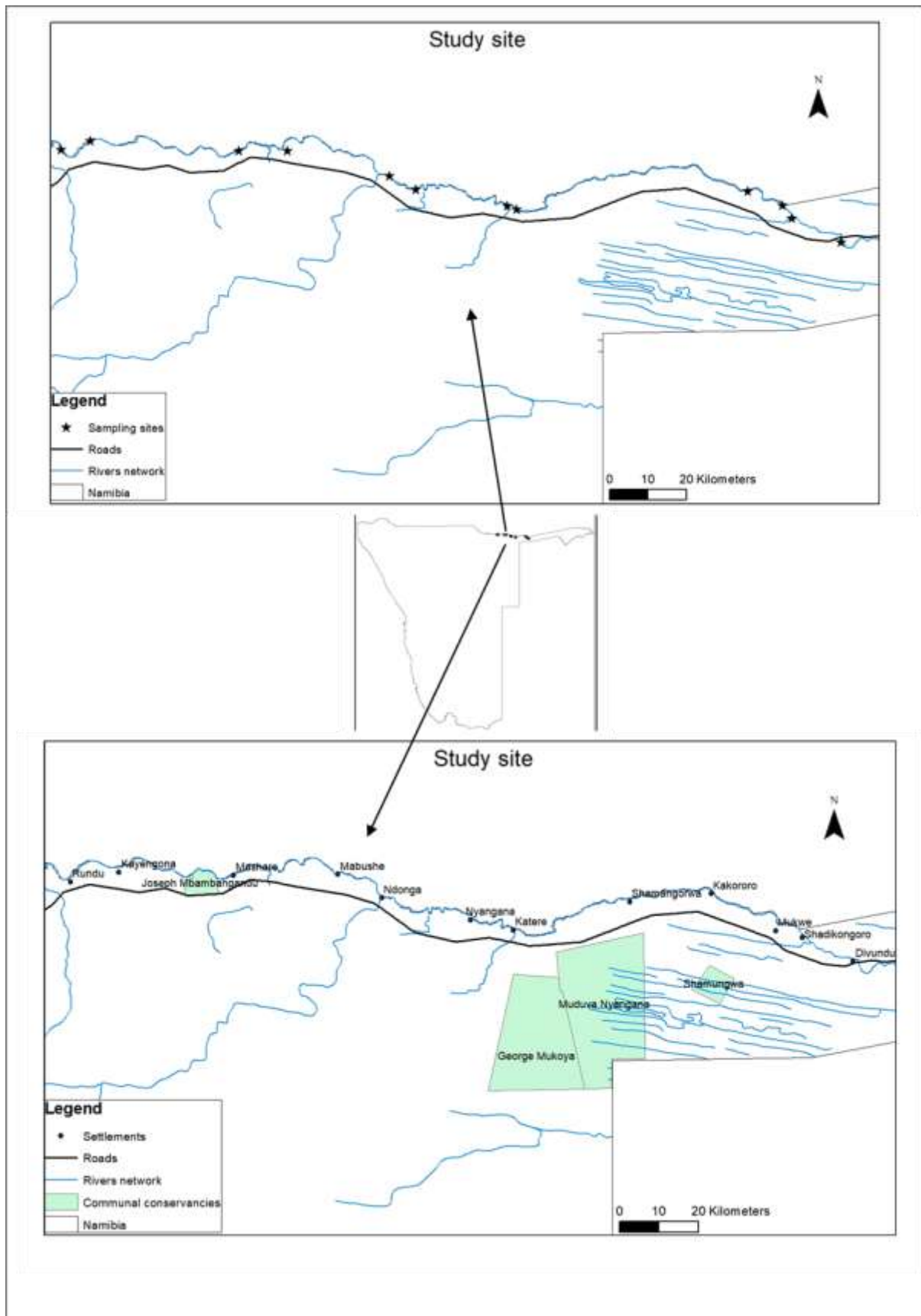


Figure 4: The location of the sampled sites along the Kavango River.

3.1.1 Climate

The climate of the Kavango's catchment area in Namibia is subtropical, with a long, dry cool season and a short, hot wet season (Hines, 1997; el Obeid and Mendelsohn, 2001). The summers are very hot with a mean maximum temperature of 34 °C, and winters are mild with a mean minimum temperature of 6 °C. The occurrence of frost is rare. The Kavango Region has a mean annual rainfall of 600 mm, although it is highly variable, both between and within years (Hines, 1997). The evaporation occurs in September and October and exceeds precipitation by a factor of three, (Ellery, 1997; el Obeid & Mendelsohn, 2001). Farmers take into account the high variability of rainfall by staggering ploughing and planting of crops through the rainy season. Wind velocity is generally low, averaging around 3 kilometers per hour, and the prevalent direction ranges from northeast to south. In January some winds may blow from the west (el Obeid & Mendelsohn, 2001).

The study area is semi-arid with an average annual rainfall of 400 - 600 mm, most of which falls during the summer (December-April) (van der Merwe, 1983). Rainfall decreases more or less in a north to south and south-west direction (van der Merwe, 1983). The mean annual temperature of the weather station at Rundu is 22.2°C. Mean summer temperature (December to February) is 24.8°C and mean winter temperature (June to August) 17.1°C Daily temperature ranges are at their highest in the winter, when frosts are a possibility. The frequency of strong winds starts increasing in winter and usually peaks during November, before the onset of the rainy season (Simmonds, 2000). During the survey period (February and April/May 1999) a total of 485.6 mm precipitation was recorded at Rundu for this rainy season.

3.1.2 Fauna

Cattle and goats are the predominate animals in the Kavango East and West regions since the majority of residents are subsistence farmers. The Kavango river supports a variety of reptiles,

fishes, and mammals. The common largest reptiles and mammals are crocodile (*Crocodilu niloticus*) and hippo (*Hippopotamus amphibious*) whereas there are approximately 25 species of fish in the river (Hocutt and Johnson, 2001). Other wildlife species in the area that are not restricted to the river include *Loxodonta Africana* roaming freely .

3.1.3 Flora

Kavango west, and east regions fall within the Broad-leaved woodlands vegetation type. As such it is dominated by more than 15 hardwood species (Burke, 2002). *Eriochrysis pallida*, *Thpha latifolia*, *Nymphoides indica*, *Potamageton schweinfurthii*, are among aquatic plants found in the Kavango river (Hocutt & Johnson, 2001).

3.1.4 Geology and soil

This is an environment of aeolian sands, which is an ancient erg extending from the Northern Cape in South Africa to the Congo; initial sand deposition started in the mid-Tertiary (Skinner, 2000). The Kalahari is underlain by thick geologically ancient Precambrian granitoid rocks, with poor surface exposure due to the thick sands (Scholes & Parsons, 1997). Two principal physiographic regions dominate the Kavango region. The first is the riverine landscape, comprised of the main Kavango River channel, floodplains with braided channels, and a fluvial terrace with alluvial deposits. The second region consists of Kalahari sands dominated by linear dune systems and undulating plains (Hines, 1997; Schneider, 1986; Simmonds, 1997).

The dune systems are flat to gently undulating with the dune ridges and slacks (omurambas) trending east-west. The substratum consists of calcareous sand and gravel from the Kalahari beds which are mainly of aeolian origin. The Nosib Formation laid down 850 to 700 million years before present, occurs at shallow depths east of Rundu and is comprised of conglomerate, phyllite, and quartzite (Dierks, 1994; Ellery, 1997). The Kalahari sands were deposited on Tertiary calcretes and have been eroded and partially reworked by wind and water (Simmonds,

1997). The principal soil types are related to the physiographic regions. Fluvisols occur in the Kavango and Omatako floodplains.

These soils are developed in alluvial deposits, and are flooded regularly along the Kavango River. These are the most fertile soils of the region and are exploited for crop production (Mendelsohn *et al.*, 2002). On the south and west banks of the Kavango River terrace system, the fluvisols can be divided into three general soil sub-types in the area: Clovelly, Oakleaf, and Hutton, using the South African Soil Classification System (Schneider, 1986). These exhibit physical, chemical and mineralogical properties typical of arid-region soils, with orthic topsoils and apedal (no structure) B horizons (Mpumalanga Soil Mapping Project, 2003).

It display a moderate to high base saturation, which results in slightly acid to slightly alkali soils (pH 6.8-7.6). The cation-exchange-capacity is low and kaolinite is the most abundant clay mineral (Schneider, 1986; Simmonds, 1997). Estimated distribution of the two main soil types, fluvisols and arenosols in the Kavango Region. The fluvisols occur with riverine forests, floodplains, Omatako drainage and dry tributaries to the Kavango River.

The soils of the sandveld surrounding the riverine environment are comprised of arenosols. These are developed in sediments of aeolian origin, and have very high sand contents. This results in rapid infiltration of water and little retention of nutrients, which makes them infertile and difficult to cultivate (Mendelsohn *et al.*, 2002). The loose grey sands of the Sandspruit series are found in the north eastern stabilized Kalahari dunes, where there is a deep sand mantle but little or no relief. A catenary succession of soils exists where relief and drainage are more defined. Red sands on higher slopes, yellowish-brown sands in the middle, and grey sands or heavier darker soils at the bottom are examples. Grey sandy loams are present in the omarumbas, which cause internal drainage problems and salinization if they are watered

(Simmonds, 1997). Where the terrace system is discontinuous, the soils are red loamy sands with inclusions of grey coarse sandy loams (Simmonds, 1997).

