EVALUATION OF SEASONAL VARIABILITY IN PHYSICOCHEMICAL WATER QUALITY PARAMETERS OF LAKE NKUGUTE, UGANDA

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ABSTRACT

This study assessed the seasonal variability in water quality of Lake Nkugute in Rubirizi District, Uganda. It gives an insight of the seasonal variability of some physico-chemical parameters of the lake due to its importance in water abstraction for Bunyaruguru Gravity Flow Scheme that supplies potable water to the vast part of Rubirizi District.

The study adopted a quantitative research design. It was conducted between August, 2018 and January 2019. Seven sampling points (S1-S7) were used with measurements taken at 0m, 5m, 10m 15m and 20m. The parameters measured included pH, temperature, electrical conductivity (EC), Total Dissolved Solids (TDS), dissolved oxygen (DO), turbidity, Colour and Total Suspended solids (TSS). Primary data was obtained through in-situ and laboratory measurements using field and laboratory equipment, whereas secondary data was obtained through document review. Data was analyzed using Microsoft Excel Version 2013 and SPSS 16.0.

Across different depths, water temperature was highest at 0.0 m and lowest at 20 m (ranged from 26.5±1.1 °C to 22.5±1.1 °C), at all stations with significant differences ($p<0.05$) in mean water temperature between the stations and depths in both wet and dry seasons. The mean concentration of DO was highest at the surface (0m) ranging between 6±2.9 mg/L at S1 and 7±2.9 mg/L at S2 and relatively lower than a typical flowing river due to stagnant water at the reservoir. Comparing by depths, there were significant differences ($p<0.05$) in the total suspended solids at all stations, TSS being lower at the subsurface of the water since the solids settle towards the bottom of the

lake with wet spell presenting 2.9±1mg/L. The TDS concentration was observed to increase with depth and the variation of concentration of TDS for the whole sampling period was significant ($p<0.05$). The pH of Lake Nkugute is relatively consistent between the dry season and wet season with mean pH of 7.75±0.20. The overall mean value of EC across all depth was 114.8±8.52 µS/cm and 107.4±8.52 µS/cm in the wet and dry season respectively. The variation of turbidity with season was not significantly different ($P>0.05$) with an overall mean of 3.1±0.1NTU. Stations S4 and S5 both at 20 m depth exhibited high average colour levels of mean of 26.68 ± 10.61PtCo and comparing by depths, there were significant differences ($p<0.05$) in the colour of Lake Nkugute in all stations.

Generally, the values of water quality parameters such as pH, conductivity, turbidity, TDS, and TSS at the different stations on Lake Nkugute were found to be within the recommended limits of World Health Organization and National Drinking Water Quality Standards. Researchers should take interest in the biological parameters of the same study area, since this study considered only physicochemical parameters.

DECLARATION

I **George Tinda Musinguzi**, declare that this is my original work and has not been published or submitted to any academic institution for award of any other degree.

George Tinda Musinguzi

Signature Date: 02/09/2024

APPROVAL

This is to certify that **George Tinda Musinguzi** under Reg no. **RM17 M45 /001** carried out this research under my supervision and guidance. This dissertation is therefore, approved for submission to the Faculty of Engineering, Design and Technology in partial fulfillment of the requirements for the award if degree of Master of Science in Water and Sanitation

Dr. Peter Mulamba Date: 2nd September, 2024

DEDICATION

This dissertation is dedicated to my family.

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/It is typical to start the acknowledgement with the funders of this research study/This dissertation has been completed with too much persistence, consistence, patience and zeal and I am glad it is finally done. I wish to acknowledge everyone who supported me in its accomplishment.

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
DLG	District Local Government
DO	Dissolved oxygen
DWD	Directorate of Water Development
FY	Financial Year
GIS	Geographical Information System
GW	Groundwater
LEAF	Lake Edward and Albert Fisheries Project.
mg/L	milligram per Liter
MWE	Ministry of Water and Environment
NDWQS	National Drinking Water Quality Standards
NEMA	National Environmental Management Authority
NWSC	National Water and Sewerage Corporation
P/S	Primary School
PCA	Principal Component Analysis
PS	Global Positioning System
SC	Sub County
T.C	Town Council
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UBOS	Uganda Bureau of Statistics
UGX	Uganda Shillings
WEAP	Water Evaluation and Planning
WHO	World Health Organization

CHAPTER ONE - INTRODUCTION

1.1 Background

Water quality deterioration is a common problem in reservoirs surrounded with anthropogenic activities receiving high loads of suspended solids, organic matter, and nutrients. The water quality of reservoirs has been observed to vary seasonally in tandem with changes in temperature and rainfall (Ling et al., 2017). High precipitation during the wet season can either decrease the pollutant concentration by dilution or deteriorate the reservoir water quality due to increased surface runoff from anthropogenic activities (Ling et al., 2017).

Besides, high volume of inflow following heavy rainfall promotes mixing and disturbs stratification in the reservoir. The increase of bottom dissolved oxygen level in the well-mixed reservoir inhibits the release of nutrients from sediments causing a rapid reduction of phytoplankton concentration in the reservoir (Hamid et al., 2020). For a reservoir, another source of pollutants is human settlements in the watershed (Gossweiler et al., 2021; Ling et al., 2013).

Uganda covers an area of 241,038 km^2 with significant surface water and ground water sources with fresh water lakes occupying 36,280 km^2. The major current issue of water resources in Uganda is the reduced water quality and quantity; and watershed degradation as a result of increased human population, urbanization, industrialization and agricultural modernization (MWE, 2014; Koster, 2011; USAID, 1994).

Rubirizi District has a land area of 1,109.45 km^2, with a population of 129,149, a growth rate of 3.0% (UBOS, 2014) and Safe water access of 68% (Uganda Water Atlas 2021. The district is endowed with more than 32 crater lakes but access to adequate, reliable and safe portable water is a great challenge. Safe water coverage has been dependent on ground water facilities (protected springs, deep boreholes and shallow wells) which have become scarce and swamps are drying up due to poor conservation methods hence investment in pumped water systems from the crater lakes is the most feasible remedy.

Lake Nkugute is a fresh water Crater Lake located in Rubirizi District, South-Western region of Uganda at latitude of 00° 19' 00" S and Longitude of 30° 06' 00" E (Online 1) with a diameter of about 1,000 m and maximum depth of 58 m (Beadle, 1966).

The lake's interaction with the surrounding water systems is highly expected through groundwater inflows and seepage loss to groundwater (Dinka, 2017). L. Nkugute, has one stream flowing into it and has settlements along its entire water shed. However, literature on the water quality variations of the entire lake is scarce. The only available previous water quality study of Beadle L.C. 1965 only concentrated on stratification and deoxygenation of Lake Nkugute.

As a reservoir in a tropical country, changes continue to occur in the reservoir and it is important to monitor the water quality in order to evaluate its suitability for multipurpose uses (Ling et al., 2017). The knowledge of the seasonal variation of the lake's water quality is hence very important. Therefore, the objective of this study is to determine the seasonal variability of water quality of Lake Nkugute.

1.2 Problem Statement

Lake Nkugute and its entire watershed has human settlements around it as well as its one main stream that flows through. The Lake is very close to the road and a lot of activities take place around its entire watershed. The impact of these anthropogenic activities on the seasonal lake water quality is largely unknown given the limited available information. Routine water quality analyses by National Water and Sewerage Corporation (NWSC) only concentrates on one point that accommodates the abstraction point for the Bunyaruguru Garvity Flow Scheme with samples collected from the surface and yet it is a deep lake.

This study, therefore, intends to do document seasonal variations of the lake's physicochemical water quality parameters and thus contribute to the international scientific body of knowledge.

1.3 Main Objective

The objective of this study was to determine seasonal variations in the physicochemical water quality parameters of Lake Nkugute.

1.3.1 Specific Objectives

The specific objectives of the study were to:

i. Determine physicochemical water quality parameters at selected locations in the lake during the wet and dry seasons.

ii. Assess the physicochemical water quality parameters at the selected locations in (i) at different depths.

iii. To establish correlations from (i & ii) between selected water quality parameters.

1.4 Research Questions

a) What is the seasonal variation of physicochemical water quality of Lake Nkugute?

b) How do physicochemical water quality parameters vary with depth of the lake?

c) Are there relationships between different physicochemical water quality parameters of Lake Nkugute?

1.5 Justification of the Research.

The major current issue of water resources in Uganda is reduced water quality and quantity, and watershed degradation due to increased population, urbanization and industrialization. Lake Nkugute is a source of Bunyaruguru Garvity Flow Scheme which is the largest water system in the district serving 23,901 people (19% of the district) in 3 subcounties and 1 town council (NWSC,2022). However, with this importance, there is scarcity of studies on its seasonal water quality given the number of activities taking place around. This study will provide data for different stakeholders to enable them take informed decision of catchment protection and management, water treatment options for portable water abstraction and use of the lake for other purposes like fish farming and recreation. This study is well aligned to Uganda National Vision 40 and Global Sustainable Development Goals (SGD6).

1.6 Scope of the study

1.6.1 Geographical scope

The study was carried out on Lake Nkugute also known as Lake Rutoto a crater lake in Rubirizi District in Western Uganda. It is located at latitude of 00° 19' 00" S and Longitude of 30° 06' 00" E with an estimated terrain of 4645 feet above sea level.

1.6.2 Content scope

This study focused on assessing the seasonal variability of physicochemical water quality parameeters of Lake Nkugute at different depths over the period August, 2018 to January, 2019.

According to Shah, (2017); physicochemical parameters are essential and impact life within the aquatic systems and these include pH, temperature, dissolved oxygen, conductivity and turbidity. For this study, the physicochemical water quality parameters were limited to Temperature, pH, TDS, TSS, Turbidity, EC, DO and Colour.

CHAPTER TWO - LITERATURE REVIEW

2.1 Introduction

This chapter discusses in detail water quality, the physicochemical and biological water quality parameters, Drinking Water Standards and Guidelines, the factors that influence the variation of water quality and Gaps there in which led to the study were also highlighted.

2.2 Water quality

Water quality refers to the physical, chemical, biological and organoleptic (taste-related) properties of water (Bwire et al., (2020); & Monitoring, (1987). The presence of certain contaminants in water can lead to health issues, including gastrointestinal illness, reproductive problems, and neurological disorders. The quality of water must be tested regulary to ensure that there are no contaminants. Chen et al., (2020) defined some of the measures that are necessary for improving water quality which include improving surface water motoring systems. The water quality of reservoirs has been observed to vary seasonally with changes in temperature and rainfall. The high precipitation during the wet season can either decrease the pollutant concentration by dilution or deteriorate the reservoir water quality due to increased surface runoff from anthropogenic activities (Ling et al., 2017).

The Water Resources Assessment report of Uganda (MWE, 2013b) summarizes that the water quality of surface water sources are mainly challenged by bacteria contamination, resulting from poor sanitation. It also notes that the excessive nutrients generated from the agricultural practices around the surface water bodies of which Lake Nkugute is unexceptional, cause algal brooms that result into eutrophication. Soil erosion has been noted in western Uganda, and causes the levels of suspended and dissolved solids high at all levels of the water depth in the surface water source (MWE, 2013b).

2.3 Water quality Parameters

There are three categories of water quality parameters. These include; Physical parameters, chemical parameters and biological parameters. According to Shah, (2017); Vital Signs, (2010), the physicochemical parameters are essential and impact life (both flora and or fauna) within the aquatic systems and these include pH, temperature, dissolved oxygen, conductivity and turbidity. The Chemical Water Quality Parameters include but are not limited to pH, Acidity, Alkalinity, hardness, nitrogen, Dissolved gases, chloride and Fluoride content. Biological parameters of water quality are those measurements that reflect the number of bacteria, algae, viruses, and protozoa that are present in water (Arora, 2018). These parameters are important indicators of the health and safety of the water for human consumption and ecosystem health.

2.4 Monitoring water quality

Monitoring water quality is the periodic or continuous collection of data which involves measuring and analysis of water parameters. Parameters to be monitored are selected depending on the anthropogenic activities around the water shed using different water quality indicators. Water quality is monitored to;

i. Characterize the water and how quality varies over time
ii. Understand environmental impacts and obtain information which may be used in making a pollution prevention or remedial plan
iii. Manage emergencies such as spills, flood etc

iv. Ensure that it is safe for human consumption and aquatic life

v. Determine compliance with drinking water standards and protect water sources

To maintain water quality, various methods are used to treat and monitor water, including filtration, disinfection, and testing. There are several ways water quality is measured. It can be done in-situ where measurements are taken directly without removing the sample. Parameters mainly tested in-situ include temperature, pH, color, DO, TDS, and Turbidity and this gives the water quality analyst the general conditions of the water source. Samples can also tested by transfering samples to the laboratory for physical, chemical and microbial analysis. Parameters mainly tested here include concentrations of metals, nutrients and pesticides.

Governments and organizations have established standards and regulations to ensure that water quality meets the minimum requirements for safe human consumption and environmental protection. Globally write in full (WHO) Drinking Water Guidelines are used to monitor water quality. In Uganda, the Uganda National Standards regulated by Uganda Nation Bureau of Statistics (UNBS) is used when monitoring water quality (UNBS, 2014) as showed in Table 1.

Water quality can be classified into types which include; potable water, palatable water, contaminated (polluted) water, and infected water (Nayla.H, 2019). The most common scientific definitions of these types of water quality are as follows:

- Potable water: It is safe to drink, pleasant to taste, and usable for domestic purposes.

- Palatable water: It is aesthetically pleasing; it considers the presence of chemicals that do not cause a threat to human health.

- Contaminated (polluted) water: It is that water containing unwanted physical, chemical, biological, or radiological substances, and it is unfit for drinking or domestic use.

- Infected water: It is contaminated with pathogenic organism.

Table 2.1: WHO and UNBS Drinking Water Standards

Parameter	**WHO Drinking water Guideline***	**UNBS Standard for Natural potable water****	**UNBS standard for Treated potable water****
Colour (TCU)	15	50	15
Taste	Acceptable to consumers and no abnormal changes	Acceptable to consumers and no abnormal changes	Acceptable to consumers and no abnormal changes
Turbidity (NTU)	4	25	5
pH	6.5-8.5	5.5-9.5	6.5-8.5
Odour	Acceptable to consumers and no abnormal changes	Odourless	Odourless
Conductivity (µS/cm)		2500	1500
Total Dissolved Solids (mg/L)	1000	1500	700
E. coli (units?)	Absent	Absent	Absent
Suspended solids (units?)	Not detectable	Not detectable	Not detectable

*WHO (2017); **UNBS (2014)

2.5 Surface water

Surface water is any water that collects on top of the ground. It could be regarded as including all inland waters permanently or intermittently occurring on the Earth surface in either liquid (rivers, temporary streams, lakes, reservoirs, bogs) or solid (glaciers, snow cover) condition (Bwire et al. 2020). In this study, the latter was not considered.

