INVESTIGATION OF THE CONTENT AND DYNAMICS OF NUTRIENTS IN THE SURFACE WATER OF LAKE MULEHE IN KISORO DISTRICT, SOUTH-WESTERN UGANDA

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A Research Report Submitted to the Directorate of Research and Publications of Kabale University

June, 2022

DECLARATION

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Signature:...Date: ....

Alex Saturday, PhD

DEDICATION

To Johnson Runyonyozi, in loving memory

ACKNOWLEDGEMENTS

I am grateful to the Directorate of Research and Publications at Kabale University for funding this research. For technical assistance, I am grateful to the National Water and Sewerage Corporation (NWSC). Mr. Steven Macha, Mr. Ronald Saturday, and Mr. Gerald Kato deserve special thanks for their help during fieldwork. Without your help, this research would not have been feasible.

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LIST OF ABBREVIATIONS

APHA	American Public Health Association
DO	Dissolved Oxygen
mg/L	Milligrammes Per Litre
NH_3-N	Ammonia – Nitrogen
NO_2-N	Nitrite – Nitrogen
NO_3-N	Nitrate – Nitrogen
NTU	Nephelometric Turbidity Unit
NWSC	National Water and Sewerage Corporation
TN	Total Nitrogen
TP	Total Phosphorus
UNBS	Uganda National Bureau of Standards
USEPA	United States Environment Protection Agency
WHO	World Health Organization
WQI	Water Quality Index

ABSTRACT

Water pollution with nutrient-based contaminants is a major concern as it may lead to the eutrophication of freshwater bodies. The purpose of this study was to investigate the content and dynamics of nutrients in the shallow (max. 6 m) Lake Mulehe. We collected 54 water samples from nine sampling stations between the wet season March‑May 2020 and the dry season (June‑August 2020). Nutrients; ammonia‑nitrogen (NH_4‑N), nitrate‑nitrogen (NO_3‑N), nitrite‑nitrogen (NO_2‑N), total nitrogen (TN), total phosphorus (TP) and soluble reactive phosphorus (SRP) were investigated in accordance with APHA 2017 standard procedures. Besides, physical parameters: Temperature, pH, turbidity, electrical conductivity and dissolved oxygen were measured in situ. The water quality index (WQI) was used to determine the water quality of Lake Muhele using drinking water quality standards developed by the Uganda National Bureau of Standards and the World Health Organization. Results indicated that nutrients (TN, NO_3‑N, TP, NH_4-N, NO_2‑N and SRP) did not differ substantially between study stations ($p > 0.05$) but did reveal significant differences ($p < 0.05$) across study months. Besides, nutrient levels differed significantly between seasons ($p < 0.05$) except for SRP and NH_4‑N. The WQI values varied from 36.0 to 74.5, with a mean of 58.69. The recorded overall WQI value places Lake Mulehe’s water quality into the ‘poor’ category in terms of worthiness for human consumption. The study, therefore, recommends continuous pollution monitoring and enforcement of local regulations to reduce pollution in the lake as a result of anthropogenic activities.

1. INTRODUCTION

1.1 Background to the Study

Freshwater is important not only in natural processes, but also in physicochemical reactions, agricultural and manufacturing operations, and human existence in general (Duan et al., 2016). Freshwater accounts for only 36 million cubic kilometres of the planet's total volume of water, which is estimated to be 1.4 billion cubic kilometres (Dunkelman et al., 2018). Nevertheless, anthropogenic activities such as industrialization, urbanization, and extensive agriculture have negatively affected freshwater quality and quantity.

Freshwater resources are damaged by waste discharge without proper treatment, according to the United Nations Environment Programme (UNEP) (2016). For example, 80 per cent of municipal wastewater discharged into water bodies is either improperly treated or untreated as a result of rapid urbanization. The nutrient-rich municipal waste discharge causes eutrophication, which results in a rise in toxic algal blooms, turbidity, and hypoxia in new areas (Mateo-Sagasta et al., 2017; Saturday et al., 2021). The wastewater discharge also poses a health risk to the public as a result of accidental water consumption or skin contact with faecal-contaminated waterways (Saturday et al., 2021). Disease-causing pathogens present in both human and animal faeces, such as bacteria, viruses, protozoa, and worm eggs, may be among the microbial contaminants. Both human life and environmental processes require water (Dunkelman et al., 2018). Freshwater is used not only for drinking and bathing but also for recreation, agriculture, energy production, industrial activities and the extraction of fish resources. Furthermore, freshwater habitats are essential for the survival of a large number of animals, plants, and microbes (Combes, 2003).