3.2 Research design

This study was done at sites in Kavango East Region along the Kavango River. The sites sampled were Rundu, Mashare, Shitemu Irrigation Schemes, Quito, Shadikongoro Irrigation scheme down to Ndonga Linene in Divundu. Upstream (before the site) and downstream (after the site) samples were taken at each location. During the dry season, from July 20th to July 24th, 2020, two samples were obtained from each site, once per site, within four days. Purposive sampling method was employed throughout the study, in keeping with the objectives of the study.

3.3 Data collection

3.3.1 Selection of the study sites and water sampling

To address the research questions and objectives, nutrient concentration data were collected at six (6) selected sites in the mainstream along the Kavango River within Namibia. The sample sites were Rundu, Mashare Irrigation Scheme, Shitemo Irrigation Scheme, Quito, Shadikongoro Irrigation Scheme, and Divundu (Figure 4). These sites are approximately 7.5 – 194.3 km apart from each other. These sampling sites were largely selected based on their proximity to settlements and Irrigation schemes. The settlements were located at Rundu and Divundu (Figure 11 and 16 respectively), and the irrigation scheme sites were Mashare Irrigation Schemes, Shitemo Irrigation Schemes and Shadikongoro Irrigation schemes (Figures 12, 13 and 15 respectively). Sampling was also done at the Cuito River (Figure 14), which is a tributary river to the Kavango. For all the selected sites, sampling was done before and after the sites in a downstream direction due to Irrigation Schemes and Land use activities taking place along the river. The sampling was done over a 4 day during the dry season, the sampling

was collected once and the total number of samples taken was 12. Sample site locations were recorded using a Garmin etrex GPS unit.



Figure 5: Photograph of Mashare Irrigation Scheme (Photo: Haikola, E. 2020).



Figure 6: Photo of Shitemo Irrigation Scheme (Photo: Haikola, E. 2020).

3.3.2 Determination of changes in concentration levels of Total Nitrogen, Total phosphate and Ortho-phosphate with distance

In this study, the Total Nitrogen, Ortho-phosphate, Total Phosphate will be addressed as nutrient indicators of Eutrophication. In order to determine changes in concentrations of Total Nitrogen, Total phosphate and Ortho-phosphate, water samples were collected at six points along the Kavango River. Samples were collected during the dry season during mid-July from 20th-24th, 2020. The river's maximum flow is usually reached in April (el Obeid and Mendelsohn, 2001), and is lowest in July. However, three methods were utilized to test for Phosphate in the water in this investigation. These are Ortho phosphate, Total phosphate unfiltered and Total Phosphate filtered. Flow rate and Dissolved Oxygen were measured at

each site during the sampling periods. Dissolved oxygen is used as an indicator of the health of a water body, where higher dissolved oxygen concentrations are correlated with high productivity and little pollution (el Obeid and Mendelsohn, 2001) .The water samples were collected 3-5 cm below the water surface following (US EPA, 2000) standards using 500 ml polyethylene bottles. The 500ml bottles (Figure 9) that were used to collect water from the river were preserved by keeping them at about 4°C in a cooler box throughout the sampling period in the field.. After sampling during the day, the water samples were refrigerated at the Kamutyonga Inland Fisheries institution (KIFI) in Divundu, until they were taken to (Namibia Water Corporation) NAMWATER Laboratory in Windhoek. During transportation, the samples were preserved by keeping them again at about 4°C in a cooler box throughout the sampling period in the field with added ice blocks.

3.3.2.1 Total Nitrogen (TN)

Total Nitrogen concentrations were analyzed using the Koroleff (1983a) methods at the NAMWATER laboratory in Windhoek. The following equipment were required for laboratory analysis for all nutrients (Total Nitrogen, Total Phosphate and Ortho- phosphate): Heating unit, Nephelometer, Hach/Lange Spectrophotometer DR 390. Hach/Lange Spectrophotometer DR 3900 (Figure 6) is a instrument that measures the absorbance of biomolecules within the visible and UV light spectrum. It is the simplest way to perform water analysis and minimizes human error (Hach, 2015). The Code used was LCK 349 with the range of 0.05-1.50 mg/l PO₄-P (Table 1).



Figure 7: Hach/Lange Spectrophotometer DR 3900 (Hach, 2015)

Procedure: 1.3 ml of sample, 1.3 ml of solution A and 1 tablet of chemical B was added in quick succession to a dry reaction tube and closed immediately without inverting. The mixture was heated immediately (Thermostat: 60 min at 100°C). Then it was cooled down and 1 microcap C was added. The reaction tube was closed, inverted few times until the freeze-dried contents were fully removed from Microcap C and all the steaks were vanished. 0.5 ml-digested samples were slowly pipetted into the Cuvette test. 0.2 ml of solution D was slowly pipetted in the cuvette and closed immediately and inverted few times until no steaks were seen. After 15 minutes the outside part of cuvette was cleaned thoroughly and evaluated. The cuvette was evaluated in the Hach/Lange Spectrophotometer DR 3900 by inserting the cuvette in the spectrometer.

3.3.2.2 Total Phosphorus and Ortho-phosphate

Water samples were analyzed by NAMWATER Laboratory in Windhoek for both Total Phosphate and ortho-phosphates using Koroleff (1983a) method. For the determination of

Ortho-phosphate and total phosphorus, the Hach/Lange Spectrophotometer DR 390 Code: LCK 138 with the range of 1-16 mg/l TNb was used.

Procedure: The sample bottle was taken out from the cooling cabinet and was kept in safe place to obtain the room temperature. The total phosphorous analyzing kit was taken, and the foil screwed on DosiCap Zip was carefully removed. As much as 2 ml of sample was pipetted into the cuvette and immediately the DosiCap Zip was screwed back and shaken firmly. The cuvette was heated in the thermostat for 60 min at 100 °C. After cooling the cuvette in ice-bath, 0.2 ml of Reagent B was pipetted in the cuvette and immediately the Reagent B was closed. A grey DosiCap C was screwed on the cuvette and inverted few times in order to dissolve the chemical present in the Dozicap C. The cuvette was left at room temperature for 10 minutes, and then the outside part of cuvette was cleaned thoroughly by soft tissue paper. The cuvette was evaluated in the Hach/Lange Spectrophotometer DR 3900 by inserting the cuvette in the spectrometer.

3.3.3 Determination of Dissolved Oxygen (DO)

Procedure: The Waterproof Multi- Purpose Meter (EC-PCSTestr35) (Figure 8) was used to measure the dissolved oxygen value of the river water. The stable value was obtained after few seconds of inserting the DO meter into the water. This was conducted on site.



Figure 8: Waterproof Multi-Purpose Meter - EC-PCSTestr35.

3.3.4 Determination of Flow rate

The flow rate was estimated using a leaf method. The leaf was dropped in the water flow of the main river from point 0 to 5 meters at each site. These points were randomly selected at each site. The stop watch was used to record the time the floating leaf reaches 5 meters. This was conducted on site.

3.3.5 Comparing Nutrient concentration against the allowable standards

The concentrations of Total phosphate calculated (mg/l), Total Nitrogen (mg/l) and Ortho-phosphate (mg/l) were compared with the corresponding IWQGES (US EPA, 2000) and

SAWQG (Department of Water Affairs and Forestry, 1996) general standards values as shown in Table 1.



Figure 9: 500ml bottles that were used to collect the water. Photo by Vilio Muunda (2020).



Figure 4: The sampled sites along the Kavango River.



Figure 5: Map of Kavango Region showing Before and after Rundu sites.



Figure 6: Map of Kavango Region showing Before and after Mashare sites.



Figure 7: Map of Kavango Region showing Before and after Shitemo sites.



Figure 8: Map of Kavango Region showing Before and after Quito sites.



Figure 9: Map of Kavango Region showing Before and after Shadikongoro Irrigation Scheme sites.



Figure 10: Map of Kavango Region showing Before and after Divundu sites.



Figure 11: A sampled site before Rundu (Sauyemwua) along the Kavango River in the mainstream. Photo by E. Haikola (2020).

3.4 Data analysis

Data were analysed using Microsoft Excel and IBM-SPSS-STATISTICS, Version 26. Nutrient concentration data were tested for normality using Shapiro–Wilk test (Shapiro and Wilk, 1965). Simple Linear Regression was used to test for the effect of distance on nutrient concentrations along the Kavango River. The Wilcoxon Signed-Rank Test was used to compare nutrient concentration levels, flow rates, and dissolved oxygen (DO) before and after the selected sites. ANOVA and then a post-hoc analysis was used to assess the level of significance in differences amongst the sites. To test for compliance with IWQGES and SAWQG acceptable standards, One-Sample Wilcoxon Signed-Rank Test was used for Total Nitrogen and Ortho-phosphate because the data were non-parametric, while a One Sample T test was used for Total phosphate data.