Surface water plays a vital role in the natural environment as it provides habitats for a wide range of aquatic plants and animals, and supports important ecological processes such as nutrient cycling, erosion control, and flood regulation. It acts as the primary source of water for human and animal consumption, irrigation, industry, and recreation. Surface water is constantly moving and changing due to natural processes such as precipitation, evaporation, and runoff. The movement of surface water is influenced by gravity, topography, and the shape of the land. Most surface water comes from rainfall (precipitation) and runoff from the surrounding land area (catchment). However not all runoff ends up in rivers, some evaporates, some is used by vegetation and part of it soaks into the ground recharging groundwater systems, some of which can then seep back into the riverbeds.

One of the key characteristics of surface water is its quality, which can be affected by a wide range of factors, including human activities, natural processes, and weather events. Pollution from agricultural and industrial activities, urban runoff, and untreated sewage can all have a significant impact on the quality of surface water.

There are three types of surface water namely;

- Permanent (perennial) surface water; permanent surface waters are present throughout the year. They are usually in the form of rivers, lakes, springs and swamps. At times when there is little or no rain, the water level is maintained by groundwater contributions or other water bodies that pour into it. Lake Nkugute is a crater lake and lies within this category.

- Semi-permanent (ephemeral) surface; Semi-permanent water bodies are those that only hold water for part of the year. These are usually small creeks, lagoons, waterholes, or low-lying areas in the arid zone.

- Man-made – surface water can also be held in manmade structures ranging from lakes, dams and turkey nests to artificial swamps and sewage treatment ponds.

The presence of live creatures in surface water and the amount of mineral and organic debris it may have accumulated during its development determine the water's quality. As rain falls through the atmosphere, it collects dust and absorbs oxygen and carbon dioxide from the air. Studies in Uganda have shown that most water resources are easily contaminated from anthropogenic activities especially in urban areas (Sekabira et al.; 2010).

Small streams draining remote or uninhabited basins in rural locations may provide water that is bacteriologically and chemically suitable for human consumption in its unaltered natural state. However, surface water is typically contaminated and polluted by harmful organisms, making it impossible to consider it safe without treatment (USEPA 2020). Furthermore, surface water is exposed to contamination risks from agricultural, industrial, and domestic activities, which may include many types of pollutants such as heavy metals, pesticides, fertilizers, hazardous chemicals, and oils.

Since surface water is more easily accessible than groundwater, it is therefore more relied on for many human uses. As a result, most human settlements are commonly concentrated next to surface water sources.

Managing surface water resources is essential for ensuring sustainable use and protecting the environment. This involves monitoring water quality, establishing water use regulations, and implementing strategies to reduce pollution and conserve water resources. The water parameters tested to gauge the quality of raw surface water include physico-chemical and bacteriological parameters as explained in Section 2.6 .

2.6 Physico-chemical Water Quality Parameters

Water quality is neither a static condition of a system, nor can it be defined by measurement of only one parameter. Rather, it is variable in both time and space and requires routine monitoring to detect spatial patterns and changes over time. The water quality parameters discussed in this section are limited to those considered in the study.

2.6.1 pH

pH is one of the most important parameters of water quality. pH is the measure of the activity of hydrogen ions in a solution, resulting in its acidic or basic quality, measured on a logarithmic scale that commonly ranges from 0 (acidic) to 14 (basic), with 7 being neutral (Ahmed et al., 2020 and Uality et al.,2000). Normal rainfall has a pH of approximately 5.6 (slightly acidic) owing to atmospheric carbon dioxide gas. Safe ranges of pH for drinking water are from 6.5 to 8.5 for domestic use and use by living organisms.

The organic and inorganic materials and other organisms in soil and water influence the pH level in the water. For example, as organic matter decomposes and organisms respire, they give off carbon dioxide gas which dissolves in water and forms a weak acid.

The lithology of the water and activities surrounding the water influence the pH range of the water. Heavy metals in water with a lower pH<6.5 tend to be more toxic, as they are more available to the body. A high pH>8.5 would make heavy metals less available, and, therefore, less toxic. Additionally, a very high or very low pH can make water unusable for certain applications. For example, hard water which contains a lot of minerals that make the water very alkaline. As the water passes through pipes and machines that use water, such as dishwashers or showers, these minerals stick to both the pipes and each other, leading to mineral buildup. Mineral buildup can cause various issues with water in the home, such as making detergents and soaps less effective. It can also lead to reduced water pressure or even blockages. On the other hand, water with a low pH may corrode metal pipes and extract metal ions into the water, making it harmful to drink or use in the home. Pollution from accidental spills, agricultural runoff and sewer overflows can also change the pH.

2.6.2. Total dissolved solids

Water is a good solvent and picks up impurities easily. Pure water is called a universal solvent and is tasteless, colourless, and odourless. TDS is a measure, in milligrams per liter (mg/L), of the amount of dissolved materials that is salts, metals, cations, anions in the water. Ions such as potassium, sodium, chloride, carbonate, sulfate, calcium, and magnesium all contribute to the dissolved solids in the water. Dissolved solids are solids that are in dissolved state in solution. Waters with high dissolved solids (>1000mg/L) (WHO, 2017) are not favourable for potable water. TDS in drinking water originate from natural sources, sewage, urban run-off, industrial wastewater, and chemicals used in the water treatment process, and the nature of the piping or hardware used to convey the water.

2.6.3 Turbidity

Turbidity of water is the measurement of suspended and non-filterable particles in water. This may also interfere with the treatment of water. Turbidity is caused by suspended material such as clay, silt, organic material, plankton, and other particulate materials in water and it makes the water aesthetically unappealing and is unacceptable in drinking water. According to Emamgholizadeh et al., (2014), turbidity is an important parameter in the water quality assessment because the degree of turbidity of stream water is often taken to be an approximate measure of the intensity of the pollution. It measures the light penetrating through the water and is determined using a secchi disc or a turbidimeter. Sunlight provides the energy for photosynthesis and determines the depth at which algae and other plants can grow, defining the ecological make-up of a water body.

A change in water clarity may be noticed after heavy rains, as silt and debris can run off, causing the visibility to decrease. A high turbidity causes aquatic systems to lose the ability to support a diversity of biotas because of the reduced oxygen levels. Increased intensity of scattered light results into higher values of turbidity. According to the WHO guidelines, the turbidity in drinking water is less than 4NTU whereas for UNBS, the turbidity in drinking water is less than 5NTU. Therefore, water in excess of 5NTU is considered objectionable to the consumers. Turbidity can be an indicator of other water quality issues, such as the presence of sediment, organic matter, and microorganisms. Monitoring turbidity levels can help identify potential sources of pollution and inform management strategies.

2.6.4 Temperature

Measured on a linear scale of degrees Celsius or degrees Fahrenheit, temperature is a measure of the average energy (kinetic) of water molecules (Ahmed et al., 2020; USEPA, 2017) and is important as it determines the aquatic life.

Factors that contribute to the water temperature are surface area, depth and flow of the water; turbidity and colour, shade and vegetation. Water temperature normally fluctuates between day, night and seasons. Aquatic organisms are dependent on certain temperature ranges for optimal health. Temperature controls the rate of all chemical reactions, and affects aquatic life. Drastic temperature changes can be fatal to aquatic life (Helen Dallas, 2009; Sharpe & DeWalle, 2019; USEPA, 2017). Temperature affects many other parameters in water, including dissolved oxygen, Salinity, alkalinity and electrical conductivity. Causes of temperature change in water include weather conditions, shade and discharges from urban sources or groundwater inflows. Temperature also affects the solubility and reaction rates of pollutants in the water. If temperature is outside the normal range, biotas are stressed and might die.

2.6.5 Electrical conductivity (EC)

EC is the measure of capacity of a substance or solution to conduct electrical current through the water. For lake and stream water, EC ranges between 198-465 µS/cm with an average of 311.19 ±65.94 µS/cm (Khatoon & Shahid, 2013). It correlates well with pH, temperature, turbidity, chlorides, sulphates, dissolved oxygen, total dissolved solids and chemical oxygen demand.

Conductivity in water is affected by inorganic dissolved solids such as chloride, sulphate, sodium, calcium and others. Conductivity in streams and rivers is affected by the geology of the area through which the water flows. Streams that run through granite bedrock will have lower conductivity, and those that flow through limestone and clay will have higher conductivity. High conductance readings also can come from industrial pollution or urban runoff, such as water flowing from streets, buildings and parking lots. Extended dry periods and low flow conditions also contribute to higher conductance. Organic compounds, such as oil, do not conduct electrical current very well, so an oil spill tends to lower the conductivity of the water. Temperature also affects conductivity withwarm water having a higher conductivity.

2.6.6 Dissolved Oxygen

Dissolved Oxygen (DO) is defined as the amount of oxygen dissolved in a water body and measures the health of the water and its ability to maintain a balance aquatic ecosystem. Oxygen is essential for both plants and animals, but high levels/how high in quantitative terms?/ in water can be harmful to fish and other aquatic organisms. Nonpoint-source pollution can decrease the amount of dissolved oxygen in water, which can be harmful to fish and other aquatic organisms. The decomposition of leaf litter, grass clippings, sewage and runoff from feedlots decreases DO concentrations. It is mostly measured with an electrometric meter or Winkler titration (Ahmed et al., 2020; Aktarul & Chowdhury, 2017; Emamgholizadeh et al., 2014).

2.6.7 Total Suspended Solids (TSS).

Total Suspended Solids is the measure the amount of particulate matter floating in water. In lakes and rivers this can include particles from algae, other organic matter, silt and clay, and other inorganic substances (such as minerals, salts and metals). Total suspended solids (TSS) are measured in mg/L. Its values are often related to the turbidity (cloudiness) of water. If TSS is high and the water is murky then light from the sun will not travel well through the water, making it difficult for plants and algae to grow. High levels of TSS can make water appear murky or cloudy, which can negatively impact the aesthetic value of water bodies such as lakes, rivers, and oceans. High concentrations of suspended solids can lower water quality by absorbing light. Waters then become warmer and lessen the ability of the water to hold oxygen necessary for aquatic life because aquatic plants also receive less light, photosynthesis decreases and less oxygen is produced. The combination of warmer water, less light and less oxygen makes it impossible for some forms of life to exist such as fish and crustaceans.

Suspended solids can occur as a result of erosion from urban runoff and agricultural land, industrial wastes, bank erosion, bottom feeders (such as carp), algae growth or wastewater discharges.

2.6.9 Color

Color is measured by comparing the water sample with standard color solutions or colored glass disks. Non-polluted water sources are colourless. Coloured water signifies that the water is unfit to drink hence indicating a public health concern even though the water might be perfectly safe for other public uses. On the other hand, the colour might indicate the presence of organic substances, such as algae or humic compounds.

The true color of water can be caused by dissolved substances and apparent color caused by colloidal substances.

Decayed organic matter such as vegetation, inorganic matter such as soil, stones and rocks impart objectionable color to water making it unfavourable for aesthetic and health reasons (Mathew et al. 2015). It is expressed in mg/L platinum or Hazen units that are numerically equal (Ma et al. 2020). Color is graded on scale of 0 (clear) to 70 Platinum Cobalt units (PtCo). Pure water is colorless, which is equivalent to 0 color units. Color in water indicates the presence of organic substance for example algae or inorganic minerals such as iron or manganesE though of late it has been used as a quantitative assessment of the presence of potentially hazardous organic material in water (Kaw, 2021).

Green/ blue water may indicate corrosion from metals such as copper and lead which pose a serious health concern. Black/ dark brown water may indicate the presence of manganese in the water or pipe sediment. Brown/ red/ orange/ yellow water is caused by iron rust from galvanized iron, steel or cast-iron pipes (Kaw, 2021). Dark brown/ yellow pigment may be from vegetation, white deposits/ scale hardness indicate the presence of dissolved metals (Bright & Njalam 2007). The presence of colour may have an effect on the turbidity of water. Therefore, colour and turbidity are directly linked.

2.7 Biological Water Quality Parameters

According to Omer, (2019) and WHO, (2011), the biological water quality parameters are used to describe the presence of microbiological organisms and water- borne pathogens. Most illnesses are caused by these organisms when the water is directly ingested by humans. These microrganisms include algae, viruses, bacteria, protozoa and indicator organisms. Indicator organisms are used as an indication of existence of pollutants in that environment. Indicator organisms are important as they help to monitor environmental changes and assess the efficiency of management systems. The major groups of pathogenic organisms are; bacteria, viruses, protozoans and helminths. Biological water quality was not analyzed in the study due to limited financial resources that were at my disposal.

2.7.1 Faecal coliforms

Faecal coliforms are the group of the total coliforms that are considered to be present specifically in the gut and faeces of warm-blooded animals. Faecal coliforms are usually not pathogenic. However, they are said to be indicator organisms meaning that they indicate the presence of other pathogenic bacteria (Mwabi, Mamba, and Momba 2012). These bacteria are found in the intestines of warm-blooded animals, including humans, and are often present in sewage and other sources of human and animal waste. The presence of faecal coliforms in water can be an indication of potential contamination with faecal matter, which can contain a range of harmful pathogens such as viruses, bacteria, and protozoa. Therefore, the presence of faecal coliforms in water can be a concern for human health.

Faecal coliform bacteria may occur in ambient water as a result of the overflow of domestic sewage or non-point sources of human and animal waste (Bain et al., 2015). The faecal coliform group includes all of the rod-shaped bacteria that are non-spore forming, Gram Negative, lactose-fermenting in 24hours at 44.5°C (Mwabi, Mamba, and Momba 2012).

Faecal coliform testing is carried out by membrane filtration as a method of choice for the analysis of coliforms in water and measured in CFU/100mL (Mahmud et al. 2019). This involves taking water samples and culturing them on special media that is designed to promote the growth of faecal coliforms. If faecal coliforms are present in the water sample, they will produce characteristic colonies that can be counted and used to estimate the level of faecal contamination in the water.

2.7.2 E. coli

E. coli stands for *Escherichia coli*, which is a type of coliform bacteria. They normally live in the intestines of both healthy people and animals. In most cases, this bacteria is harmless and aids digestion in the human body. *E. coli* in faeces from both animals and humans can end up in all types of water sources including ponds, lakes, streams, rivers, wells, swimming pools and even in local city water supplies that have not been disinfected. Certain strains of *E. coli* can cause sickness when ingested causing symptoms including diarrhea, stomach pain and cramps and low-grade fever. Some E. coli infections can be dangerous.So??