According to Brusseau et al. (2019), only 3% of the water on Earth is fresh, with the bulk (79%) locked up in the polar ice caps, 20% in aquifers, and 1% in lakes and rivers. The potential consequences of an ever-increasing human population, coupled with rapid development in terms of industrialization and widespread agriculture are raising serious worries about the future sustainability of freshwater supplies. They can change the biological, chemical and physical properties of freshwater lakes (Fouchy et al. 2019). Toxic compounds and excess nutrients, as well as detrimental anthropogenic practices near the lake, for example, endanger the water quality in freshwater ecosystems. The massive rise in pollution flow into freshwater lakes kills aquatic creatures like fish, and industrial wastes change the pH of the water and offer abundant bacterial nutrients, which often hamper the ability of natural processes to inactivate and eradicate diseases (Islam et al., 2012).

Sewage discharge into freshwater lakes raises biological oxygen demand to the point where all available oxygen is depleted. As a result, bottom-dwelling creatures, fish and even marine plants get poisoned and/or killed, disrupting the food chain significantly (Galarpea & Parilla, 2012). Sewage-related diseases have been linked to water pollution, ranging from minor gastrointestinal disturbances to serious and life-threatening infections (Islam et al., 2012). Agricultural runoff into lakes adds a lot of nitrogen and phosphorus, which causes algae to grow out of control, reducing water clarity and light penetration. The activity of degrading and oxygen-consuming bacteria increases as primary productivity rises, while oxygen levels fall (Teklu et al. 2018). The examination of physical parameters and nutrients is critical to completely comprehend any lake habitat.

Most freshwater lakes in Africa are under threat as a result of rapid socioeconomic development (Fouchy et al. 2019). Excessive pollution discharge, excessive water abstraction, and excessive nutrient loading into freshwater bodies have all been linked to rapid industrialization and population growth in the lake's catchments (Sun et al., 2016). Due to high nutrient loads, some lakes in Eastern Africa are becoming eutrophic while others are experiencing siltation and hazardous pollution discharges, lowering their economic and aesthetic values. Teklu et al. (2018), for example, revealed that nutrient concentrations in Ethiopia's Lake Ziway had surpassed local and international standards in more than 50% of the cases that were studied.

Uganda is well endowed with freshwater resources, having 36,280 km^2 (15%) of freshwater resources (Failler et al., 2016;

Saturday et al., 2021). Surface runoff, urban wastewater effluents and agricultural runoff into freshwater systems, according to the Ministry of Water and Environment (2017), are the biggest risks to the country's freshwater ecosystems. The pollution of Uganda's lake water bodies is expected to quadruple by 2025 as a result of wetland reclamation for agriculture, industrialization and urban expansion (Kangume & Mulungu, 2018).

In the Kigezi sub-region, Lake Mulehe's shoreline has been encroached on by farmers and settlements (KDLG, 2017). Rapid population growth, intensive agricultural activities, and challenges in managing waste from recreational places are all thought to be contributing to increased external nutrient load and eutrophication, as well as a considerable shift from clear to turbid water. Unfortunately, despite the lake's socioeconomic and ecological importance, little is known about its present water quality trends. Whereas several studies have been conducted to assess the limnological status of other lakes in the sub-region (Tibihika et al., 2016; Saturday et al., 2021; Saturday et al., 2022), none has investigated the content and dynamics of nutrients in Lake Mulehe, despite its socioeconomic significance in the region. As a result, a study was required to better understand the spatial and temporal fluctuations in nutrient levels in Lake Mulehe. The findings would aid in understanding of the lake's ecosystem responses and long-term management.

1.2 Statement of Research Problem

The rising human population around the Lake Mulehe sub-catchment, combined with agricultural practices, has had a negative influence on the lake’s biophysiochemical water quality parameters. The fact that Lake Mulehe is situated in a densely populated agricultural area (656.6 people per square kilometre), it is vulnerable to pollution from communities and farmlands. For example, eutrophication could have caused the lake water to change from clear to eutrophic turbid. High algae bloom in a lake system reduces water transparency, depletes DO, and potentially releases toxins, all of which have a detrimental influence on biophysiochemical water quality, as well as altering ecosystem functioning (Ke et al., 2019). Despite its socioeconomic importance, little was known about the water quality of Lake Mulehe. As a result, the current study investigated the content and nutrient dynamics on the surface of the water of Lake Mulehe to recommend the appropriate mitigation measures.