CHAPTER 4: RESULTS

4.1 The effect of distance on nutrient concentrations.

Table 3. Outputs and p value of Nutrient concentration.

Nutrients	R ² Value	P value	Significant
Total Nitrogen	0.2399	0.106	No
Total Phosphate	0.1852	0.219	No
Ortho-phosphate	0.42971	0.028	Yes

4.1.1 Total Nitrogen (N)

There was no significant relationship between Total Nitrogen (mg/l) concentration in the Kavango river and the distance downstream from Rundu to Divundu ($p=0.106$; $R^2=0.2399$) table 3.

4.1.2 Total Phosphate (P)

Simple linear regression analysis showed no significant relationship between Total Phosphate (P) (mg/l) and distance along the Kavango River. ($p=0.219$; $R^2=0.1852$) Table 3.

4.1.3 Ortho-phosphate (O)

Simple linear regression revealed a negative significant relationship between the concentration of Ortho-phosphate (mg/l) and distance along the Kavango River ($p= 0.028$; $R^2=0.42971$). Approximately 43% of the changes in Ortho-phosphate along the river were due to changes in distance along the river (Figure 18).

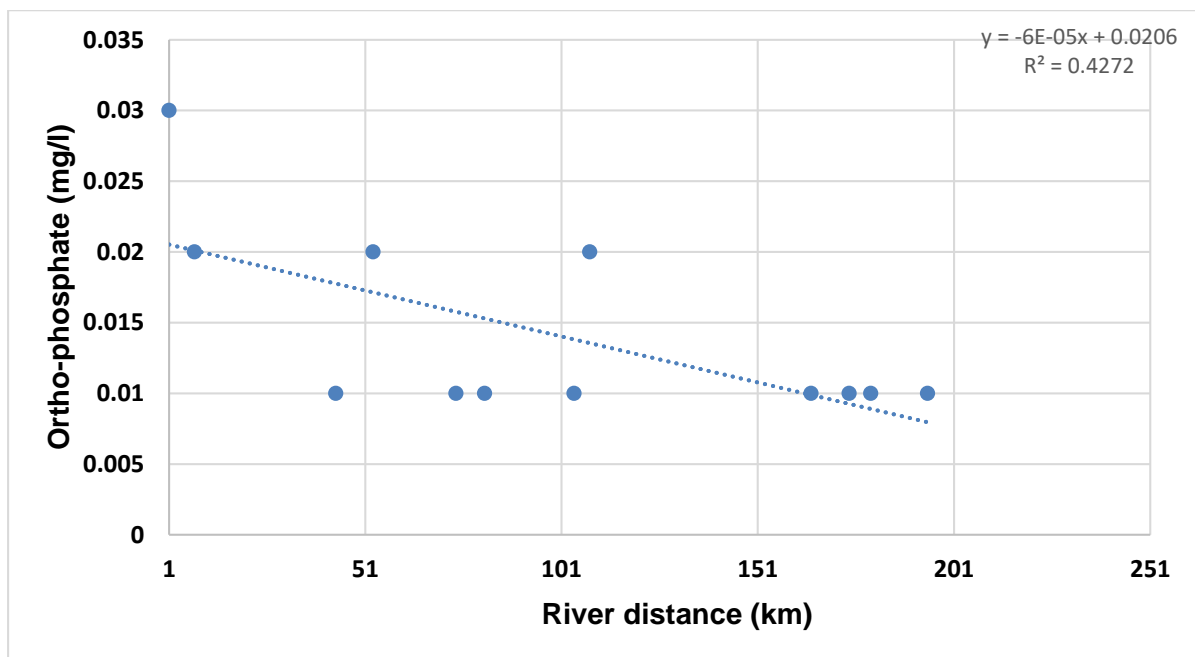


Figure 18: Ortho-phosphate (mg/l) concentration along the Kavango River, distance from Rundu.

4.2 Nutrients elements before and after sampling sites.

4.2.1 Total Nitrogen

Wilcoxon signed ranked test showed no significant difference ($Z=-1.342$, $p = 0.414$) in Total nitrogen (mg/l) Before and after the sampled sites. The total Nitrogen (mg/L) in Before and after sampling sites ranged from 0.10 mg/L to 0.30 mg/L and 0.10 mg/L, respectively, (Figure 19).

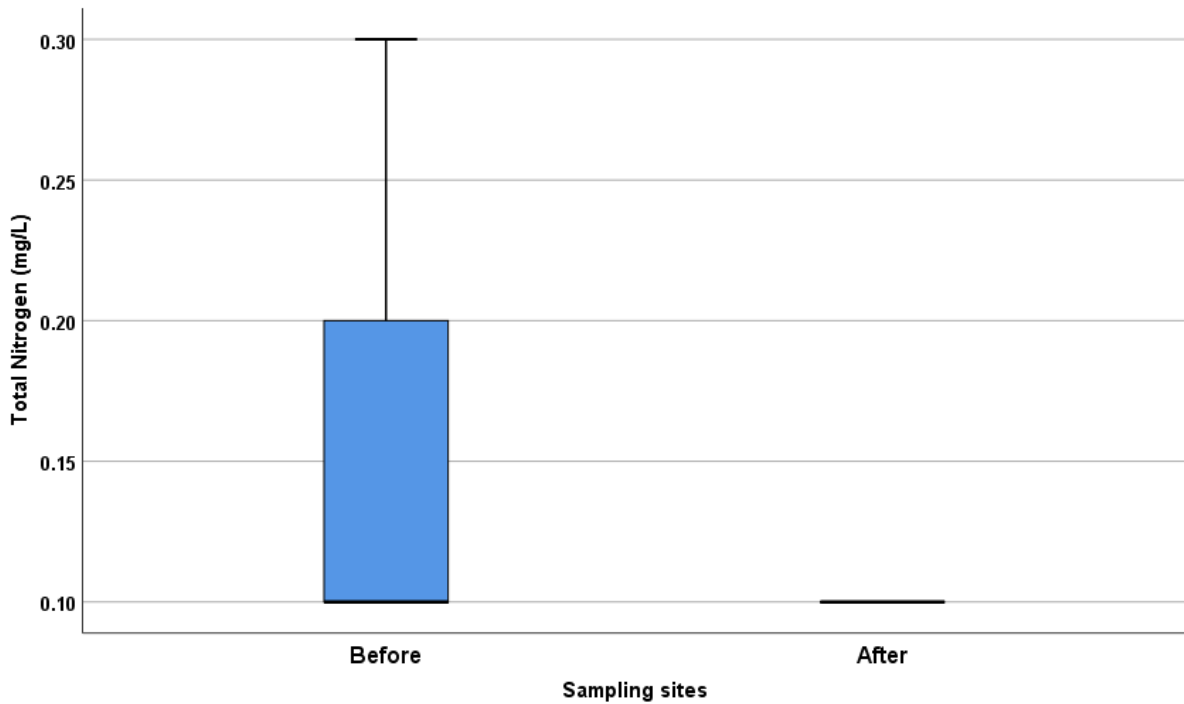


Figure 19: The difference in TN (mg/l) between before sampled sites and after sampled sites along the Kavango River.

4.2.2 Total phosphate

Wilcoxon signed ranked test showed no significant difference ($Z=-0.943$, $p = 0.345$) in total Phosphate (mg/l) between Before and after the sampled sites. The total phosphate (mg/L) in before and after sampling sites ranged from 0.07 mg/L- 0.46mg/L and 0.08 mg/L -0.36 mg/L see Figure 20.

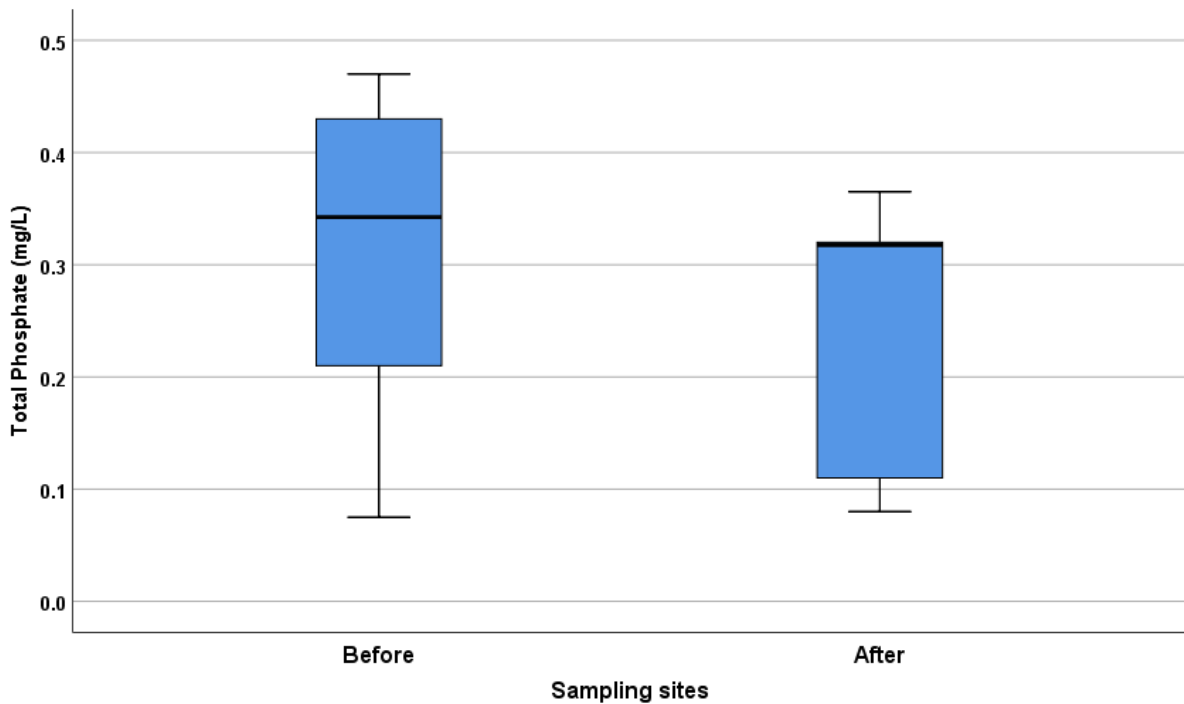


Figure 20. The differences in TP (mg/l) between before and after sampled sites along the Kavango River.