2.8 Factors that influence Water Quality Parameters in surface water

Water quality varies naturally with location and time. There are a number of factors affecting Water quality and that can lead to variations. These include Sedimentation, runoff, erosion, dissolved oxygen, pH, temperature, decayed organic materials and pesticides among others. For example, the headwaters of streams at high elevations tend to be cooler than wide streams at lower elevations. These could affect the physiochemical parameters, and biological parameters of the water. Cristina et al., (2022); Fn & Mf, (2017); Guo et al., (2018); Khatri & Tyagi, (2015); Mainali & Chang, (2021); Oketola et al., (2013); and Wang et al., (2021) discuss the general causes of water quality variation. Anthropogenic activities such as runoff from agriculture, mining, industrialization through waste water discharge, fishing, forestry among others also significantly affect the quality of surface water. The geology, geomorphology and climate of the area contribute to the quality of water. During rain, fertilizers, pesticides and animal waste from farms wash nutrients and pathogens such as bacteria and viruses into our water ways.

2.9 Water Quality Standard

Water quality standards in Uganda are based on Uganda National Bureau of Standards, 2007. Parameters studied have been compared with the UNBS standards which are presented in Table 2.2.

Table 2.2: National Water Quality Standards

Parameter	Potable treated water	Potable untreated water	Standard
Colour (TCUa max)	15	50	ISO 7887
Turbidity (NTU max)	5	25	ISO 7027
pH	6.5-8.5	5.5-9.5	ISO 10523
Taste	Not objectionable	Not objectionable	-
Odour	Odourless	odourless	-
Conductivity (uS/cm), max	1500	2500	ISO7888
Suspended matter	Not detectable	Not detectable	ISO11923
TDS	700	1500	ASTM D 5907
Total Hardness as $CaCO_3$	300	600	ISO 6059
Dissolved Oxygen	6.5	8	ISO
Phosphates	2.2	2.2	ISO 7393

Source: UNBS, 2007

CHAPTER THREE- METHODOLOGY

3.1 Introduction

This chapter presents the materials, techniques and procedures that were employed in achieving the study specific objectives as presented in Section1.3.1

3.2 Research design

The research was both qualitative and quantitative in nature where experimental, survey and observational methods were employed in data collection. Qualitative methods were used in order to generalize the findings of the study and quantitative methods were used to quantify and discuss the findings.

3.3 Area of study

Lake Nkugute is a fresh water Crater Lake located in Rubirizi District in Rutoto subcounty along the Ishaka – Kasese highway in South Western Region of Uganda at latitude of 00° 19' 00" S and Longitude of 30° 06' 00" E (Figure 3.1). Its diameter is about 1,000m with maximum depth of 58 m. Steeply to a ridge, Kasunju, about 430 m above the lake. Kasunju slope continues steeply under water with the depth being over 50m within 200m of the shore. The areas around the lake are predominantly subsistence farmlands. The catchment area is small and there is no well defined and permanent inlet, although the forested valley to the south may provide most of the surface water that trickles irregularly through culverts under the road. During the wet season, surface water reaches the lake at many points. There may be some subsurface inflow through the surrounding light volcanic soil, but there is no direct evidence of this.

The volcanic eruption partially blocked the valley, and water has filled not only the crater but also part of the valley to the east to form a shallow arm, at the northern end of which is the small permanently outflowing stream. The main drainage line is thus through the shallow arm that is bordered by long grass, scrub, and occasional patches of cultivated land. The lake is closely surrounded by hills and is well protected from heavy winds. Prolonged stratification in the crater is marked by anoxic water from about 20 m to the bottom (58 m) (Beadle, 1965).

Rubirizi District is located at an average elevation of 1333.17 meters (4373.92 feet) above sea level (Rubirizi DDP, 2015). It has a Tropical wet and dry or savanna climate. Its annual temperature is 22.67ºC (72.81ºF) and about 479.74 millimeters (18.89 inches) of precipitation with 330.83 rainy days (90.64% of the time) annually . Table 3.1 below shows the major climate characterization of Rubirizi District.

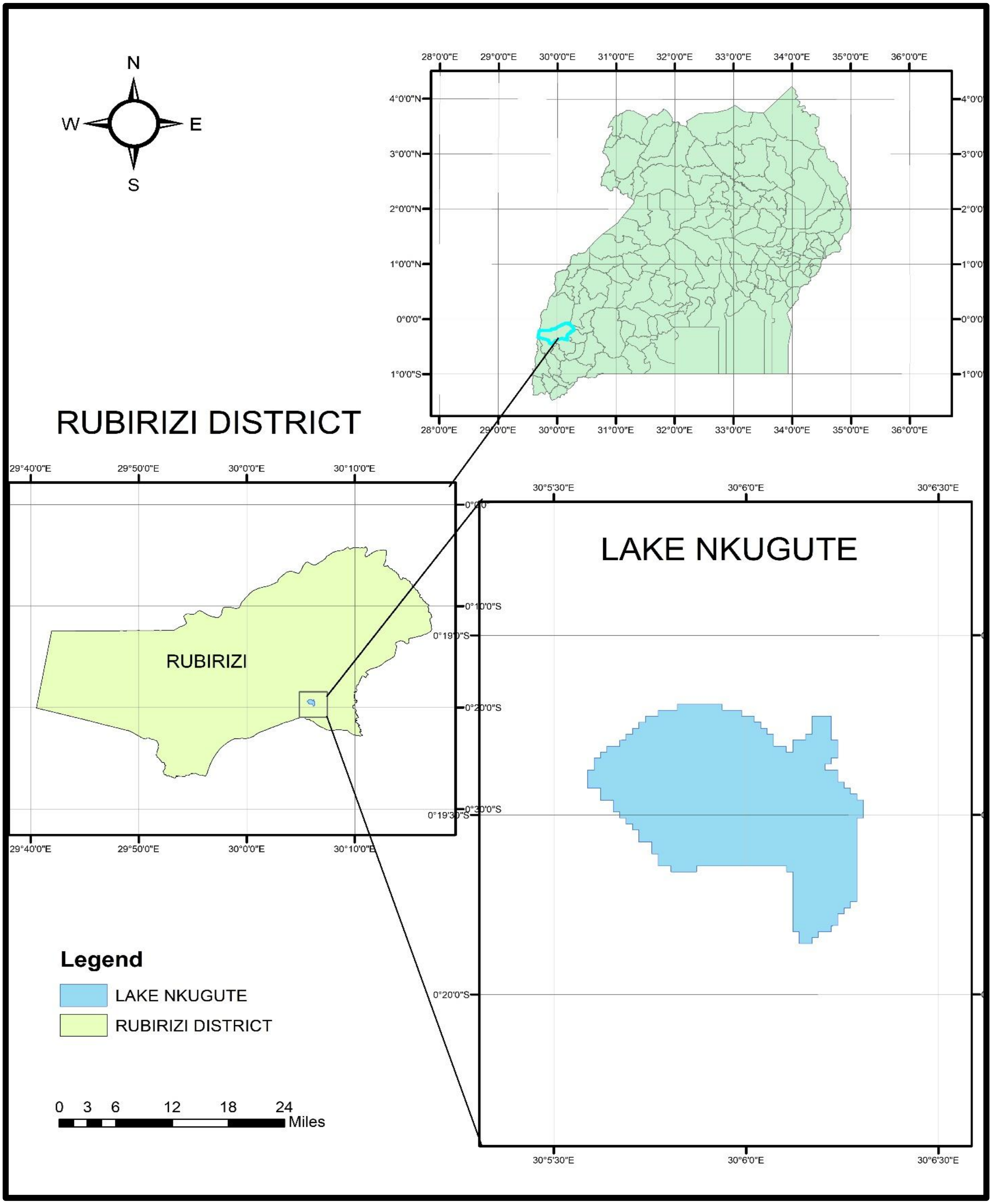

Figure 3.1: Map showing the location of Lake Nkugute

Table 3.1: Climate characterization of Rubirizi District

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Avg Max Temp °C	29.74	30.53	29.21	27.48	26.09	26.22	27.14	27.49	27.53	27.1	26.56	27.48	27.71
Daily mean °C	24.5	25.19	24.1	22.64	20.88	20.68	21.35	22.05	22.69	22.72	22.27	22.93	22.67
Avg Min Temp °C	14.71	15.57	14.22	13.81	11.91	11.87	12.45	13.19	13.42	13.39	13.52	13.73	13.48
Avg precipitation mm	156.08	277.22	539.72	655.7	610.28	433.07	297.46	448.95	600.97	709.99	687.08	340.41	479.74
Avg precipitation days (≥ 1.0 mm)	18.0	21.0	29.36	29.55	30.55	28.45	27.55	29.18	29.82	30.91	29.91	26.55	27.57
Avg relative humidity (%)	63.7	62.31	70.25	77.87	82.21	77.93	69.96	69.86	74.12	77.54	80.15	73.74	73.3
Mean monthly sunshine hours	11.28	11.14	10.91	10.93	10.77	10.95	11.09	11.03	11.02	11.06	10.83	11.14	11.0

Source: Rubirizi District Development Plan, 2015.

3.4 Materials and Methods

3.4.1 Materials

Distilled water was used to prepare solutions and for dilution purposes. All glassware was washed and dried in the oven at 105°C. Bottles for collecting water samples were cleaned and rinsed several times with distilled water prior to sample taking.

3.4.2 Sampling points

The information about each of the stations is given in Table 3.1. Seven sampling stations (S1 – S7) were established on the lake. The sampling sites were marked and the locations identified by a GPS satellite navigator with geographical coordinates in decimal degrees (Figure 3.2). The details of the sampling stations are as follows;

Table 3.1: Water Sampling Locations

Station	Description	Northing	Easting	Elevation
S1	At the entry of the inflow stream into the lake	S0.3306°	E30.1031	1410
S2	In the middle of the lake	S0.3288°	E30.1033°	1411
S3	Below a primary school and a mosque	S0.3255°	E30.1033°	1411
S4	In the middle of the lake	S0.3242°	E30.0993°	1411
S5	Southern part adjacent to highly eroded and land slide areas	S0.3232°	E30.0943°	1411
S6	Below a recreation area.	S0.3223°	E30.0984	1410
S7	At the lake outflow (in take works)	S0.3214°	E30.0996	1411

3.4.3 Sample collection

Water samples at each station were collected by using a Van Dorn water sampler in triplicates at four depths; 0m, 5m, 10m and 20m at the different sampling sites. Sites S1 and S7 were shallow with depth less than 10m. Sampaaling depth were chosen based on the literature review of similiar studies (Beadle, 1965). Samples were placed in 1 L of acid washed polyethylene bottles and stored in cool boxes at temperature of less than 10°C before being transported to laboratory for analyses.

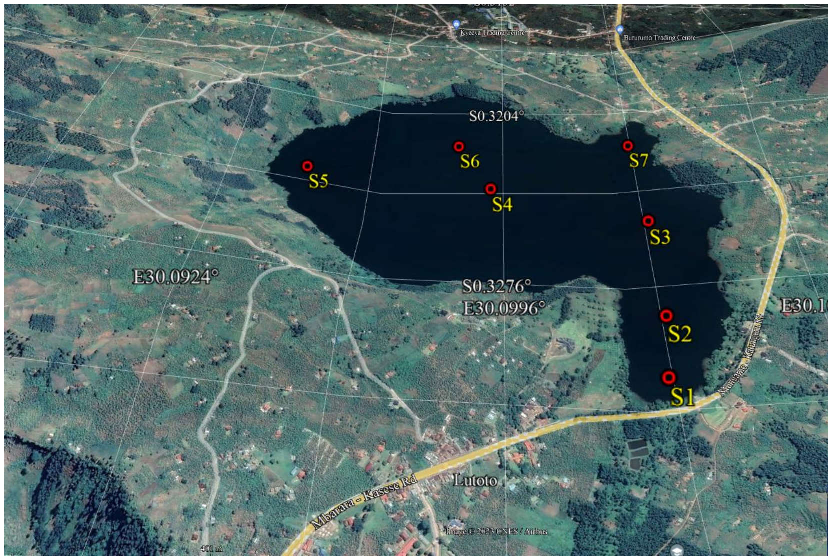

Figure 3.2: The stations of water sampling in Lake Nkugute

3.4.4 Sampling Regimes

Water samples at each station were collected by using a Van Dorn deep water sampler in triplicates at three depths; 0 m, 10 m and 20m. Four sets of samples were collected and analyzed for this study namely; two sets in early October and November, 2018 to represent the wet season, and two sets in early December 2018 and January 2019 to represent the dry period. A motorized boat was used to access all the points.

3.5. In-situ water quality parameter measurements

The parameters that were measured in-situ were pH, temperature, electrical conductivity, TDS, dissolved oxygen, water depth, transparency, turbidity and Phosphates. For each sampling location, these were measuredat the three depths. The analytical techniques are equipment utilized in these measurements are presented in the subsequent subsections.

3.5.1pH

pH was measured by using a Multiparameter meter (Mettler Toledo) which was first calibrated to ± 0.02 accuracy and tests conducted with reference to APHA 4500-H* using the electrometric technique (APHA, 2017).

3.5. 2 Electrical Conductivity, Temperature, and TDS Measurements

These parameters were measured in-situ using a multi-parameter meter (Mettler Toledo) that was first calibrated. EC (µS/ cm), temperature (˚C) and TDS (mg/L) were measured to ±1% accuracy with reference to APHA 2540C (APHA, 2017)

3.5. 3 Turbidity

Turbidity (NTU) was measured in-situ using a Portable Turbidimeter (HACH 2100Q) which was first calibrated for accuracy with reference to APHA 2130 B (APHA, 2017).

3.5. 4 Dissolved Oxygen (DO)

Dissolved oxygen was measured using an Oxygen Meter (MRC model). Its units are mg/L with refence to APHA 4500 O, name of method? (APHA, 2017).

3.5. 5 Colour

Color was measured by comparing the water sample with standard color solutions called platinum cobalt reference solution. It was measured platinum-cobalt (PtCo) units (APHA, 2017).

3.6 Laboratory water quality measurements.

analysis was conducted to determine the total suspended solids (TSS). The water sampLaboratoryles were placed in 1 L of polyethylene bottles that were acid-washed and rinsed with distilled water prior sample collection and stored in cooler boxes before being transported to laboratory for analyses. The write in full (NWSC) laboratory in

Bushenyi District was used. The procedure for determining total suspended solids (TSS) followed the standard method (2540-D) used by APHA (2000) (Standard Method, 2017) using the photometric method (Reference?). Glass microfiber filter disc with the size of 0.45µm was used to filter water sample. Clean filter paper was rinsed, dried and weighed to constant weight using analytic balance equipment and recorded before being placed on the base which connects the flask and before samples were poured on top of it. Then, one funnel was placed on top of the base with the filter paper. A 500 mL of sample was shaken vigorously and transferred to the filter. After, the filter paper was then removed from the base carefully and wrapped in aluminium foil. The wet filter paper was then dried in the oven for an hour at 103°C to 105°C. After that, the dried filter paper was left to cool and then weighed to a constant weight.