1.3 Research Objective

To investigate the content and dynamics of nutrients in the surface waters of Lake Mulehe, South-western Uganda

1.3.1 Specific Objectives

The specific objectives of the study were:

i. To determine the spatial and seasonal variations in the physical parameters (turbidity, pH, temperature, EC and DO) of water in the study area;

ii. To determine the spatial and seasonal variations in the nutrient concentration levels (TN, NH_3-N, NO_2-N, and NO_3-N, TP, and SRP) in the surface water of the lake;

iii. To assess the quality of water in Lake Mulehe using the Weighted Arithmetic Water Quality Index Method (WAWQI).

1.4 Justification of the Study

From the limnological point of view, understanding water ecosystems is of primary concern. Therefore, monitoring physiochemical water quality in relation to aquatic life and the watershed of the water body, among others, cumulatively may reveal the true status of the water body. As per Uganda Vision 2040, subsection 4.1.9, water resources provide the country with an opportunity to stimulate social-economic transformation through development and utilization. These opportunities include, among others, fisheries and aquaculture, domestic water consumption, and tourism. Thus, the study provides the baseline information essential for the sustainable utilization of lakes in a move to achieve Uganda Vision 2040 as per paragraph 169. One of the targets for Sustainable Development Goal (SDG) 6 is to protect and restore water-related ecosystems, such as wetlands, rivers, aquifers and lakes by 2020. Therefore, the results of this study help in designing and implementing appropriate measures to protect and restore the lake’s unique attributes.

2. LITERATURE REVIEW

2.1 Freshwater Resources

Freshwater resources are essential for human survival as well as ecological processes (Dunkelman et al., 2018). Freshwater is utilized for agriculture, recreation, industrial operations, energy production, waste disposal, and the extraction of fish resources, in addition to drinking and bathing. Besides, freshwater habitats are essential for the survival of a large number of animals, plants, and microbes (Combes, 2003). Fresh water is in short supply all around the world. The oceans hold 97 per cent of the Earth's water, which is saline, whereas 3 per cent is freshwater, most of which (79 per cent) is locked up in glaciers, icecaps, and permanent snow cover (Ranjan et al. 2006). Nonetheless, rapid population growth, rapid urbanization, and extensive agricultural operations are increasing, all of which can affect the underlying nutrient concentration in lakes (Fouchy et al., 2019).

Excess nutrient levels as well as damaging land-use practices around lakes; for example, endanger the freshwater ecosystem's water quality and habitats. The massive rise in pollution flow into freshwater lakes kills aquatic creatures like fish, and industrial wastes change the pH of the water and offer abundant bacterial nutrients, which often hamper natural processes' ability to inactivate and eradicate diseases (Islam et al. 2012).

Sewage discharge into freshwater lakes raises biological oxygen demand to the point where all available oxygen is depleted. As a result, fish, bottom-dwelling creatures, and even marine plants get poisoned and/or killed, disrupting the food chain significantly (Galarpea and Parilla 2012). Water contamination has been linked to a variety of sewage-related ailments, ranging from minor gastrointestinal issues to life-threatening infections (Pant et al., 2012). In Africa, people are routinely admitted to hospitals with cholera, gastroenteritis, diarrhoea, and dysentery

(WHO & UNICEF, 2010), which are most frequent during the rainy season, demonstrating the impact of pollution in populated areas. Runoffs with agricultural product residues flow into lakes, adding a lot of nutrients (nitrogen and phosphorus), which cause algae to grow out of control, lowering water clarity and light penetration (Teklu et al. 2018).

2.2 Water Quality Assessment

Regular assessment and monitoring of water quality in lakes are important for the sustainable management of water resources. Besides, water quality monitoring helps in the identification and quantification of pollution sources, as well as the examination of the available water usage regulations (Walakira & Okot-Okumu 2011). To fully comprehend the Lake Mulehe ecosystems, the analysis of the content and dynamics of nutrients was paramount.

2.2.1 Physical Water Quality Parameters

Dissolved oxygen (DO), electrical conductivity (EC), pH, temperature and turbidity are all essential physical indicators used to monitor and study freshwater quality. In the aquatic ecosystem, these variables regulate both abiotic and biotic activity. An increase in biological and chemical reactions, for example, is caused by a rise in water temperature. BOD, microbiological growth and mortality, metabolic activity, and aquatic species dispersion are all influenced by water temperature (Bano et al., 2017).

The ability of aquatic aerobic organisms to live and carry out their ecological tasks is dependent on DO levels. Since water is the main source of oxygen for aerobic aquatic life, DO is also regarded as a crucial metric of purity for fresh waters (Bano et al., 2017). Death can be caused by low DO levels, which can also be used as a sign of freshwater pollution. The DO levels are affected by discharges from industrial facilities, as well as wastewater from residential areas and treatment plants (Bano et al., 2017).