4.2.3 Ortho-Phosphate

Wilcoxon signed ranked test showed no significant difference ($Z=-0.577$, $p = 0.564$) in total Ortho-phosphate (mg/l) between before and after the sampled sites. Orthophosphate in before and after ranged from 0.010 mg/L only and 0.010 mg/L-0.020 mg/L) respectively, figure 21.

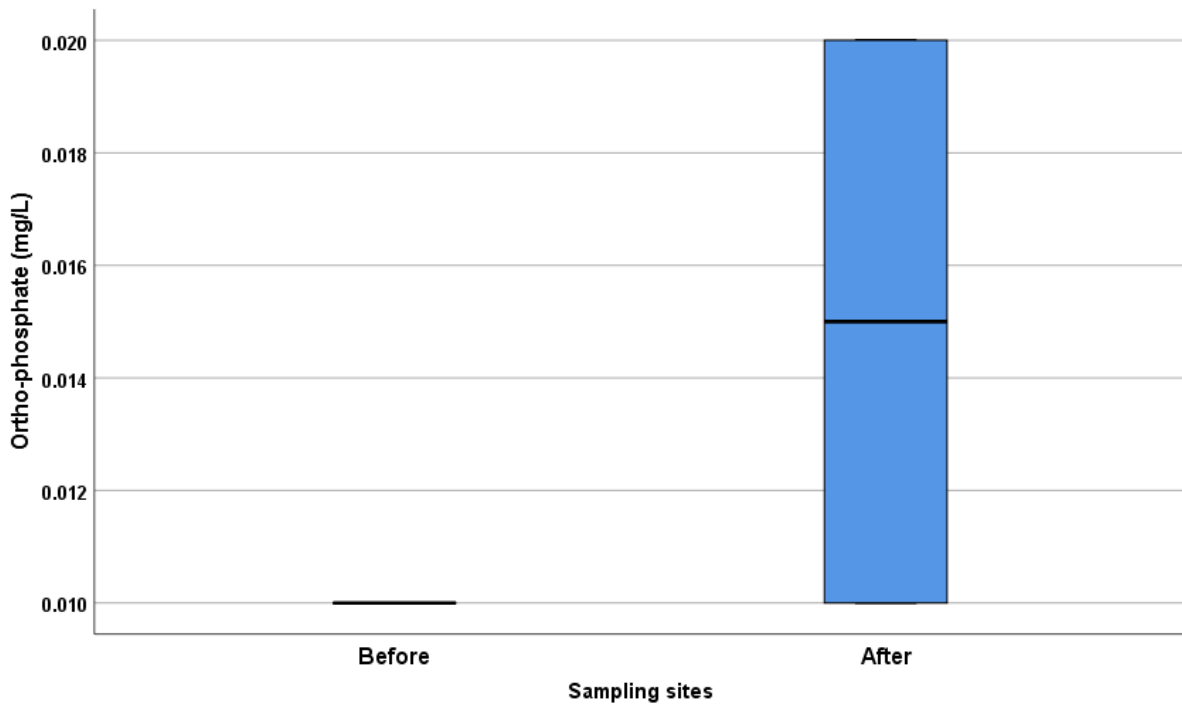


Figure 21: The differences of Orthophosphate (mg/l) between Before sampling sites and After Sampling sites along the Kavango River.

4.2.4 Nutrients elements amongst the sampling sites.

There was a statistically significant difference between the sites as determined by one-way ANOVA ($F(2,27) = 29.253, p = 0.000$). According to a Tukey post hoc test revealed that Total Phosphate and Total Nitrogen concentration resulted in significantly higher than the Ortho-phosphates among the sites ($p = 0.000, p = 0.000$ and $p = 0.005$, respectively). It is also visible in figure 22.

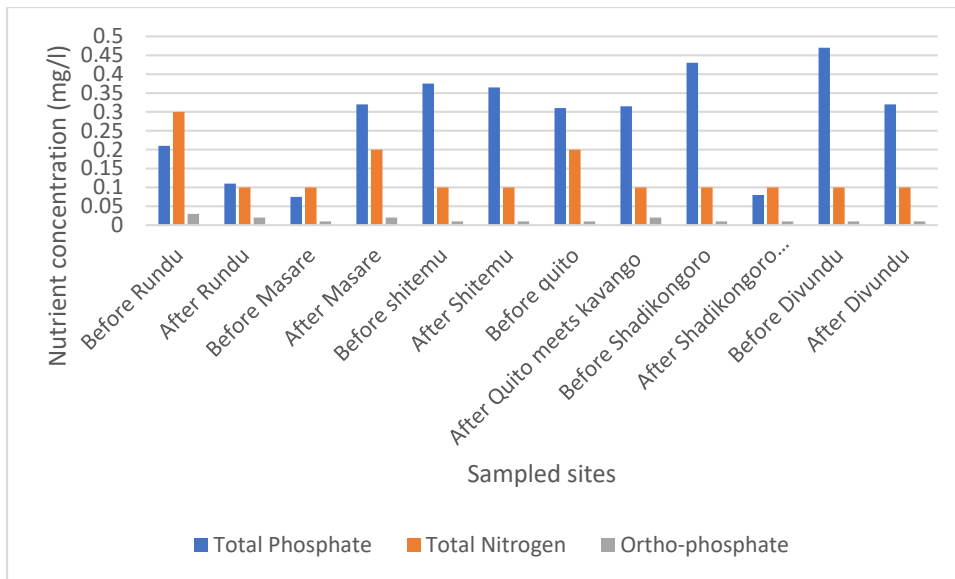


Figure 22: Nutrient concentration (mg/l) among the sites along the Kavango River.

4.3 Flow Rate

Wilcoxon signed ranked test showed no significant difference ($Z=-1.214$, $p = 0.225$) in the flow rate (mg/l) of the Kavango River between before and after the sampled sites.

4.4 Dissolved Oxygen

Wilcoxon signed ranked test showed no significant difference ($Z=-0.943$, $p = 0.345$) in Dissolved Oxygen along the Kavango River between before and after sampled sites.

4.5 Comparisons between the observed nutrient concentration with regional and international standards

4.5.1 Total Nitrogen (IQWES)

One-Sample Wilcoxon Signed Rank test indicated that the Total Nitrogen concentration allowable (general standards limit of 0.3mg/l set by US EPA (2000)) was significantly higher than the Total Nitrogen concentration observed value ($Z =0.000$; $p = 0.001$) (Figure 23). Total Nitrogen concentration was the same at all sites (0.1mg/l) except at "Before Masare irrigation scheme" and "Before Quito river" which also appear to be the same at 0.2 mg/l.

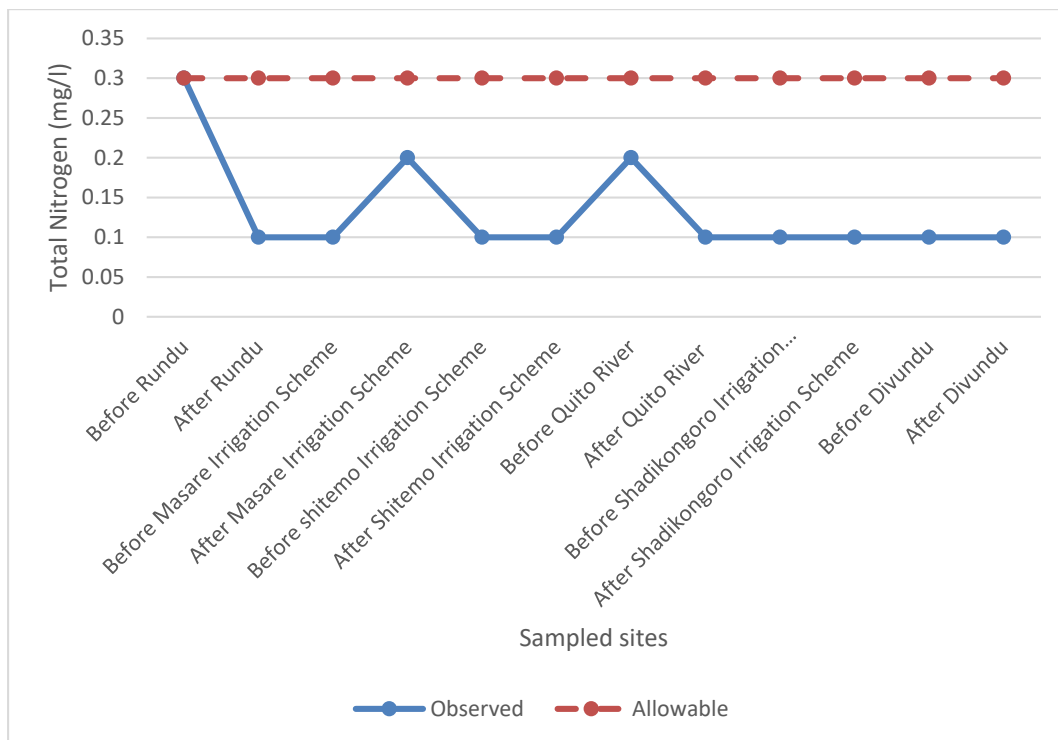


Figure 23: Total Nitrogen concentration in the Kavango river against the allowable concentration limits set by the International Water Quality Guidelines for Ecosystems (US EPA, 2002).