The calculation for TSS is as follows:

$$TSS = [(A-B) \times 1000]/C.$$

Where, A is the weight of filter paper + residue (mg); B is the weight of filter paper (mg); and C is the volume of water sample filtered (mL).

3.7 Quality control

To maintain the validity of results, the turbidimeter used in the study was calibrated using three standard solutions of 10,20 and 100 NTU before use and buffer solutions of pH 4.5 and 7 were used for calibration of pH. All reagents used were of high analytical purity. Triplicate samples were collected for analysis in the dry and wet seasons and different depths to maintain validity and reliability. All the procedures and controls were undertaken to APHA, 2017 Standard methods.

3.8 Data analysis and interpretation

Data was recorded on record sheets in the field and copies were regularly kept by the researcher and entered into the data storage software. The data was then analyzed using write in full (SPSS, Version 16). In the record sheets, each water sampling site was identified by a unique code. Comparison of water quality parameters between the stations and the depths in the reservoir was conducted using one-way ANOVA and Tukey's pairwise comparisons with 5% significance level.

Student's *t*-test was used to compare the water quality of the reservoir between the wet and dry seasons. Pearson's correlation analysis was performed to determine the relationship among all the parameters in the reservoir during each season aiming to evaluate significant differences within and among the sites for all water quality variables.Here, the data was analysed using multivariate statistical technique i.e., the two-way analysis of variance (ANOVA) at 0.05% level of significance. All statistical analyses were performed using the SPSS statistical software (Version 16). This technique helps to achieve the research objectives, which involves many variables. In addition, this technique will produce accurate results and easy to handle (Hamzah et al., 2016).

CHAPTER FOUR - RESULTS AND DISCUSSIONS

4.1 Introduction

In this chapter, all results obtained from the water quality are presented and discussed. Statistical relationships between various parameters and variations at the different depths are also discussed.

4.2 Descriptive statistics of water quality parameters

The descriptive statistical results of the analysed water quality parameters (temperature, pH, EC, TDS, TSS, Turbidity and dissolved oxygen, and colour) from the 7 sampling stations are presented in Table 4.1. The degree of correlation between any two of the analysed variables were measured by Pearson’s correlation coefficients as shown in section 4.3.

Table 4.1: Descriptive statistics for water quality parameters

	N	Range	Minimum	Maximum	Mean	Std. Deviation	Variance	Skewness
Temp(˚C)	92	4.00	22.50	26.50	24.2026	1.06592	1.136	0.204
DO(mg/L)	92	10.60	0.40	11.00	4.3096	2.90183	8.421	0.484
pH	92	1.34	6.86	8.20	7.7518	0.20837	0.043	-0.857
EC(µS/cm)	92	41.30	100.30	141.60	110.8139	8.52252	72.633	0.814
Turbidity(NTU)	92	4.00	1.90	5.90	3.2678	0.93058	0.866	0.562
TDS (mg/L)	92	34.62	51.78	86.40	68.9540	6.00175	36.021	0.197
TSS (mg/L)	92	8.00	0.00	8.00	2.7391	1.48893	2.217	0.849
Color (PtCo)	92	59.00	8.00	67.00	23.2826	11.48465	131.897	1.045
Valid N (list wise)	92							

4.3 Physico-chemical parameters for L. Nkugute across dry and wet seasons

4.3.1 Temperature

Temperature plays a vital role in controlling the chemical and biological composition of a freshwater body. The mean water temperature in Lake Nkugute is 24.2 ± 1.1ºC. The readings ranged from 22.5ºC to 26.5ºC. Temperature profile (Figure 4.1) shows the variation of temperature with depth, such that as the depth increases, temperature decreases. Among the stations, the mean water temperature in Lake Nkugute was highest at S5 (26.5± 1.5ºC) and lowest at S5 (22.5 ± 0.9ºC) in dry season, and ranged between 23.4±0.5 ºC to 24.8±0.5 ºC for the wet season. A comparison of temperature with depth shows that water temperature was highest at 0.0 m and lowest at 20 m (ranged from 26.5ºC to 22.5 ºC), at all stations. There were significant differences ($p<0.05$) in mean water temperature between the stations and among depths at all stations. The lake is in agreement with the range of thermal stratification of 0.5°C to 5°C for a tropical reservoir. Temperature is a good indicator to determine thermocline (Girishkumar et al., 2013; Luoto & Nevalainen, 2013; Romero et al., 2022). In the early stage of this study, thermocline occurrence was observed at 0 to 10 m depths.

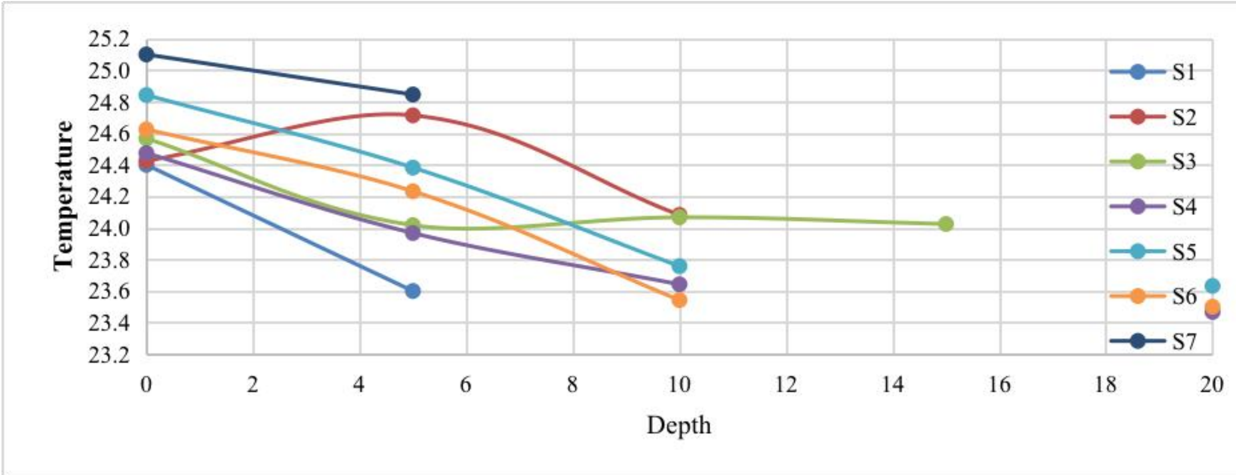

Figure 4.1: Variation of Mean Temperature with Depth in dry season.

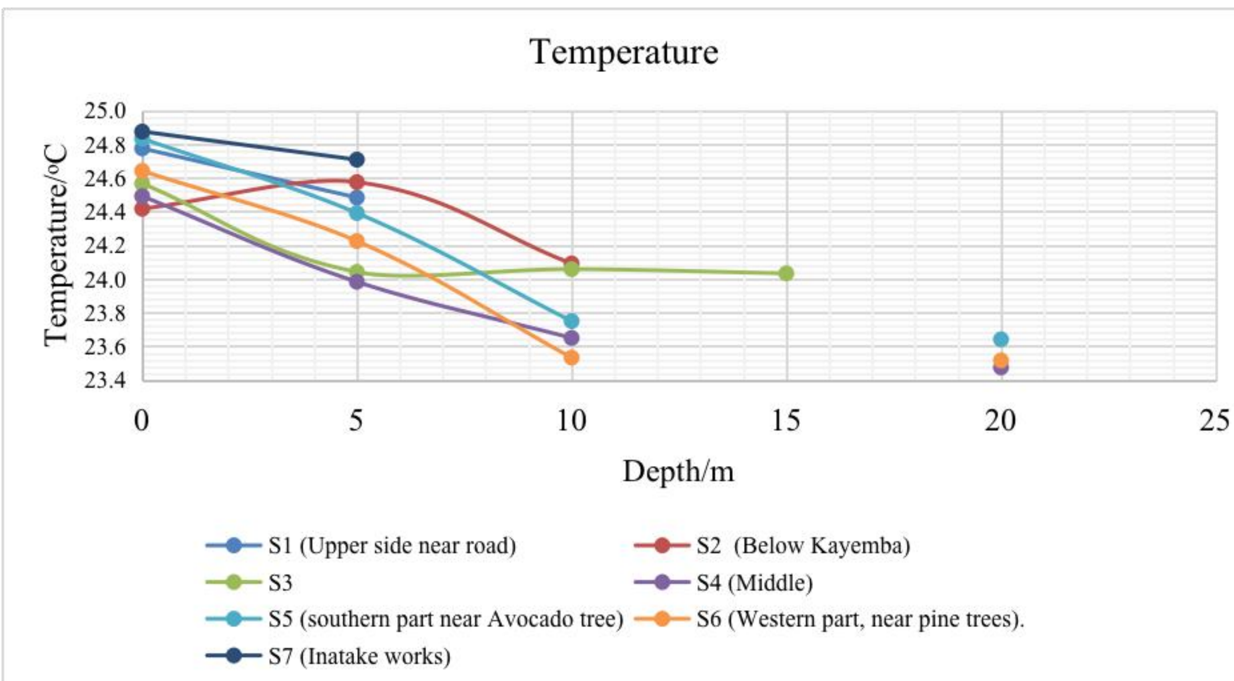

Figure 4.2: Variation of Mean Temperature with Depth in Wet season

4.3.2 Dissolved Oxygen

The dissolved oxygen (DO) concentration is a crucial environmental parameter in the dynamics and characterization of aquatic ecosystems (Rodger et al., 2005). DO is an essential factor for maintaining aquatic life. Its level in lakes varies according to the lake trophic levels. Dissolved oxygen content depends on photosynthetic activity and microbial decomposition of autochthonous and Allochthonous organic matter. Figure 4.3 shows the profiles of dissolved oxygen at all stations during the wet season in Lake Nkugute. The DO concentration in Lake Nkugute ranges from a minimum of 0.4± 2.9mg/L to a maximum value of 11.0± 2.9mg/L with a mean value of 4.3 ± 2.9 mg/L. Mean concentration of DO was highest at the surface(0m) depth with the range between 6 mg/L at S1 and 7 mg/L at S2. The concentration of DO further decreased towards zero, reaching an anoxic level at all stations, starting from an average depth of 15m to 20m while it did not exceed 15m for wet season. This means that DO was more concentrated between 0 to 15m in all stations in wet season.

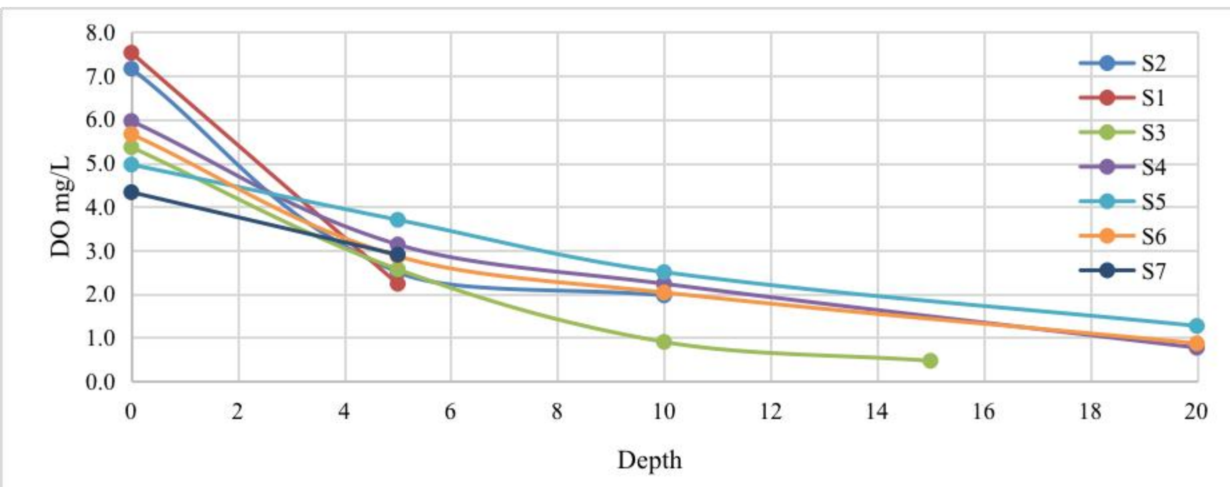

Figure 4.3: Variation of Mean DO with depth in the dry season

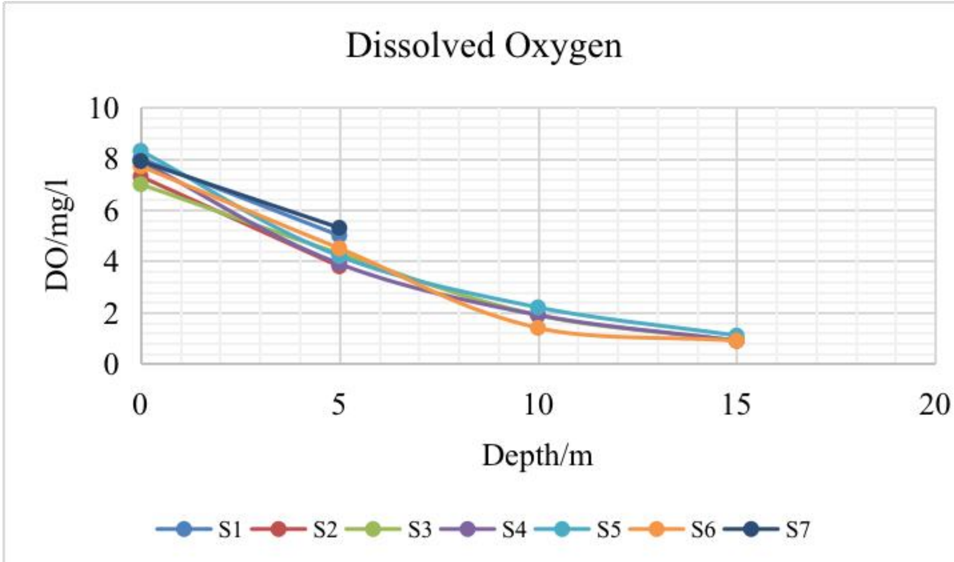

Figure 4.4: Variation of Mean DO concentrations with depth in wet Season

The concentration of DO was significantly different ($p<0.05$) among stations and depths. At the depth of 0.5 to 10 m, the concentration of DO was significantly different ($p<0.05$) among stations. The concentration of DO was highest at S5 (11.0 mg/L, at 0m depth) and lowest at S4 and S6 (0.4 and 0.6 mg/L respectively, both at 20 m depth). There were no significant differences ($p>0.05$) in the concentration of DO at the depth 10 to 20 m among the stations. Higher concentration of DO at the subsurface of the water may be due to atmospheric diffusion (Mack, 2003).