The EC of water is a popular metric for determining the total salt content. It is extremely dependent on nutrient conditions as well as ion content in the water. According to Sallam and Elsayed (2018), low EC indicates that a pristine environment or the majority of the salts in the lake have been removed. Light is blocked by high volumes of suspended particles such as clay, silt, bacteria, and finely divided organic substances, causing water turbidity. Because suspended particles at the surface absorb heat energy from the sun, higher levels of turbidity block out the light needed by submerged aquatic plants and raise surface water temperatures (Cooper et al., 2017).

In a study conducted on craters in western Uganda by Busobozi (2017), it was found that dissolved oxygen ranged from 6.7 mg/l

(94.7%) to 16.2 mg/l (237.9%) and pH values ranged from 7.52 to 8.9, with all lakes showing slightly alkaline pH. The conductivity ranged from 267.7µS/cm to 649.3 µS/cm and temperatures varied from 22.7 ºC to 27.1 ºC. Busobozi's study, however, did not establish the effect of seasonal variations on physicochemical parameters. The current study has filled this gap with information.

2.2.2 Nutrient Dynamics in Freshwater Lakes

Freshwater nutrients (nitrogen and phosphorus) are very dynamic because they can be used, stored, changed, and excreted by a variety of aquatic organisms quickly and repeatedly. When compared to available nutrient rations, phosphorus is the most limiting nutrient. Weathering of minerals rich in hydroxyapatite ($Ca_5(PO_4)_3OH$) and anthropogenic activities such as agriculture, industrialization, sewage, and urban runoff into the lake's catchment area are the main sources of it entering freshwater systems (Rashmi et al., 2014). Algal and macrophyte growth is controlled by phosphorus, and the inability to regulate phosphorus input can result in algal blooms.

Phosphate levels in natural freshwater lakes fluctuate between 0.005 and 0.05 ppm, according to Rashmi et al. (2014). Species diversity is high in freshwater lakes with dissolved phosphorus values < 0.005 mg/L, but no algal plant development. Medium phosphorus concentrations (between 0.005 and 0.025 mg/L) promote algal and plant growth and diversification. Furthermore, concentrations greater than 0.025 mg/L lead to a reduction in species diversity, and increased proliferation of nuisance algal blooms (Rashmi et al., 2014).

Nitrogen is a biogenic element that is found in abundance in nature (Shen et al., 2013). Nitrogen release into a freshwater body has a significant impact on water quality and aquatic life health. The principal forms of nitrogen in natural aquatic systems are NO_2-N, NH_3-N, NO_3-N, and N_2. The most dominating type of nitrogen is determined by water system variables such as temperature, pH, oxygen, and microbe activity, as well as organic nitrogen mineralization rates, which are controlled by seasonal fluctuations (Shen et al., 2013). Runoff with agricultural residues, waste treatment stations, precipitation, and rivers are the main inputs to the Lake Mulehe sub-catchment, all of which contribute to the lake ecosystem's nitrogen accumulation. However, there is a scarcity of data on nutrient concentrations and fluctuations in the lake's spatiotemporal structure.

2.3 Water Quality Index

The Water Quality Index (WQI) is widely considered to be the most accurate method of determining water quality. It converts a complicated dataset into information that is easy to understand and use (Akter et al., 2016). In 1965, Horton developed the index to assess water quality and since then, specialists have modified the methods. The weights assigned to each parameter are defined by the relevant standards, and the assigned weight indicates the parameter's importance and impact on the index. There are three steps in the WQI approach: (1) parameter selection, (2) quality function determination for each parameter, and (3) aggregation utilizing mathematical equations (Tyagi et al., 2013). The WQI generates a single number that reflects overall water quality at a certain location and time based on many water parameters.

Globally, four WQI measurement methods are widely utilized. They include the Weighted Arithmetic Water Quality Index Method (WAWQI), the Oregon Water Quality Index (OWQI), the National Sanitation Foundation Water Quality Index

(NSFWQI), the Canadian and the Council of Ministries of the Environment Water Quality Index (CCMEWQI). Because of its advantage over other methods, the WAWQI method was used in this investigation. Its mathematical equation contains several water quality variables that may be used to assess the health of a water body and determine if surface water is fit for human consumption. The scale of water quality is presented by the water quality index (Table 1). Between 0 and 25, the WQI indicates "Excellent" water quality; 25 to 50, "Good" water quality; 51 to 75, "poor" water quality; 76 to 100, "Very poor" water quality; and >100, the water is "Unsuitable" for drinking (Noori et al., 2019).