4.5.2 Total Nitrogen (SAWQG)

The results of the One Sample Wilcoxon Signed Rank test showed that the observed concentration of Total Nitrogen was significantly lower than the allowable concentration limit of 2.5mg/l as set by South African Water Quality Guidelines for Aquatic Ecosystems, Department of Water Affairs and Forestry (1996) value ($Z = 0.000$; $p = 0.001$) (Figure 24).

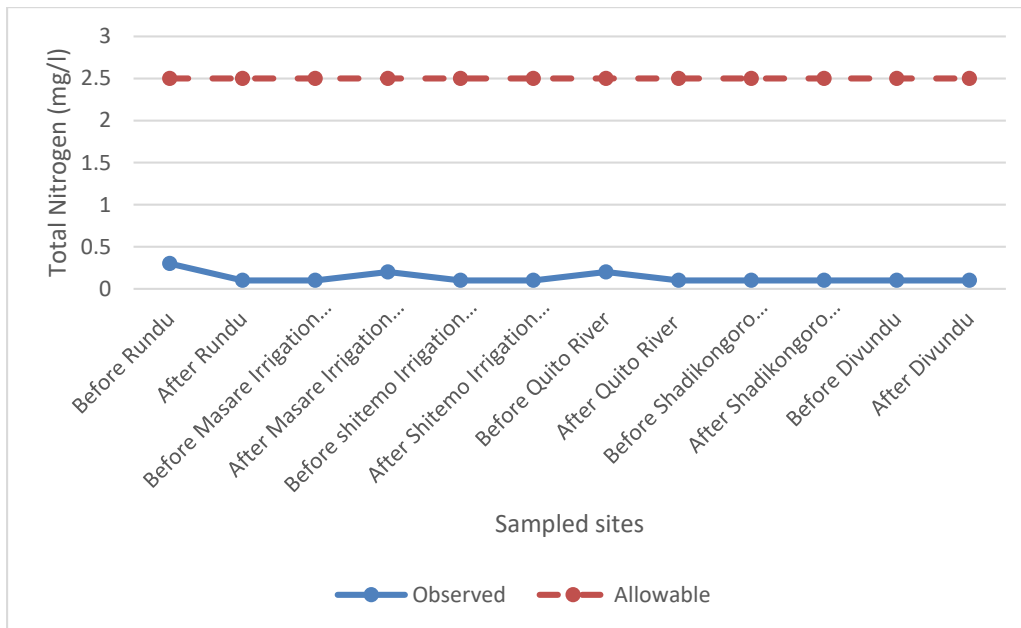


Figure 24: Total Nitrogen concentration in the Kavango river against the allowable concentration limits set by South African Water Quality Guidelines for Aquatic Ecosystems (SAWQG) (Department of Water Affairs and Forestry, 1996).

4.5.3 Total Phosphate (IQWES)

A one-sample t-test showed a significant difference ($t_{11} = -44.597$; $p = 0.000$) between the Total phosphate in Kavango waters and the allowable general standards Total phosphate concentration limits of (0.1mg/l) set by US EPA (2000). The observed values of Total Phosphate were higher than the allowable general standards (Figure 25). Amongst all these other sites, the "After Shadikongoro and Before Masare irrigation " sites are the only one whose TP concentrations were the lowest.

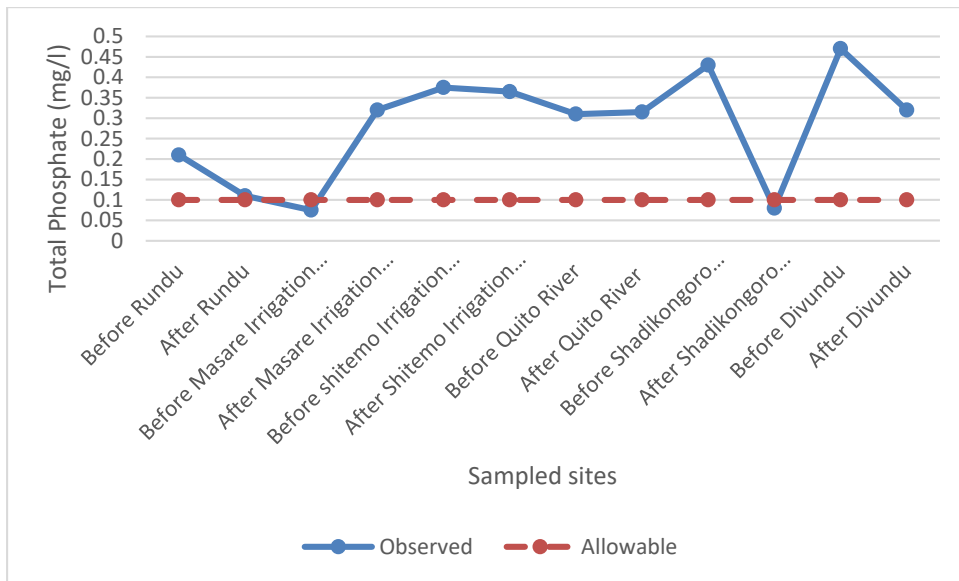


Figure 25: The Total Phosphate in the Kavango river and the allowable value from the allowable general standards value set by International Water Quality Guidelines for Ecosystems (US EPA, 2000).

4.5.4 Total Phosphate (SAWQG)

The results of the One Sample T test showed that the concentration of Total phosphate was significantly lower than the allowable concentration limit of 2.5mg/l as set by South African Water Quality Guidelines for Aquatic Ecosystems, Department of Water Affairs and Forestry (1996) ($t_{11} = 4.715$; $p = 0.001$) (Figure 26).

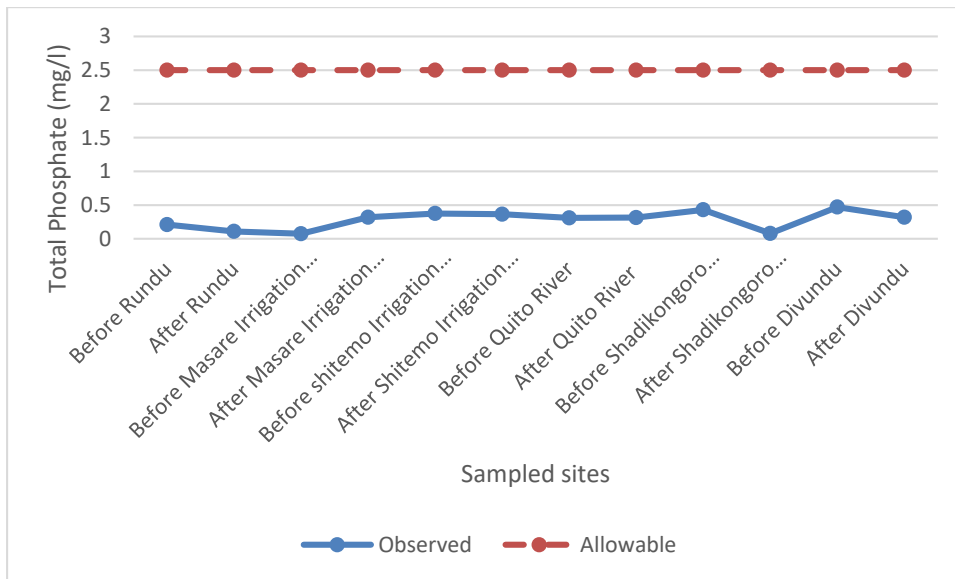


Figure 26: The Total Phosphate in the Kavango river and the allowable value from the allowable general standards value set by South African Water Quality Guidelines for Aquatic Ecosystems (SAWQG) (Department of Water Affairs and Forestry, 1996).

4.5.5 Ortho- Phosphate (IQWES)

One sample Wilcoxon Signed Rank test indicated that the Ortho-phosphate concentration allowable standard set by US EPA (2000) was significantly higher (the limit is 0.1mg/l) than the observed Ortho-phosphate concentration ($Z = 0.000$; $p = 0.002$) (Figure 27).