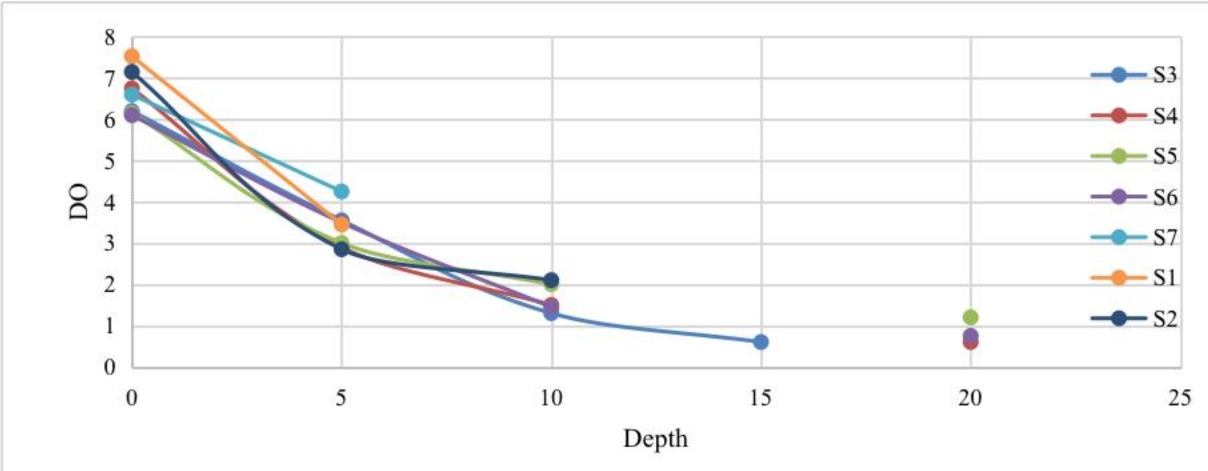

Figure 4.5: Variation of Mean DO with depth during the Wet Season

The decrease in concentration of DO with depth could be due to decomposition taking place as microorganisms consumes oxygen to breakdown excess feed and physiological waste (Abdulmouti, 2022; Ling et al., 2013). As the concentration of DO drops below 3 mg/L, the rough fish will eventually die, while high DO concentration(>8 mg/L) are also toxic to fish and will cause physiological dysfunctions and development abnormalities in fertilized eggs and larvae (Ali et al., 2022; Shroff et al., 2015). At Lake Nkugute, the concentration of DO reduced to a minimum of 0.4mg/L at what depth of 20m which implied that as the depth increased, the lake tended to an anoxia state as result of intensive decomposition of organic matter leading to depletion of oxygen.

4.3.3 Total Suspended Solids (TSS)

The availability of total suspended solids in lake water is caused by the human activities around the lake, and the pathogens and other pollutants can find themselves attached to these solids thus reducing the quality of water.

There are several human activities like farming, fishing, recreation and car washing taking place around lake Nkugute catchment, contributing to contamination of the lake water. Results of this study indicate that Lake Nkugute has TSS concentrations in a range of 1.00 to 5.5mg/L between 0 and 20m for all the stations, with stations S4 to S6 having the highest level of total suspended solids (5.5mg/L).

Figures 4.6 and 4.7, show the variation of TSS in Lake Nkugute in the wet and dry seasons with depth. The average TSS in Lake Nkugute during the dry season is 4.79±1.5mg/L. Stations S3, S5 and S6 present high levels of total suspended solids with an average ranging from 2.6 to 2.9mg/L.

The average concentration of TSS in lake Nkugute during the wet season is 2.9±1.0mg/L. The TSS at all sampled stations ranged between 1.5 and 5mg/L, with stations S4, S5 and S6, exhibiting higher TSS levels at the depth of 15m. This indicates that the deeper you go, the more the water gets contaminated with TSS.

The Total Suspended Soils of lake Nkugute were significantly different ($p<0.05$) among stations and depths. . From the later, it can be seen that the TSS concentrations generally increase with depth.

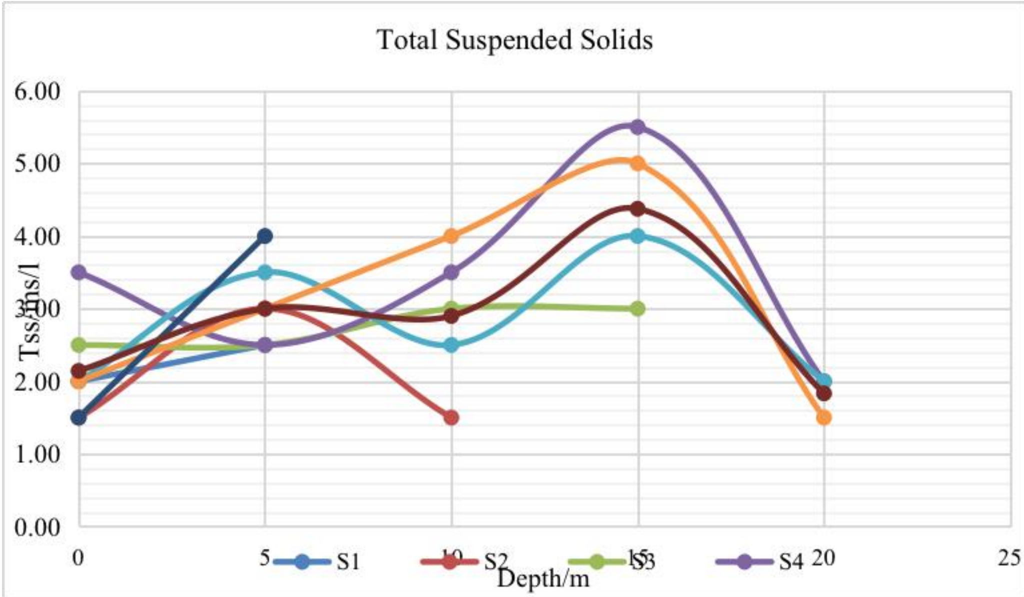

Figure 4.6: Variation of Total Suspended Solids with depth in the dry season

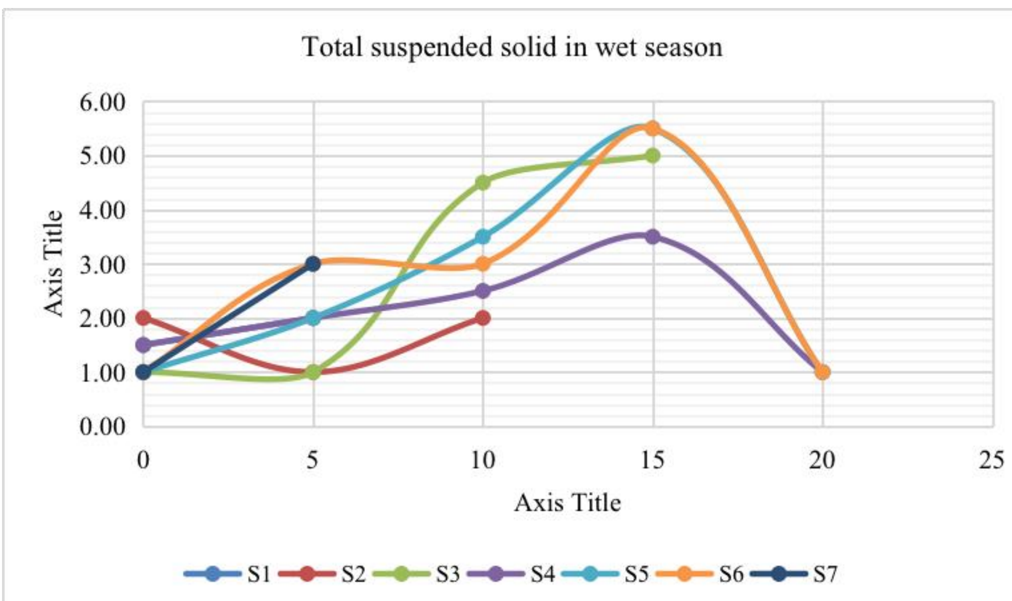

Figure 4.7: Variation of Total Suspended Solids with depth during the wet season.

4.3.4 Total Dissolved Solids

The Mean TDS in Lake Nkugute was 68.0 ± 5mg/L TDS ranged from 64.5 mg/L at 5m of station S5 to 73mg/L at 11m depth of station S3. At Station 3 higher TDS values were measured compared to other stations in the dry season. The mean TDS concentrations in the wet and dry seasons were 64±5mg/L and 73±5mg/L respectively. Figure 4.8 shows that the TDS concentration increased with depth and the variation over the entire sampling period was significant ($p<0.05$). The variation of TDS between stations was not significant ($p>0.05$) whereas it sshowed significant variations with depth at each location. Survival, growth or reproduction of any aquatic organisms is very much controlled by the dissolved ions concentration in lake water. Given the levels of the TDS in the lake (ranging from?? to ??), the water may be considered to be within the freshwater category (TDS<1000mg/L) according to Godsey (2011),and Pal et al., (2015).

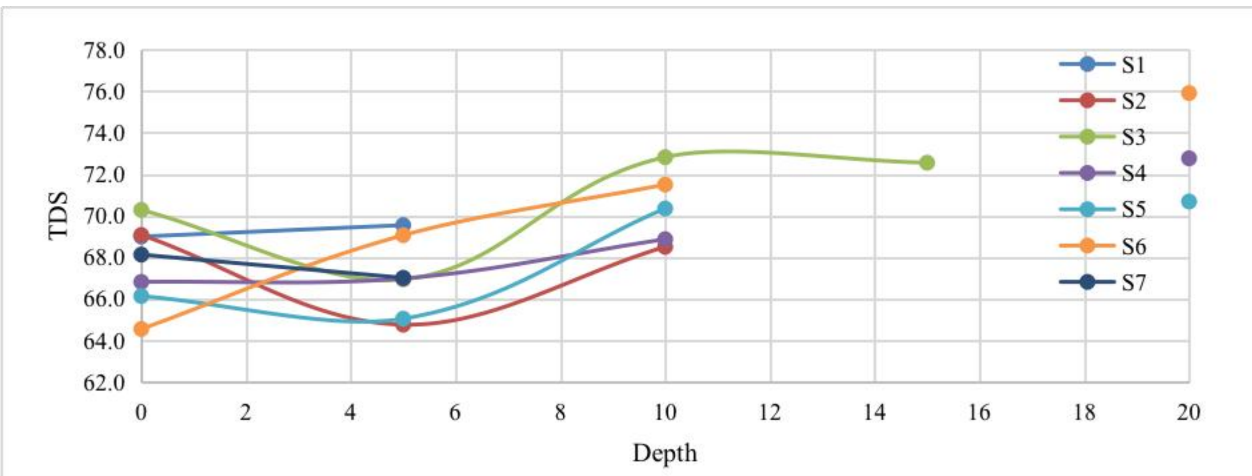

Figure 4.8: Variation of Total Dissolved Solids (TDS) with Depth during the dry season

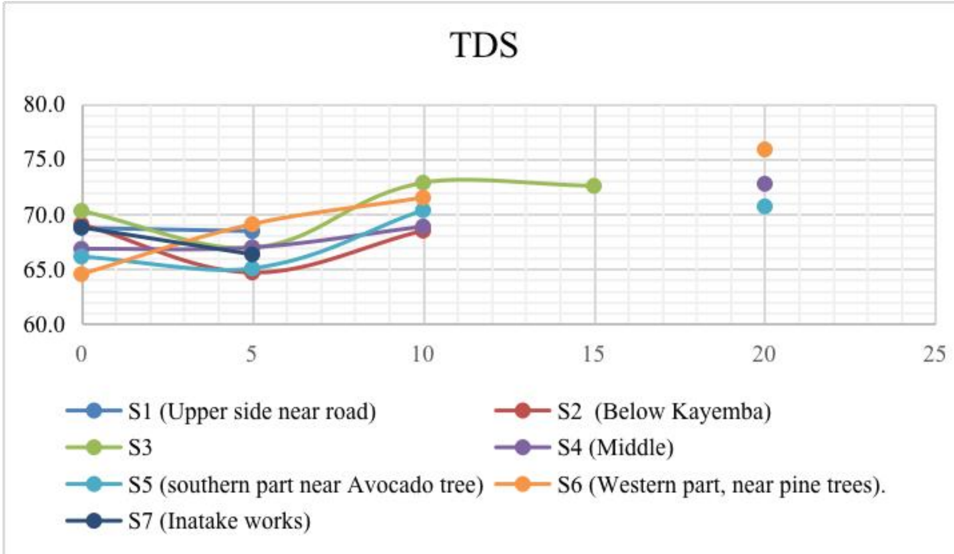

Figure 4.9: Variation of Total Dissolved Solids (TDS) with Depth during the wet Season

4.3.5 pH

Due to its influence on nutrients' solubility and availability as well as their utilization by aquatic organisms, pH becomes an important factor. The pH of Lake Nkugute ranged between 6.86 and 8.2 with mean of 7.75±0.208. The mean dry season pH was 7.73±0.138 (Figure 12) while the wet season mean pH was 7.75±0.208 (Figure 13) with the lowest and highest pH value being observed at station 1 (6.86) and station 7 (8.2) respectively. The pH of Lake Nkugute is relatively consistent between the dry season and wet season with mean pH of 7.75. The vertical distribution of the pH values in the lake is not significantly different ($p > 0.05$) between seasons.

Generally during both the dry and wet seasons the pH decreases with depth though slightly with no significant difference with the exception of station 5, 2 and 3 whose pH values were observed to increase to 7.8, 7.8 and 7.85 respectively. The pH values then decreased for the proceeding depth. S1 is the major inlet into the lake with very shallow depth (from 5m to 8m) and S7 is the outlet with equally shallow depth (from 5m to 8m).

S4 is the deepest part of the lake, S3, S5 and S6 are deeper than S1, S2 and S7. At inlet S1, the surface runoff from anthropogenic activities is of lower pH (range?) however as the water approaches the outlet at S7, there is more dilution raising the pH value to 8.2 (Figure 12). A similar study carried out by Ling et al., (2013), on crater Lake/Reservoir showed that the slight dilution in water column at S5, S2 and S3 might be responsible for the increased pH though limited to depth between 0 to 5m after which its stabilises even in wet season.

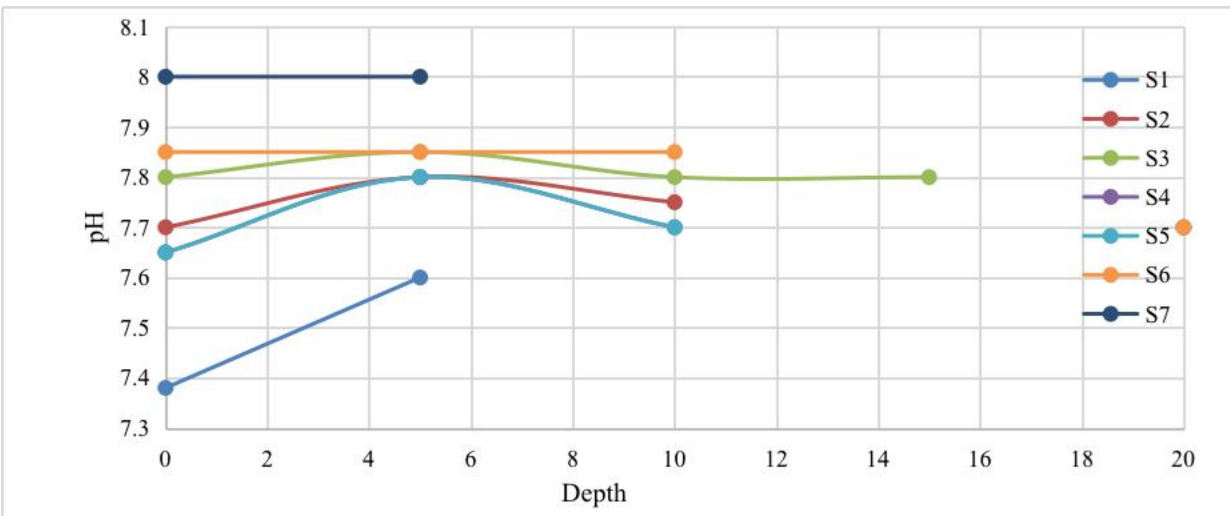

Figure 12: **Variation of pH variations with depths at various locations in dry season**

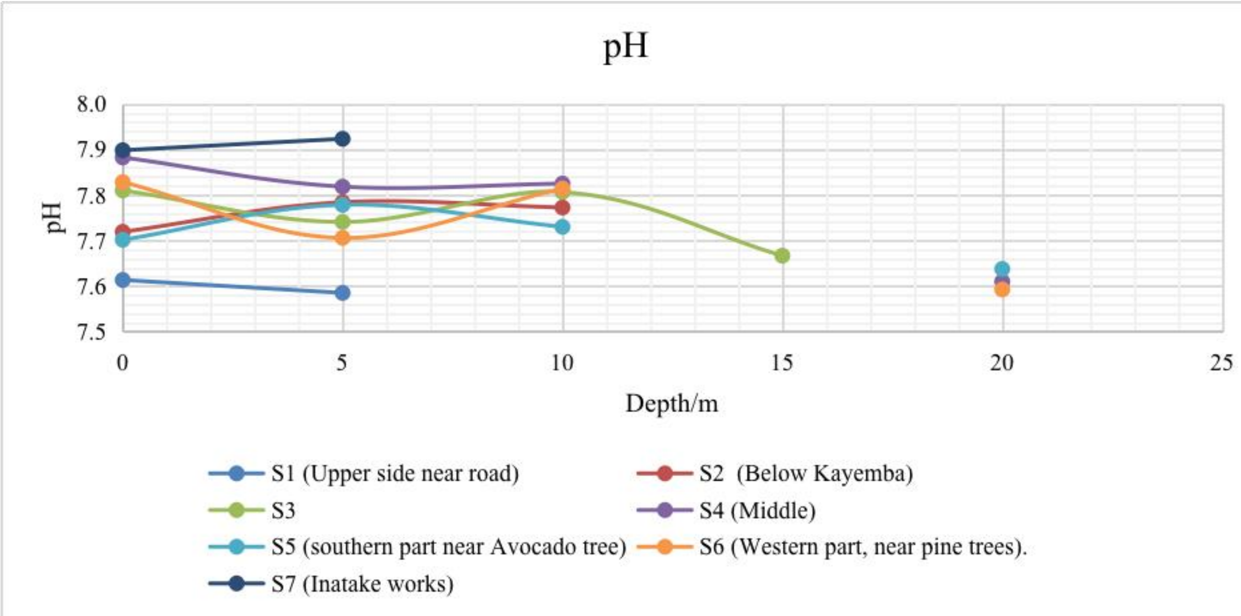

Figure 13: **Variation of pH variations with depths at various locations in wet season**

4.3.6 Electrical Conductivity

The water quality at varying depths reveals a decline in EC values at depth of 5m and then an increase to 10m across all sampling locations (Figure 14 & 15). The average EC value at depth of 5m was 108.3±8.52µS/cm. Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions, on the total concentration, mobility and valence of these ions, and on the temperature of measurement (Rahman et al., 2016; Sripathy et al., 2012). Figure 14 indicates the variation of EC with depth in Lake Nkugute.

Conductivity outside the range between 150 and 500 µS/cm of inland fresh waters could indicate that, the water is not suitable for certain species of fish or macro-invertebrates (APHA, 2012). The variation of EC with season was significant ($P<0.05$). The overall mean across all depth was 114.8±8.52µS/cm in wet season and 107.4±8.52µS/cm in dry season. The means indicate that EC is within the acceptable and suitable ranges for fish and other aquatic. The sample at S2 obtained at depth of 10m had the highest EC value of 120.1±8.52 µS/cm in the wet season with the sample obtained at S1 at depth 0.0m had the highest EC value of 113.6±8.52 µS/cm in the dry season.

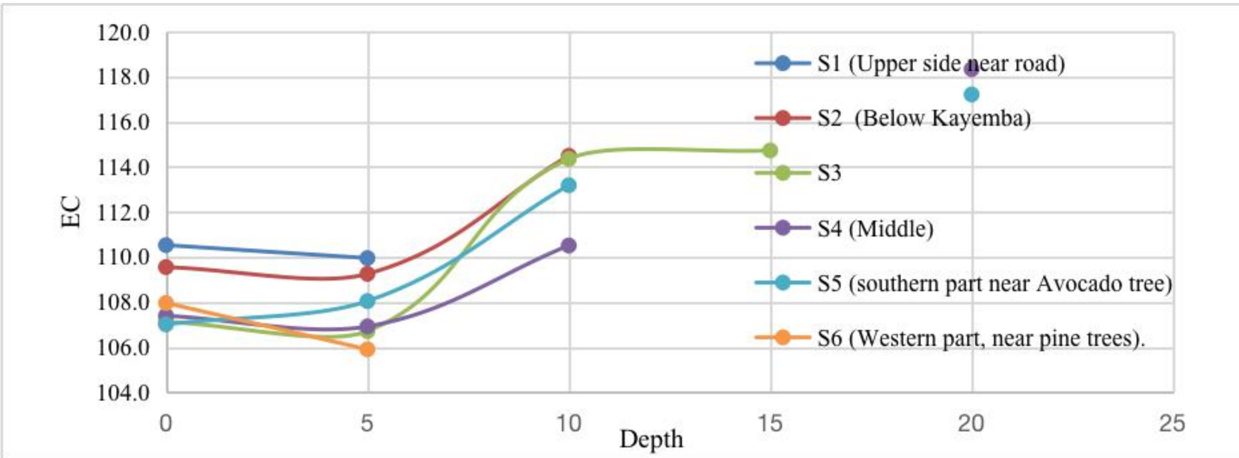

Figure 14: **Variation of EC with depth in Lake Nkugute in the dry season**

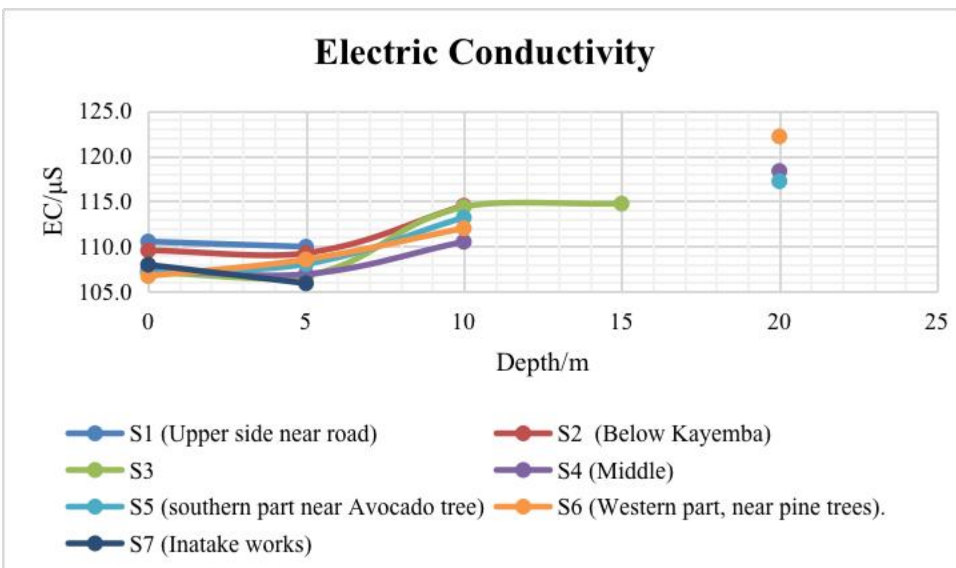

Figure 15: **Variation of EC with depth in Lake Nkugute in the wet season.**

4.3.7 Turbidity

Turbidity varies with depth changes. The deeper the lake sections, the more turbid the water becomes. The value of Turbidity at the surface ranges between 2NTU and 3NTU while that at 20m depth ranges from 0 to 5NTU. It is seen that for some sites like S3, S6 and S7, the water is almost free from impurities that form turbidity. The average value of turbidity is 3.6±0.09NTU at the average depth of 10m. Figure 16 indicates the variation of Turbidity in Lake Nkugute in the wet season.

The sample at S6 obtained at depth of 20m had the highest turbidity value of 4.9±0.09NTU. At all stations, turbidity increased as the depth increased commensurate to the studies carried out showing that turbidity increases with increase in depth (Karimpour et al., 2013). The variation of turbidity with season was very significant ($P<0.05$) with mean across all depth was 3.53±0.09μS/cm in wet season and 2.8±0.09μS/cm in dry season.

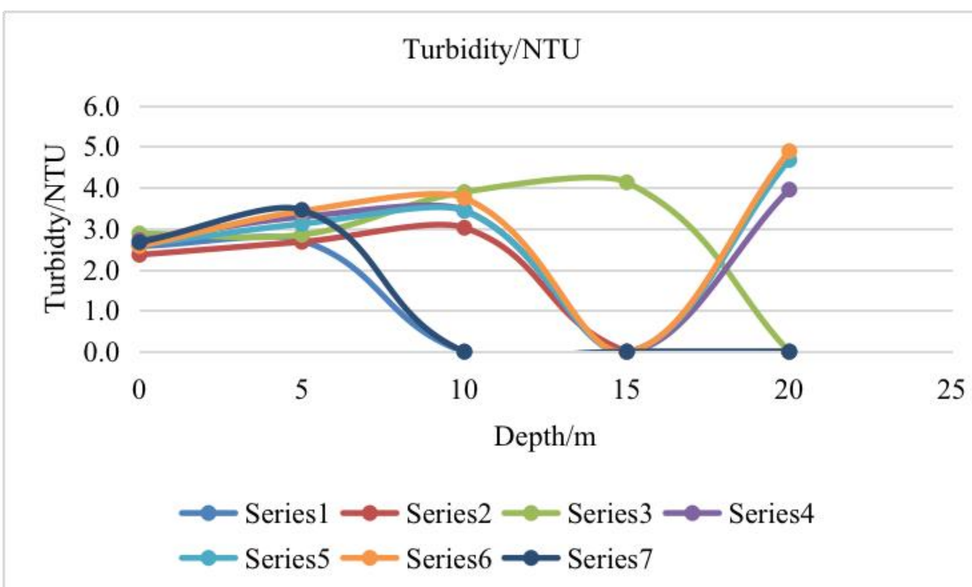

Figure 16: **Variation of Turbidity with depth in the Wet Season**

Turbidity for Lake Nkugute is within the acceptable range of potable untreated water of less than 15NTU (WHO, 2017; UNBS, 2014).

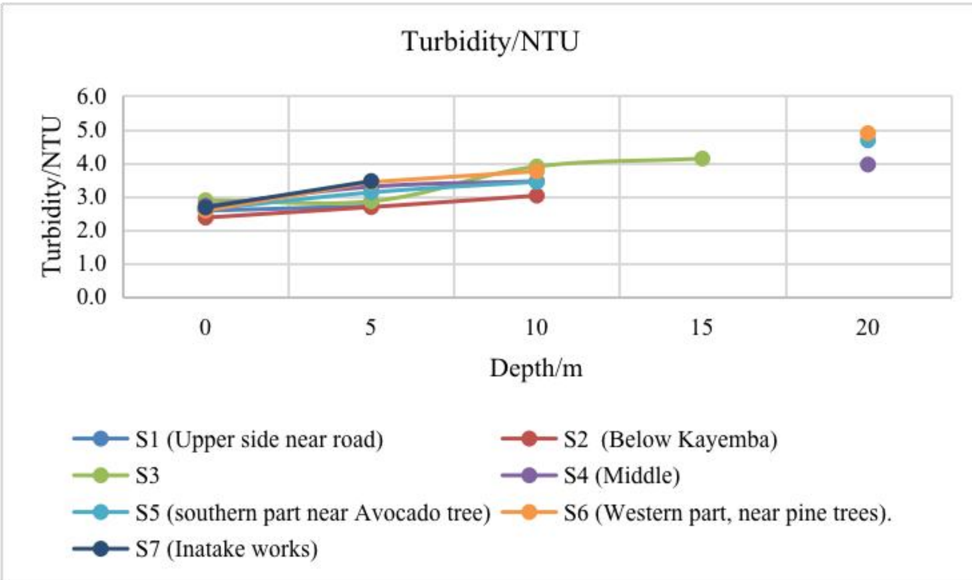

Figure 17: **Variation of Turbidity with depth the Wet Season**

4.3.8 Colour

Anthropogenic influences can affect the colour of the water. For example, natural organic matter that causes a yellow-brown colour of water is a result of humic matter (Karimpour et al., 2013; Wilson, 2010). Colour is essential in maintaining the aesthetics of water and by standard should not exceed 15True Colour Units (MWE, 2013a).

The colour in Lake Nkugute ranges from 5PtCo to 43PtCo with a mean value of 26.68 ± 10.61PtCo. Water discoloration increases with depth (20m) in lake Nkugute especially at stations S4, S5 and S6 in mean ranges of 25 and 29PtCo, and is relatively lower at the surface (0m to 5m) at stations S1 and S2 in the range of 9 to 13PtCo.

Figures 18 and 19 show the mean colour profile in the wet and dry seasons of lake Nkugute respectively. It is shown that on average, Water loses its true colour more in the Wet season than in the dry season. This may be attributed to the washing away of soils and humic substances from the surrounding hills where there are many anthropogenic activates taking place which include agriculture, lumbering, recreation and car washing.