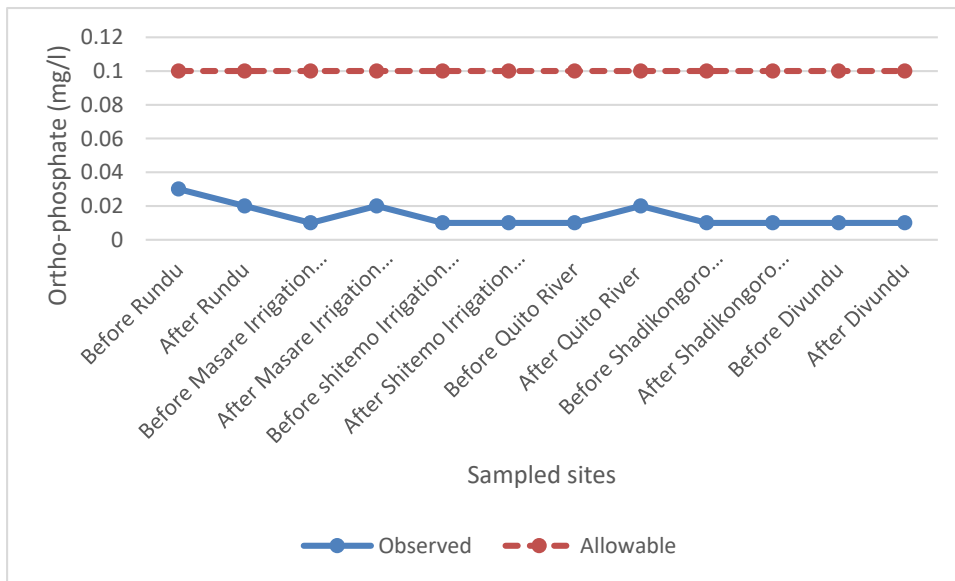


Figure 27: The Ortho-phosphate in the Kavango river and the allowable value from the allowable general standards value set by international Water Quality guidelines for Ecosystems (IQWES) (US EPA, 2000).

4.5.6 Ortho- phosphate (SAWQG)

The results of the One Sample Wilcoxon Signed Rank test showed that the concentration of Ortho- phosphate is significantly lower than the allowable concentration limit (0.1 mg/l) as set by South African Water Quality Guidelines for Aquatic Ecosystems, Department of Water Affairs and Forestry (1996) value. ($Z = 0.000$; $p = 0.002$), Figure 28.

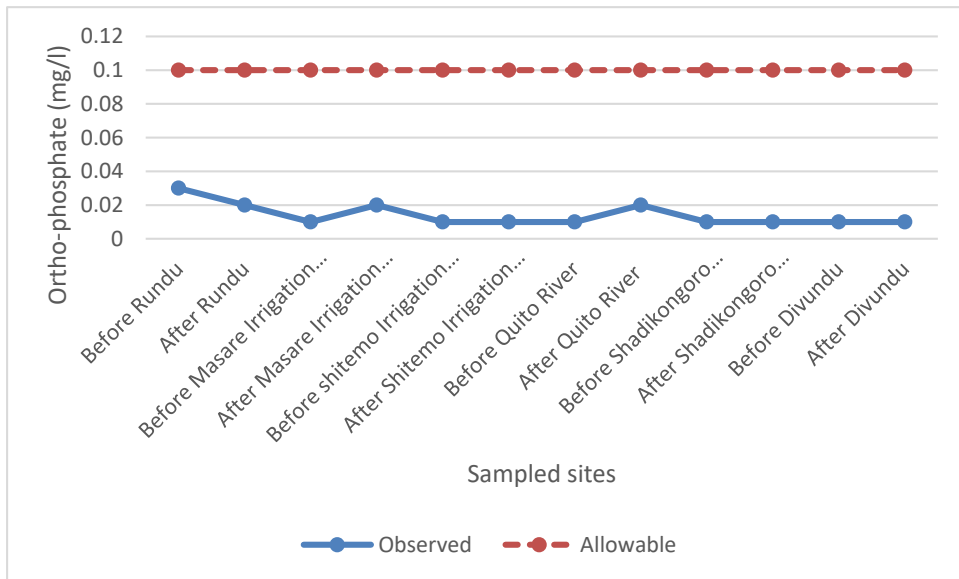


Figure 28: The Ortho-phosphate in the Kavango river and the allowable value from the allowable general standards value set by South African Water Quality Guidelines for Aquatic Ecosystems (SAWQG) (Department of Water Affairs and Forestry, 1996).

CHAPTER 5: DISCUSSION

5.1 Level of Nutrients and Distance

5.1.1 Total Nitrogen (N)

The present study revealed no significant relationship between Total Nitrogen (mg/l) concentration and the distance along the river. This could be attributed to the same land use practices along the Kavango River, which is mostly farming (both subsistence and commercial irrigated crop farming). Lienberg (2009) stated that subsistence farming on a few hectares of mahangu (pearl millet) with small numbers of goats and cattle remains the dominant land use, particularly along the Kavango River and the area under irrigation in Kavango Region is 2 197 ha (Figure 3). In this study it was observed that subsistence farming was practised from Rundu downstream to Divundu. More-or-less the same farming activities are prevalent along the river, leading to no significant difference in Total Nitrogen concentration load downstream. In addition, the soils of the Kavango River are typically of sandy nature and contain low clay and organic matter (Liebenberg, 2009). This causes the soil to have a high infiltration rate and a low water retention capability. In order to guarantee good soil fertility, it is necessary to introduce compost, organic and inorganic material into the soil (Liebenberg, 2009). The most common irrigation schemes see figure 3 include Musese Irrigation Scheme etc. Intensive agricultural operations and settlements in river basins, according to Mvungi et al., (2003); FAO, (2005), cause mainstream nutrient load.

Bethune (1987) also found that the water quality remains stable for the length of the river. Consequently, Total Nitrogen concentrations were low at all the sites throughout the year and did not show significant differences between different sites. However, in this study conducted by Trewby (2003) based on the Kavango water quality found that, although the Total Nitrogen did not have a significant spatial trend, higher concentrations were observed at areas with high population density and widespread bare ground.

5.1.2 Total Phosphate (P)

No statistically significant relationship was observed between Total Phosphate (P) (mg/L) and distance along the Kavango River. This could be attributed to the fact that majority of the sampled sites are access points for both humans and animals. Humans do wash laundry and cars using detergents in the River while cattle and other livestock drop excretion of body wastes in the river leading to more or less the same Total Phosphate concentration load downstream. This could be associate with the fact that there is a dilution effect in Total Phosphate downstream. This trend in nutrient concentrations indicates that point-source pollution that can be a result of washing in the river at major access points and livestock grazing is more likely of importance than non-point source pollution like irrigation run-off and sewage disposal in the Kavango River.

5.1.3 Ortho-phosphate (O)

The present study showed a significant decrease in the concentration of Ortho-phosphate (P) (mg/l) from upstream to downstream along the Kavango River (Figure 18). This could be attributed to the Quito River tributary. The Cuito tributary is flowing into the Kavango Mainstream diluting the nutrient concentration. Vushe *et al.*, (2014) stated that Cuito contributes 45% of flow into the Kavango River, probably the increased flow (after the Cuito confluence) leading to a decrease in Ortho-phosphate concentration in the Kavango River. This is supported by the findings of Vushe *et al.*, (2014) who stated that increased mainstream flow rate due to inflows from the Cuito tributary could also have reduced the ortho-phosphate attenuation rate.

A study done by Bethune (1987) reported that Ortho-phosphate concentrations were highest in the mainstream sites compared to the backwaters. However, the present study only focused on mainstream and most of the sites that had high Ortho-phosphate were at or near human

access points of the river. This could be due to laundry that is being done inside or near the river using detergents therefore potentially contributing to high Ortho-phosphate at these sites. Quayle *et al.*, (2010) stated that the use of phosphate-containing detergents may lead to increased phosphate levels in rivers.

5.2 Nutrient load before and after sites

5.2.1 Total Nitrogen (TN)

No significant difference in Total Nitrogen (mg/l) concentration was observed before and after the sampled sites. This could be attributed to the numerous human and cattle access points throughout the river making no difference in Total Nitrogen concentration at before and after sites. The conditions before and after the sampled sites were generally the same. The presence of cattle added Total Nitrogen concentration in the river due to excretion of body wastes in or near streams, and this could contribute to equal Total Nitrogen concentration at all the sites. Also, it might be led by the fact that there is nutrient dilution effect downstream. These results are in agreement with those obtained by Bethune (1991) who reported that the Total Nitrogen concentration did not show a significant difference between the different studied sites.

However, Trewby (2003) found that the highest concentration was recorded in May of 2002 at some sites while other sites had low Total Nitrogen concentrations. A study done by Bethune (2009) stated that a slightly higher concentration of Total Nitrogen was recorded in some sites such as the isolated floodplain pool during the dry season. This could be attributed to the high decomposition rate in that floodplain. Higher Total Nitrogen levels at some sites after the confluence with the Cuito River, showed that inflows from Angola contributed higher Total Nitrogen into these sites. While the lower Total Nitrogen level at some sites showed that there was a net uptake of Total Nitrogen in these sites. Therefore, Total Nitrogen decreased with an increase in reach length on these sites (Vushe *et al.*, 2014). However, in sites that had high

Total Nitrogen concentration, it could be caused by localized impacts of the irrigation schemes, as they are a factor of nutrient loading in this system.