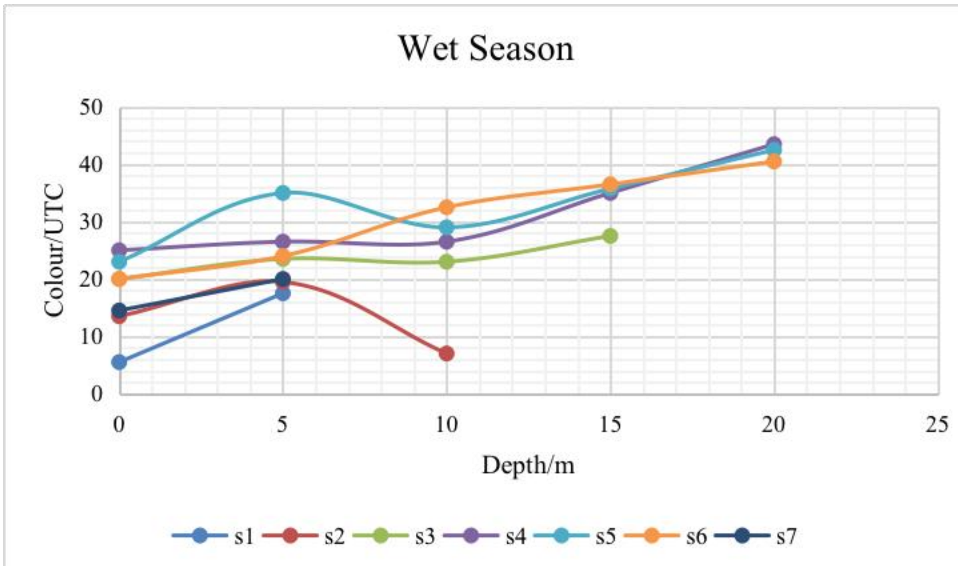

Figure 18: **Variation of Color in Wet season**

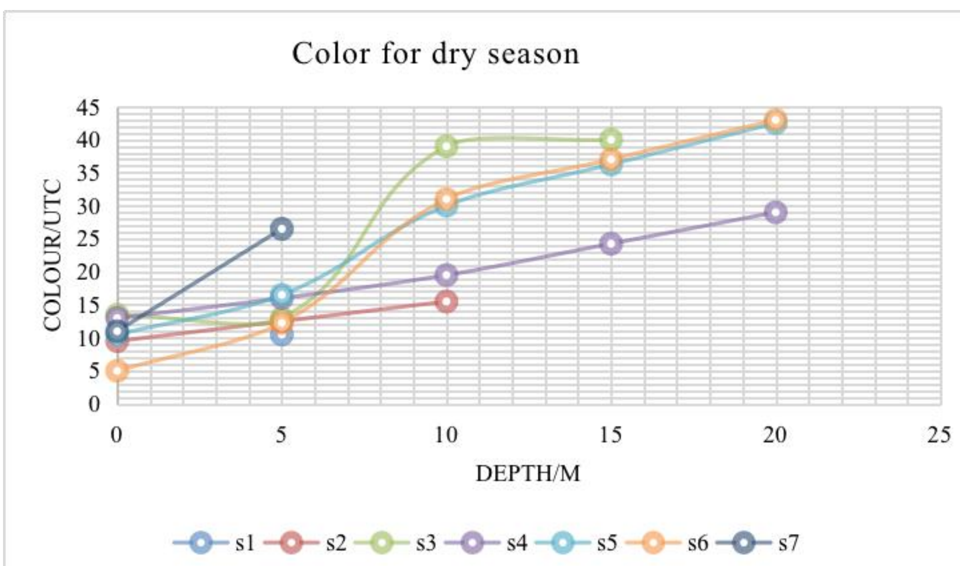

Figure 19: **Variation of Color in the dry season**

The colour was significantly different ($p<0.05$) among stations and depths. At the depth of 0.5 to 10 m, the colour was significantly different ($p<0.05$) among stations. The average colour levels were significantly high in wet season (42.17PtCo) and significantly lower in dry season (38.17PtCo). S4 and S5 both at 20 m depth were with average high colour levels (how high in quantitative terms?). There were no significant differences ($p>0.05$) in the colour between 0 and 5m in all stations in both seasons.

4.4 Correlations and analysis of Variance for different parameters

Correlation matrix was developed between different parameters (Table 6). The correlation coefficient (r) has a value between +1 and -1. According to Muthulakshmi et al., (2013) & Shroff et al., (2015), the correlation between the parameters is characterized as strong, when it is in the range of ±0.8 to ±1.0, moderate in the range of ±0.5 to ±0.8, weak when in the range of 0.0 to ±0.5. From Table 6, there was a strong negative correlation (-0.794) between EC and TDS which is significant ($p<0.05$) and both increase with depth. Turbidity had strong positive correlation with TSS (0.846), colour (0.862), moderate with EC(0.614) and weak with TDS (0.478). Turbidity showed a very strong negative correlation with DO (-0.670).

Colour had strong positive correlation with TSS (0.884), Turbidity (0.862), moderate with EC(0.614) and weak with TDS (0.478) and showed a very strong negative correlation with DO (-0.654). EC showed strong positive correlation with TDS (0.794), TSS (0.606) and moderate correlation with colour (0.633). The pH was found to have very weak relationships with all the other parameters.

Table 6: Correlation matrix for different parameters

Correlation Matrix									
		DO	Temp	EC	Turbidity	TDS	TSS	pH	Colour
Correlation	DO	**1.000**	0.586	-0.413	-0.670	-0.281	-0.581	0.133	-0.654
	Temp	0.586	**1.000**	-0.178	-0.444	-0.035	-0.250	0.181	-0.360
	EC	-0.413	-0.178	**1.000**	0.614	0.794	0.606	-0.029	0.633
	Turbidity	-0.670	-0.444	0.614	**1.000**	0.478	0.846	-0.144	0.862
	TDS	-0.281	-0.035	0.794	0.478	**1.000**	0.526	0.076	0.545
	TSS	-0.581	-0.250	0.606	0.846	0.526	**1.000**	-0.103	0.884
	pH	0.133	0.181	-0.029	-0.144	0.076	-0.103	**1.000**	-0.129
	Colour	-0.654	-0.360	0.633	0.862	0.545	0.884	-0.129	**1.000**
Sig. (1-tailed)	DO								
	Temp	0.000							
	EC	0.000	0.045						
	Turbidity	0.000	0.000	0.000					
	TDS	0.003	**0.371**	0.000	0.000				
	TSS	0.000	0.008	0.000	0.000	0.000			
	pH	**0.104**	0.042	**0.391**	**0.085**	**0.237**	**0.164**		
	Colour	0.000	0.000	0.000	0.000	0.000	0.000	**0.109**	

With the objective of evaluating significant differences among the sites for all water quality variables, data was analyzed using one-way analysis of variance (ANOVA) at 0.05% level of significance.

During the wet season the EC, pH, TDS, TSS, and Turbidity increased while Temperature and Dissolved Oxygen (DO) decreased (Cross reference where these results depict this). However, the variations of means for DO, TSS and pH between seasons were not significant as indicated in Table 6. The significance of variation of water quality parameters between the wet and dry season is indicated in Table 6 and Table 7. The results reveal that variations are significant with temperature, DO, Turbidity, EC and TDS ($P<0.05$) while insignificant variations were observed for TSS and Color ($P>0.05$). The positive value of mean difference indicates that the parameter studied is higher during the wet season whereas the negative value indicates that the parameter studied is higher during the dry season (Table 8).

Table 7: Analysis of Variances for different parameters with Seasons

		ANOVA				
		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Temp	Between Groups	48.2	1	48.184	78.546	0
	Within Groups	55.2	90	0.613		
	Total	103.4	91			
DO	Between Groups	55.1	1	55.134	6.978	0.01
	Within Groups	711.1	90	7.902		
	Total	766.3	91			

		ANOVA				
		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	0.1	1	0.06	1.388	0.242
	Within Groups	3.9	90	0.043		
	Total	4.0	91			
EC	Between Groups	1085.8	1	1085.804	17.691	0
	Within Groups	5523.8	90	61.376		
	Total	6609.6	91			
Turbidity	Between Groups	9.4	1	9.382	12.164	0.001
	Within Groups	69.4	90	0.771		
	Total	78.8	91			
TDS	Between Groups	195.7	1	195.728	5.715	0.019
	Within Groups	3082.2	90	34.246		
	Total	3277.9	91			
TSS	Between Groups	4.3	1	4.348	1.982	0.163
	Within Groups	197.4	90	2.193		
	Total	201.7	91			
Color	Between Groups	344.4	1	344.391	2.659	0.106
	Within Groups	11658.3	90	129.536		
	Total	12002.7	91			

Table 8: Comparison of Means for different parameters

Parameter	**Sampling**	**Depth**	**Station**								**Mean**	**Difference**	**P value (<0.05)**
			S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**Total**			
Temp	Wet season	0	23.7	23.5	23.8	23.5	23.8	23.5	24.8	23.8	23.5	-1.5	0.0000
		5	23.6	23.6	23.6	23.5	23.2	23.4	24.8	23.7			
		10		23.5	23.5	22.8	23.1	23.3		23.2			
		15			23.3		22.9	23.0		23.3			
		20				22.9				22.9			
		Total	24.6	23.5	23.2	23.2	23.2	23.3	24.8	23.5			
	Dry Season	0	25.8	25.4	25.4	25.5	25.9	25.8	25.3	25.6	24.9		
		5		25.5	24.4	24.4	25.6	25.1	24.9	25.0			
		10		24.7	24.6	24.5	24.5	23.8		24.4			
		15			24.8			24.0		24.8			
		20				24.0	24.4			24.1			
		Total	25.8	25.2	24.8	24.6	25.1	24.7	25.1	**24.9**			
DO	Wet	0	7.5	7.2	6.2	6.8	6.2	6.1	6.6	6.6	3.54	-1.54	

Parameter	Sampling	Depth	Station								Mean	Difference	P value (<0.05)
			S1	S2	S3	S4	S5	S6	S7	Total			
	season	5	3.5	2.9	3.6	2.9	3.0	3.5	4.3	3.4			
		10		2.1	1.3	1.5	2.0	1.5		1.7			
		15			0.6		1.2			.6			
		20				0.6		0.8		.9			
		Total	4.8	4.0	2.9	2.9	3.1	3.0	5.4	**3.5**			
	Dry Season	0	7.9	7.5	7.9	9.0	10.6	9.2	9.2	8.8			0.10
		5		5.0	5.0	4.9	5.4	5.6	6.8	5.5			
		10		3.4	2.5	2.3	2.4	1.4		2.4	5.08		
		15			1.2					1.2			
		20				1.2	1.0	1.1		1.1			
		Total	7.9	5.2	4.1	4.4	4.9	4.3	8.0	**5.1**			
pH	Wet season	0	6.9	7.7	7.8	7.9	7.7	7.9	8.0	7.8	7.78	0.05	
		5	7.6	7.8	7.9	7.9	7.8	7.9	8.0	7.8			

Parameter	Sampling	Depth	Station								Mean	Difference	P value (<0.05)
			S1	S2	S3	S4	S5	S6	S7	Total			
		10		7.8	7.8	7.9	7.7	7.9		7.8			
		15			7.8					7.8			
		20				7.7	7.7	7.7		7.7			
		Total	7.6	7.8	7.8	7.8	7.7	7.8	8.0	**7.8**			
	Dry Season	0	7.8	7.7	7.8	7.9	7.7	7.9	7.8	7.8	7.73		0.242
		5		7.7	7.7	7.7	7.8	7.6	7.8	7.7			
		10		7.8	7.8	7.8	7.8	7.8		7.8			
		15			7.6					7.6			
		20				7.6	7.6	7.5		7.5			
		Total	7.8	7.7	7.7	7.8	7.7	7.7	7.80	**7.7**			
EC	Wet season	0	110.6	115.5	110.8	111.8	110.8	110.2	112.6	111.7	114.2	6.87	
		5	113.	114.	110.	109.	112.	110.	109.	111.			

Parameter	Sampling	Depth	Station								Mean	Difference	P value (<0.05)
			S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**Total**			
			7	1	6	5	9	5	4	5			
		10		120.1	117.7	114.3	116.0	113.2		116.2			
		15			118.9					118.9			0.000
		20				123.7	116.5	124.8		121.6			
		Total	113.6	116.5	114.5	114.8	114.0	114.7	111.0	**114.2**			
	Dry Season	0	113.6	103.7	103.5	103.0	103.3	103.2	104.7	104.4	107.4		
		5		105.7	102.9	104.4	103.2	106.7	103.0	104.3			

Parameter	Sampling	Depth	Station								Mean	Difference	P value (<0.05)
			S1	S2	S3	S4	S5	S6	S7	Total			
		10		109.0	111.1	106.8	110.4	110.8		109.6			
		15			110.6					110.6			
		20				113.0	117.9	119.5	103.8	116.8			
		Total	113.6	106.1	107.0	106.8	108.7	110.1	103.8	**107.4**			
TDS	Wet season	0	65.0	72.9	70.2	68.3	68.3	66.1	70.8	68.8	70.41	2.92	
		5	69.6	65.2	67.0	68.2	71.8	69.3	70.2	68.7			
		10		67.9	72.4	70.4	74.0	71.8		71.3			
		15			74.9					74.9			
		20				75.5	70.8	79.4		75.2			

Parameter	**Sampling**	**Depth**	**Station**								**Mean**	**Difference**	**P value (<0.05)**
			S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**Total**			
		Total	66.8	68.6	71.1	70.6	71.2	71.6	70.5	**70.4**			
		0	79.5	65.3	70.4	65.4	64.0	63.0	66.4	66.8			0.019
		5		64.5	66.9	65.8	58.3	68.8	64.9	64.8			
	Dry	10		69.2	73.3	67.3	66.8	71.2		69.6	67.50		
	Season	15			70.2					70.2			
		20				70.1	70.6	72.5		71.1			
		Total	79.5	66.1	70.2	67.1	64.9	68.9	65.6	**67.5**			
		0	3.0	1.5	2.5	3.50	2.0	2.0	1.50	2.1			
		5	2.5	3.0	2.5	2.50	3.5	3.0	4.00	3.0			
	Wet	10		1.5	3.0	3.50	2.5	4.0		2.9			
TSS	season	15			3.0					3.0	2.96	0.26	
		20				5.50	4.0	5.0		4.8			
		Total	2.7	2.0	2.8	3.75	3.0	3.50	2.75	**3.0**			

Parameter	Sampling	Depth	Station								Mean	Difference	P value (<0.05)
			S1	S2	S3	S4	S5	S6	S7	Total			
		0	1	2.0	1.0	1.5	1.0	1.0	1.3	1.3	2.70		0.163
		5		1.3	1.0	2.0	2.0	3.0	2.7	2.0			
		10		2.0	4.5	2.5	3.5	3.0		3.1			
		15			5.0					5.0			
	Dry	20				4.5	5.5	5.5		4.8			
	Season	**Total**	1	1.7	2.9	3.1	3.0	3.1	2.0	2.5			
Turbidity		0	3.2	2.5	3.4	3.2	3.3	3.3	3.4	3.2			0.001
		5.0	3.3	3.2	3.5	3.8	3.8	3.7	3.7	3.5			
		10.0		3.2	3.5	4.0	3.7	4.2		3.7			
		15.0			3.9					3.9			
	Wet	20.0		2.6	3.5	4.6	4.2	4.6		4.5			
	season	**Total**	3.3	2.9	3.5	3.9	3.7	3.9	3.5	3.6	3.53		
	Dry	.0	1.9	2.3	2.5	2.2	2.0	1.9	2.0	2.1	2.8	0.73	

Parameter	**Sampling**	**Depth**	**Station**								**Mean**	**Difference**	**P value (<0.05)**
			S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**Total**			
	Season	5.0		2.1	2.2	2.8	2.5	3.2	3.0	2.6			
		10.0		2.8	4.3	2.9	3.2	3.4		3.3			
		15.0			4.4					4.4			
		20.0		2.4	3.3	3.3	5.2	5.2	2.5	4.6			
		Total	1.9	2.4	3.3	2.8	3.2	3.4	2.5	2.9			

5 CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

In this study, physicochemical parameters of water quality of lake Nkugute were determined during the wet and dry seasons. There were significant differences ($p<0.05$) in Temperature, Electric Conductivity, turbidity, TSS, TDS and Colour whereas pH and DO showed no significant differences between wet and dry periods.

At different depths of the lake water, there were significant differences ($p<0.05$) in Temperature and DO which reduced with increase in depth; Turbidity, TSS, TDS, Colour and EC which increased with increase in depth. There was no significant difference ($p<0.05$) in pH wariation with depth.

The correlations between the selected water quality parameters were determined. There was a strong correlation (-0.794) between EC and TDS. Turbidity had strong correlation with TSS (0.846), colour (0.862), moderate with EC(0.614) and weak correlation with TDS (0.478). Turbidity had a strong correlation with DO(-0.670). Colour had strong correlation with TSS (0.884), Turbidity (0.862), moderate with EC(0.614) and weak with TDS (0.478). EC showed strong correlation with TDS (0.794), TSS (0.606) and moderate correlation with colour (0.633). The pH was found to have very weak relationships with all the other parameters

The water quality parameters measured from Lake Nkugute were found to be within the recommended limits of World Health Organization and National Drinking Water Quality Standards. The results provide a better understanding of seasonal variations in water quality of the lake.

5.2 Recommendations

- The water quality parameters measured from Lake Nkugute were found to be within the recommended limits of portable water implyinng that pollution levels are still low. The government should hence put into place measures of ensuring proper conservation of its watershed.

- This study considered the physiochemical parameters only to assess the seasonal variation of water quality in the lake depth. Researchers should take interest in the biological and nutrient parameters and the of the same study area. It is important that the Water managers continue monitoring Lake Nkugute.

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DIRECTORATE OF POSTGRADUATE STUDIES

DISSERTATION CORRECTION COMPLIANCE REPORT BY THE CANDIDATE (POST VIVA FORM)

Date: 2nd September 2024

Name of Candidate: MUSINGUZI GEORGE TINDA

Reg. No: RM17 M45 /001

Title of Dissertation: EVALUATION OF SEASONAL VARIABILITY IN PHYSICOCHEMICAL WATER QUALITY OF LAKE NKUGUTE, UGANDA.

SN	COMMENTS BY EXTERNAL EXAMINER	ACTION TAKEN	INDICATOR
1	**Overall structure and presentation**		
	There is need to revisit the abstract and address the comments raised. Overall structure and presentation	The abstract was reviewed in line with the advice given. Then rest of the comments were addressed in the chapters below of this matrix.	Page i
2	**Introduction**		
	The background to the study (section 1.1) is quite long (spanning 3 pages) and very disjointed...jumping from one thing to another without any systematic flow! The background should be reduced such that it does not exceed 1.5 pages.	This has been revised to to fit on 1.5 pages and the flow edited to flow systematically.	Pages 1&2
	The write up of this background should follow the "inverted triangle concept." The candidate should be mindful of their English grammar write up.	This has been done and the grammar corrected. The flow of content has been adjusted from global to national and then to the study area.	Pages 1&2
	The problem statement needs to be revisited such that it is utmost with two paragraphs not exceeding half a page to clarify the problem that motivated this study.	This has been done	Page 3
	There is need to revisit the tense of the main objective and specific objectives write up as guided in the reviewed soft copy of the dissertation. The monotony of the start of the research questions needs to be broken.	This has been corrected accordingly.	Pages 3 & 4
	The write up under the section on justification of the research (Section 1.5) needs to be revisited to clearly address the question "Why was this study undertaken?" in one	This has been addressed.	Page 4

	paragraph.		
3	**Literature review**		
	The candidate has made use of some relevant literature but needs to include more literature from sub-saharan Africa or low-middle income countries. In some sections, old references (more than 10 years old are used). The candidate should utilize more recent references (less than 10 years old). The presented literature is largely drawn from other people's work without the candidate providing the implication of some of this to their study.	Some references have been included like Bwire et al.; 2020; Sekabira, et al.; 2010) Implications from literature of other works have been included.	Page 6 Pages 8 & 9
	Whereas the candidate presents some literature on the bacteriological quality of water under section 2.7, it is clear as pointed out earlier that he did not undertake any measurements on this in their study and no plausible reason(s) is given for not having done so! Hence despite what was measured, the candidate cannot make a conclusion on how the safety of the sampled lake water source varies with season, a key output.	The bacteriological study was not conducted due to inadequate financial resources to conduct all parameters. This reason has been included in the report. This has been provided as a gap for other studies.	Page 19.
	In section 2.7.1 on faecal coliforms, the candidate states "The presence of faecal coliform in a water sample often indicates recent fecal contamination, meaning......." The candidate needs to note that this is not true! He needs to undertake more literature review and correct this statement with the specific group of coliforms mentioned here instead of faecal coliforms.	This was adjusted accordingly.	Page 20
4	**Methodology**		
	In Table 3.1 (formerly labelled as Table 4) it is noted that the candidate presents only 6 sampling sites (S1-S6) and yet in the results chapter, he has plots for S7! There is need to	Point S7 has been included with its coordinates and description. Sampling points have been corrected to 7 (S1-S7).	Page 26

	clarify what S7 is in Table 3.1.		
	In Section 3.4.3, the candidate should provide the rationale for the sampling depths that were chosen.	The sampling depth were chosen based on the literature review of similiar studies (Beadle, 1965). The explanation has been provided.	Page 26
	The data provided in Table 3 is without this detail.	The details for table 3 have been provided (Climate characterization of Rubirizi District) and refered to in the main text.	Pages 23 & 25
	In section 3.6, no methodology is provided for colour and hence the type of colour measured in this study.	This has been provided	Pages 27 $ 46
	The candidate should provide the actual name of the methods used for each of the parameters measured in this study and their respective references for completeness in this chapter.	This has been done	Page 26 & 27
5	**Presentation and analysis of data**		
	English grammar write up is poor in many areas distorting the clarity of what it is the candidate wants to say.	Grammar has been corrected in line with the advice given.	Pages 29, 37, 38, 40, 45, 48,
	In the results, the plots only have two points for S1 and S7 which, is difficult to appreciate! Additionally, considering the nature of the plots, the candidate has overfitted the data which, can be misleading.	S1 and S7 were shallow points with depth between 5 to 8m hence only two depth were obtained at 0m and 5m. This has been explained in the main text. The plots were generated by a computer Aided soft ware and gave those results.	Page 26
	2 data sets in the wet and 2 data sets in the dry season is relatively limited data.		
	To help with the discussion, some of the plots should have been placed side by side with the same axis scales. This would have worked better for wet and dry season plots to		

	bring out the comparison better.		
	Additionally, some parameters, especially surrogate parameters could be plotted in the same figure using both the left Y and right Y axes (E.g., Turbidity and TSS). To improve the presentation of results so that it is systematic.		
6	**Discussion of results**		
	However, there is need to improve on the discussion of the findings presented here. The results are largely presented in some cases without being discussed adequately. Where there is an attempt to discuss, the arguments put forward are not substantiated and hence the discussion is in isolation. The candidate needs to make use of stipulated national drinking water standards in their discussion to clarify whether these waters comply or not. The candidate needs to substantiate whatever inferences are made from the presented results as pointed out in the reviewed soft copy of the dissertation with plausible references else these remain speculative. Also, there is need for clarification in some sections of the write up regarding the discussion (especially where queries are posed) so as to enhance the interpretation/discussion of the results. Additional comments are presented in the submitted soft copy of the dissertation.	The discussion has been enhanced by considering the comments given in the submitted soft copy from the examiner. Clarifications have been made, standards (WHO and NBS) provided. In depth discussions have been made.	Pages 32- 50
7	**Conclusions and Recommendations**		
	The write up of the conclusions and recommendations is inadequate! The conclusions need to be improved in such a way that they are clearly articulated following from the findings presented in the reviewed soft copy of the	Conclusions have been improved in line with the study specific objective.	Pages 60 & 61

	dissertation. These for clarity should be presented systematically with at least a minimum of one conclusion emanating from each study specific objective. The conclusions should be exclusive of repetition of findings and their discussion as pointed out in the reviewed soft copy of the dissertation. The candidate should ensure that the recommendations presented follow from the conclusions made and the discussion of the results and findings presented in Chapter 4 of the dissertation so as to be clearly relevant. No new information that has not been discussed in Chapter 4, should be presented under the recommendation section. The recommendations should be bulleted text and it should be clear what needs to be done, by who and for what purpose!	Recommendations have been bulleted and clearly stated.	
8	**References and Appendices**		
	The write up of the list of references is systematic (alphabetical order). However, the candidate should ensure that the write up of these in the list complies with the recommended University guideline style of referencing for consistency. The information provided for each reference in the list should be sufficient to ensure that a reference can be traced (This is possible if the recommended referencing style is adhered to). In cases where it is stated "incomplete", "Date of access", these need to be addressed for completeness for the references. Also noted that the appendices in the reviewed soft copy of the dissertation is without anything presented there. There is need for the candidate to have some material presented in the appendix as guided in the reviewed soft copy of the dissertation. Additional comments are provided in the soft copy of the reviewed dissertation to improve the write up of these.	This has been done according to the advice given.	Page 61

SN	COMMENTS BY INTERNAL EXAMINER	ACTION TAKEN	INDICATOR
1		No comments were given	

SN	COMMENTS BY VIVA VOCE PANNEL	ACTION TAKEN	INDICATOR
a	Your catchment characteristics need to be clear – How did you take this location of 1m in depth? – Justify your coverage area?	Sampling depth were taken at 5m not 1m based on the literature review of similiar studies. Area of coverage, sample points were selected as mentioned in Table 3.1.	Page 26
b	Bacteriological analysis for water quality was an important aspect to take note of, for instance, water could be brown and safe	Biological water quality was not analyzed in the study due to limited financial resources that were at my disposal	Page 19
c	Seasonal variations needed to be appreciated, if some parameters were to be considered.Different seasons have different characteristics.	This was considered in the methodology and discussion of results	Chapter 3 and 4.
d	Since a lake is more complex, - How did you derive to your samples? - Did you get GPS coordinates of each location ?	- Sample points were selected considering the activities in the nearest watershed as well as in the middle of the lake. - GPS coordinates of each location was obtained.	Page 26 Page 27
e	You needed to justify the parameters used - Clarify why you chose those - What you chose - Why you didnt choose what you didnt.	Parameters were selected based on the literature review of similiar studies.	Page 20
f	Explain the choice of the 7 sampling points ?	- Sample points were selected considering the activities in the nearest watershed as well as in	Page 26

	- Which logic was used - Explain this to the reader	the middle of the lake.	
g	The TD, PH, turbidity and colour were not averaged in the sample. These are not simple parameters to be left out.	The averages were obtained for these parameters.	Table 4.2
h, i	Where necessary use graphs for mathematical relationships only . Do not use curves. Represent your information using a map.E.g a map can be marked using a different colour.	This has been noted but not done due to limited time available.	
j, k	What informed the study design used ? What was your motivation for this study ?	This has been well explained in the Justification, chapter 1.5	Page 4
l	What was the implication connected to the socio economic activities around the lake and how was it connected to the water resource ? - What are the implications of the economic activities to the water Resource	This was not considered in the study.	
m	What is your contribution to the body of knowledge ?	The study provide data for better understanding of seasonal variations in water quality of the lake which was not available.	Pages 4, 60
n	Elaborate more about the nature of the lake and its influencing factors. - This is a crater lake and the biggest in the area - Many things influence what happens around crater lake	This has been elaborated in the Chapters 1. The comprehensive watershed characteristics were not done in this study.	Pages 2 and 3.
o	Why was a pairwise test considered ?	Tukey's pairwise comparisons with 5% significance level was used to compare	Page 30

		parameters between stations and depths in the lake.	
p	Which variables were strongly correlated then which ones were more significant.	This has been considered in detail in Chapter 4 and Executive Summary	Pages 31 - 59
q	At what points were motorized boats used - At what point did you turn off the engine.	A boat was used for all the sample points. The engine would be turned off before the samples would be taken.	Page 27
r	Spatial variability is not clear when relating to lakes, seasons, and in depth. - Comment on the climate change in the area - Comment on the rate of population growth in the area and the rate of urbanisation - What GIS software was used to locate your sampling points - What informed your sample in depth ?	The point was noted and spatial variability component has been removed from the study since it was not captured during data collection. Population growth in the area has been included in Chapter 1 Sampling depth was taken at 5mbased on the literature review of similiar studies	Page 2 Page 26
s	The results were presented but not discussed well.The samples do not make references to the graphs used.	The discussion has been enhanced in line with the guidance from the examiners.	Pages 32 -50
t	During your discussion of spatial distribution, divide the lakes into different grids. If the objective seems impossible, it can be deleted.	The point was noted and spatial variability component has been removed from the study since it was not captured during data collection.	
u	The title needed to be revised if possible	This has been done to include only physicochemical parameters.	
v	Significant parameters needed to be corrected The water shed characteristics were missing Bacteriological characteristics were missing	Due to time constraint, biological parameters and watershed characteristics could not be obtained after Viva presentation. This remained a gap to be stuties as included in the recommendation.	Page 61

MUSINGUZI GEORGE TINDA	....	**Dr. Peter Mulamba**	....
Candidate's Name	Signature	Supervisor's Name	Signature