5.2.2 Total Phosphate (TP)

The present study showed no statistically significant difference in total Phosphate (mg/l) between before and after sampled sites. This could be attributed to the elements found in rocks and soils which are the same throughout the river. Bista (2016) stated that the exposure of the rocks to the atmosphere weathers them and causes them to break down via different environmental processes. The weathering of these rocks release phosphate ions to the soil and then to the water sources. In addition, Bista (2016) reported that the decomposition of dead plants and animal matter contains a large amount of phosphorus in the soil environment. The present study supports the results obtained by Ortmann (2009), who reported a non-significant variation with respect to Total Phosphorous concentrations at locations above the large-scale agricultural developments and the locations below these developments. Furthermore, Trewby (2003) found that only 3 sites among seven in July had high concentrations of Total Phosphate.

According to a study conducted by Vushe et al. (2014), there is a longitudinal natural attenuation of phosphorus in the Kavango River, and some places with high Total Phosphates could be, but not limited to, irrigation schemes because those sites had the most area under irrigation. This study differs from the previous one in that the number of irrigation schemes has increased since 2014, and all of the sampled sites are located within or close to irrigation schemes.

5.2.3 Ortho-phosphate (O)

The present study showed no statistically significant difference in total Ortho-phosphate (mg/l) between before and after the sampled sites. These findings are supported by the one of Vushe *et al.*, (2014) who stated that sixty-eight percentage of the population of the Kavango Region

are living within a locus of 10km from the Kavango River. In this study, therefore, it was observed that the homesteads of local people are found both before sampling sites and after sampling sites contributing the same Ortho-phosphate levels in the river (Figure 21).

Study done by Vushe *et al.*, (2014) and Trewby (2003) reported that the water quality of Kavango River was uniform with low downstream longitudinal differences within the water-quality parameters. However, in this study, same nutrient load in the sites upstream and downstream could be due to the fact that this study was only conducted in one month of the year (July) (1-month average), compared to the studies mentioned above whereby sampling was done once in a month for three months (3 month averages). Besides, sampling took place during the dry season only. It is plausible to believe that the river's potential impact was at its lowest point of the year during this time. It is reasonable to assume that the potential impact on the river was at its seasonal minimum during this time. Bethune (1991) reported that the concentration of the Ortho-phosphate was not the same throughout the river but low in the mainstream.

5.3 Flow Rate

The present study showed no statistically significant difference in flow rate (mg/l) between before and after the sampled sites of the Kavango River. This could be attributed to the fact that this study was only based on a one-month average. In addition, it was also done on the mainstream of the river alone. The flow rate is faster in mainstream than the backwaters (Hay *et al.*, 2000). Furthermore, this study was conducted in the low flow season. Vushe *et al.*, (2014) stated that Kavango River is a perennial river with two distinctive flow regimes, the high flow season (peaking in April) and the low flow season (lowest in November) with two transition periods between the two seasons. A study done by Liebenberg (2009) found that the increase of flow rate makes the nutrients to be diluted faster and increases the nutrient concentration in

the overlying water, and then tends to be stable. In slow-flowing water, the decomposition of organic material takes place faster and the nutrient concentration increases. Fast flows over rapids increase aeration and thus the concentration of oxygen in water (Vushe *et al.*, 2014).

5.4 Dissolved Oxygen

The present study showed no statistically significant difference in Dissolved Oxygen (mg/l) between before and after the sampled sites of the Kavango River. These results agree with those obtained by Ortmann (2012) who recorded no statistically significant deterioration of water quality including DO with the Kavango River distance downstream. Additionally, the results of a Limnological Baseline Survey of the Kavango River of 1984 – 1986 found that the dissolved oxygen concentration measured within a season was more or less the same throughout the length of the river at the mainstream and channel sites, with the exception that below the Popa Rapids, the DO concentration increased slightly due to aeration. However, a study done by Bethune (1987) found that the oxygen concentrations increased from March to October. A study by Anderson (2006) indicated that dissolved oxygen levels were elevated at sampling sites below the Cuito River confluence with the Kavango River. Ortmann (2009) also found that at Kapako, the DO concentrations in both the mainstream and the side channel sites were less than required during the wet season, which is necessary for the health of aquatic life. In the dry season, the DO concentrations were higher and showed a similarity in the mainstream and floodplain pools due to the mixing of water.

Ortmann (2009) recorded that during both seasons, the trend from previous studies that DO levels are higher where water is tumbling over rough surfaces was confirmed. However, Ortmann (2009) added that the Dissolved Oxygen in the mainstream and backwater samples at Popa Rapids was higher than at Kapako (Sites along the Kavango River), except the floodplain pool which had a higher concentration. The difference in the DO concentration at Popa Rapids

between the mainstream and the back stream can be due to the time of the day that readings were recorded for these samples (Ortmann, 2009).

5.5 Comparisons between the observed nutrient concentration with regional and international standards

5.5.1 Total Nitrogen (IQWES) and (SAWQG)

The present study has revealed that the Total Nitrogen concentration in the Kavango River is significantly lower than the allowable general standards set by the National Effluents Standards set by South African Water Quality Guidelines for aquatic ecosystems, the Department of Water Affairs & Forestry (1996), and US EPA (2000). This could be because the Kavango River system appears to be able to regulate the nutrient concentrations at their present levels (Trewby, 2013). The present study's results agree with those obtained by Ortmann (2012) who reported that the Total Nitrogen values were generally low throughout the channel. In the present study, the Total Nitrogen values were generally low throughout the channel, but higher than the values recorded by Bethune (1987) who found that the Total Nitrogen concentrations in the river were too low to be detected during the Baseline Survey of 1984 -1986 . However the present studies results were also lower than the findings of Ortmann (2012). This could be attributed to the management of domestic wastewater in the river reach (Vushe *et al.*, 2014). Wastewater-treatment facilities that do specifically remove Nitrogen, for example, since 2010, wastewater from Rundu Town was treated mainly in sewage ponds located 10 km away from the mainstream, where it evaporated (Vushe *et al.*, 2014). However, the study done by Anderson (2006) found that Total Nitrogen levels were almost exclusively below the detection limit except for the special samples where pools below the Rundu sewage works without direct overland connection to the river. However, in conditions of hydrological connectivity, the sewage works could elevate the nitrogen levels of the river. Anderson (2006) added that similar

pools of elevated nutrient concentrations could probably be found in connection to areas of more intensive livestock farming. In comparison to previous studies, the Total Nitrogen concentration results were surprisingly low. This could be caused by sampling at different stages of a potentially dynamic nutrient cycle and, in that case, in this study, the samples were gathered at a stage of low concentration in the water body end of July. In the present study variations in Total Nitrogen concentration were found at 3 sites (Before Rundu, Before Mashare Irrigation Scheme, and After Shitemo Irrigation schemes) (Figure 24), where it was slightly elevated. This could be due to the Irrigation schemes which are in and some are close to this area, namely; Mashare Irrigation Scheme, Vungu Irrigation Scheme, and the Shitemo Irrigation Scheme. Irrigation Schemes increase nutrient levels in the river.

5.5.2 Total Phosphate (IQWES) and (SAWQG)

The present study revealed that the concentration of Total Phosphate in the Kavango Rivers was significantly higher than the allowable Total Phosphate concentration limits set by US EPA (2000). This could be attributed to the increasing number of Irrigation schemes along the Kavango River which uses fertilizers containing Total Phosphate and run off to the river during the rainy season. These results agree with Ortmann (2012) who stated that the return-flow from the irrigation schemes is believed to be the biggest threat to possible eutrophication and degradation of the river water quality. However, Liebenberg (2009) stated that the area currently under irrigation in the Kavango area is 2197 ha. Another potential reason why there is high Total Phosphate in the river could be attributed to the aquaculture farms that are along the Kavango River. Talbot & Hole (1994) found that in open water aquaculture systems, the excess fish feed introduces extra nitrogen and phosphorous directly into the water. Ortmann (2012) stated that the Government had developed three community-based fish farms in the Kavango Region. Each fish farm is approximately 1.8 hectares large with 14 earthen-based

ponds (4 Breeding Ponds, 4 Nursery Ponds, and 6 Production Ponds) Ortmann (2012). However, some wastewater from the fish ponds is re-used for the limited irrigation of vegetables and fruits (Nashipili, 2009) and runs off to the river. In addition, higher Total Phosphate can be attributed to the fact that the majority of the sampling points are major access points for bathing, washing clothes and vehicles (Ortmann 2012).

Surprisingly, the present study revealed that the Total Phosphate in the Kavango Rivers was significantly lower than the allowable Total Phosphate concentration limits set by the National Effluents Standards set by South African Water Quality Guidelines for aquatic ecosystems, the Department of Water Affairs & Forestry (1996). This poses a new question, regarding the accuracy of our regional standards as measures of eutrophication in our freshwater systems.

By and large, the results of this study are similar to those obtained by Bethune (1987) and Trewby (2003), who indicated that the Total Phosphorous levels in the Kavango River are generally lower and more undetected (Bethune, 1987). Total Phosphate concentrations of the Kavango River are below the acceptable regional limit, but do not comply with the standards set by the USEPA.

5.5.3 Ortho- Phosphate (IQWES) and (SAWQG)

The Ortho-phosphate in the Kavango Rivers was significantly lower than the allowable Ortho-phosphate concentration limits set by the Department of Water Affairs and Forestry (1996) and the one set by US EPA (2000). This could be because there is high uptake of Ortho-phosphate by biotic organisms. In addition, Anderson (2006) stated that nutrients in the Kavango River are quickly assimilated into the food chain. Another reason why the Ortho-phosphate was low in the Kavango River compared to the allowable standards is that the Cuito tributary is flowing into the Kavango Mainstream diluting the nutrient concentration as mentioned above. Vushe

et al., (2014) stated that Cuito contributes 45% of flow into the Kavango River, probably the increased flow and this could decrease the ortho-phosphate concentration rate in the Kavango River. This is similar to the findings of Vushe *et al.*, (2014) which stated that increased mainstream flow rate due to inflows from the Cuito tributary could also have reduced the ortho-phosphate attenuation rate. The present study results agree with those obtained by Anderson (2006) who found that the Ortho-phosphorous concentrations in the Kavango River were low as well as a study done by Trewby (2003) and Mendelsohn & el Obeid (2003) revealed low Ortho-phosphate concentration in the Kavango River, although Trewby's results were principally below the detection limits during comparable seasons. It is also important to note that the above-mentioned three studies' sampling strategies were related to large-scale agricultural farms, mainstream/Backwaters, and populated places respectively, whereas this study specifically focused on mainstream, populated places, and Irrigation schemes.

CHAPTER 6 CONCLUSION AND RECOMMENDATION

6.1 Conclusions

The level of eutrophication of the Kavango river downstream from Rundu to Divundu in Namibia was evaluated by assessing concentration levels of Total Nitrogen, Total phosphate and Ortho-phosphate. The present study has concluded that there was no significant relationship between the level of nutrient concentration (Total Nitrogen and Total Phosphate) and distance along the river. However, there was a significant relationship between the level of Ortho-phosphate concentration and distance along the river.

There was no significant difference between the level of nutrients (Total Nitrogen, Total Phosphate, and Ortho-phosphate) before and after 6 sampled sites. Additionally, the study also concluded that there was no statistically significant difference in flow rate (mg/l) and Dissolved Oxygen between before and after the sampled sites of the Kavango River. Interestingly, the present study has revealed that the Total Nitrogen concentrations in the Kavango River are significantly lower than the allowable general standards set by the National Effluents Standards set by South African Water Quality Guidelines for aquatic ecosystems, the Department of Water Affairs & Forestry (1996) and US EPA (2000). The Total Phosphate in the Kavango Rivers was significantly higher than the allowable Total Phosphate concentration limits set by US EPA (2000), but also significantly lower than the allowable Total Phosphate concentration limits set by the National Effluents Standards set by South African Water Quality Guidelines for aquatic ecosystems, the Department of Water Affairs & Forestry (1996).

The Ortho-phosphate in the Kavango Rivers was significantly lower than the allowable Ortho-phosphate concentration limits set by the Department of Water Affairs and Forestry (1996) and the one set by US EPA (2000).). The results clearly showed that the Kavango river waters are nutrient-poor. Therefore, the Kavango River is oligotrophic.

6.2 Recommendations

In order to ensure the long-term oligotrophic status of this river, there is a lot of effort that needs to go into monitoring of the Kavango River system. More research is needed to constantly monitor the water quality indicators in order to detect and quantify possible man-made sources of contaminants. However, A longer sampling period is hereby recommended to enable comparisons of results with other similar studies in the region. Public consultations involving all stakeholders should be conducted to educate the local people as well as communal and commercial farmers about how they could minimize the nutrient load of the river. However, in this study, it is noticeable that the current effect of irrigation schemes and local agricultural activities pose low threats to water quality of the Kavango River. It is vital that a detailed soil investigation be carried out, and that effective irrigation practices are applied to ensure that no leaching of nutrients take place, and that these do not wash down into the river as back flows that could lead to future eutrophication of these nutrient poor waters (Liebenberg, 2009). In addition, proper measures should be applied to reduce the nutrient addition in the river from the agricultural practices and human settlements. Effective policies should be implemented in industrial and agricultural practices to limit their nutrient loading into the aquatic ecosystems. Less application of Total Phosphorus and Total Nitrogen fertilizers will reduce the nutrient loading remarkably. Furthermore, provision of piped water supply to the riverine communities will also assist in minimizing and eventually cancelling out the washing of clothes, humans and vehicles in the river and hence minimize the phosphorous concentration in the river that was observed at sites of human and animal access. While the data collection period of the present study was of short duration, the limited data available highlighted the critical need for further studies on the effects of other levels of nutrient concentration in the Kavango River. There is, however, a need for extensive and organized water quality monitoring

in the Kavango River all year round to provide more comprehensive information through the different seasons and flood patterns.

There is a need for Government departments such as the Department of Water Affairs to expand their monitoring exercises beyond measurements, such as pH and conductivity, to metals, pesticides, and other emerging contaminants. All in all, since time series of the database of this project was really short (4 days), was due to Covid 19 outbreak which caused a lot of lock downs and restriction to enter regions, there is a need for studies like this with a large sample size and long time series data, which would give us a good snapshot of the state of water quality in the river during the dry season.

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CHAPTER 8: APPENDICES

APPENDIX A: ETHICAL CLEARANCE CERTIFICATE



ETHICAL CLEARANCE CERTIFICATE

Ethical Clearance Reference Number: SOS-0019 **Date:** 25 October 2021

This Ethical Clearance Certificate is issued by the University of Namibia Ethics Committee (REC) in accordance with the University of Namibia's Research Ethics Policy and Guidelines. Ethical approval is given in respect of undertakings contained in the Research Project outlined below. This Certificate is issued on the recommendations of the ethical evaluation done by the ethics committee.

Title of Project: AN ASSESSMENT OF THE LEVEL OF EUTROPHICATION OF THE KAVANGO RIVER DOWNSTREAM FROM DIVUNDU, NAMIBIA

Student: ESTER HAIKOLA

Student Number: 201184133

Supervisor(s): PROF EZEKIEL. G. KWEMBEYA (UNIVERSITY OF NAMIBIA)

Centre for Research Services

Take note of the following:

1. Any significant changes in the conditions or undertakings outlined in the approved Proposal must be communicated to the ethics committee. An application to make amendments may be necessary.
2. Any breaches of ethical undertakings or practices that have an impact on ethical conduct of the research must be reported to the ethics committee
3. The Principal Researcher must report issues of ethical compliance to the ethics committee (through the Chairperson) at the end of the Project or as may be requested by the ethics committee
4. The ethics committee retains the right to:
 - i) Withdraw or amend this Ethical Clearance if any unethical practices (as outlined in the Research Ethics Policy) have been detected or suspected,
 - ii) Request for an ethical compliance report at any point during the course of the research.

The ethics committee wishes you the best in your research.

A handwritten signature in cursive script, appearing to read 'Z. Chiguvare', is written over a horizontal line.

Dr. Zivayi Chiguvare (Chairperson Ethics Committee)

A handwritten signature in cursive script, appearing to read 'D. Mumbengegwi', is written over a horizontal line.

Prof. Davis Mumbengegwi (Head, Multidisciplinary Research)

APPENDIX B: RESEARCH PERMISSION LETTER

CENTRE FOR RESEARCH SERVICES

Office of the Pro-Vice-Chancellor: Research, Innovation & Development

University of Namibia, Private Bag 13301, Windhoek, Namibia

340 Manzuma/Ndembulaya Avenue, Pioneer Park, Office F223 - Floor Second Floor

☎ +264 61 206 4573, ✉ mail@crs.unam.na, URL: <http://www.unam.edu.na>



RESEARCH PERMISSION LETTER

Date: 06/06/2022

Student Name: Ester Ishwa Haikola

Student Number: 201184133

Programme: Master of Science (Biodiversity Management)

Approved Research Title: EUTROPHICATION ASSESSMENT IN THE KAVANGO RIVER SYSTEM FROM RUNDU TO DIVUNDU, RUNDU.

TO WHOM IT MAY CONCERN

I hereby confirm that the above-mentioned student is registered at the University of Namibia for the programme indicated. The proposed study met all the requirements as stipulated in the University guidelines and has been approved by the relevant committees.

The proposal adheres to ethical principles as per attached Ethical Clearance Certificate. Permission is hereby granted to carry out the research as described in the approved proposal.

Best Regards

A handwritten signature in black ink, appearing to read 'AEE Shikongo'.

Dr. AEE Shikongo
Head: Postgraduate Support Services
Tel: +264 61 206 3129
E-mail: aeshikongo@crs.unam.na



APPENDIX C : URKUND ANTIPLAGIARISM RESULTS

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