Table 1: WQI classification (Noori et al., 2019)

WQI	Water Quality Status	Possible Usage
0 – 25	Excellent	Drinking, domestic and recreational purposes
26 – 50	Good	Drinking, domestic use and recreation
51 – 75	Poor	Agriculture
76 – 100	Very poor	Agriculture
Above 100	Unfit for human consumption	Requires treatment before any usage

2.4 Research Gaps

In both space and time, lake waters are heterogeneous. Water quality characteristics vary spatially and temporally as patterns of human activities and effects change. As a result, regular and consistent water quality monitoring of surface water bodies is required. Magumba (2000), and Tibihika et al. (2016) conducted the only known recorded study on Lake Mulehe to examine its limnological state. Nonetheless, the findings of these investigations were based on data collected on a single day. Furthermore, no detailed investigation of bio-physicochemical variables in relation to anthropogenic activities had been done on Lake Mulehe. As a result, the current research aimed to close this knowledge gap.

3. MATERIALS AND METHODS

3.1 Study Area

The study was conducted at Lake Mulehe located in Kisoro District, South-western Uganda. Lake Mulehe is located at 1°13'5" S latitude and 29°43'17" E longitude. The lake is 4.2 km^2 in size and has a maximum depth of 6 metres. With considerable subsistence farming, the Lake Mulehe watershed experiences bimodal rainfall. In the lake sub-catchment, the temperature ranges from 19°C to 25°C with an average value of 22°C. Agriculture is the major economic activity, and crops such as beans, sorghum, irish potatoes, and vegetables are cultivated. The waters of Lake Mulehe are used for fishing and trip guiding.

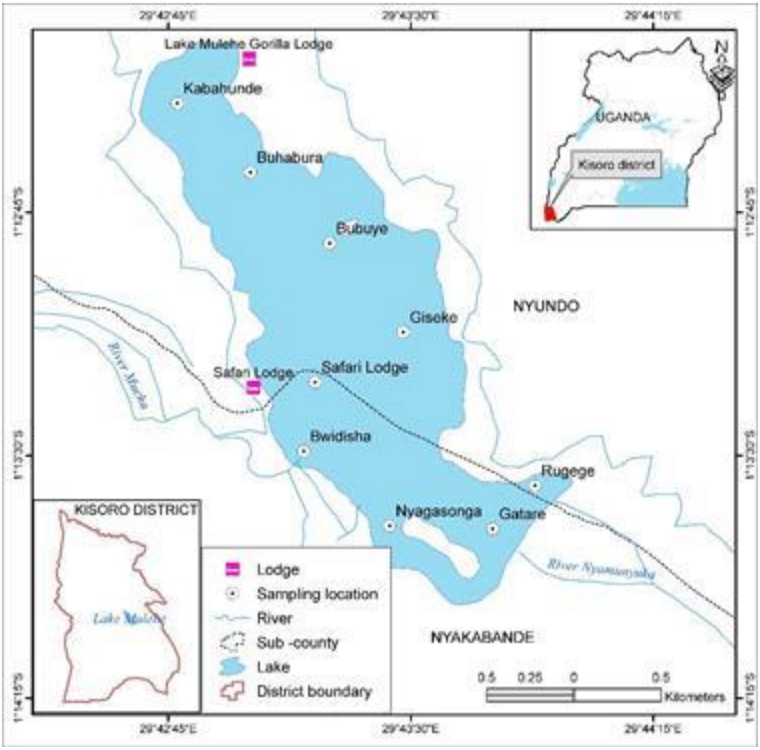

Figure 1: Location Map of Lake Mulehe, South-western Uganda

3.2 Selection of Study Stations

Lake Mulehe was divided into upper and lower study sites. Kabahunde, Buhabura, Bubuye Safari Lodge and Giseke were stations in the upper Mulehe site. Crop farming, human settlements and fishing dominated this study site. Besides, the site hosts the landing site, Safari Resort Mulehe as well as a daily market. The water in the lake looked turbid though people use it for drinking and household purposes. Stations in the lower Mulehe included Rugege, Gatare, Nyagasonga, and Bwidisha. Both upper and middle Mulehe sites drain into this site. The Nyamunyuka and Mucha rivers flow in and out of this study site. Table 2 shows the geographical locations of study stations at Lake Mulehe.

Table 2: Sampling site location for physical parameters and nutrients at Lake Mulehe

Study	Sampling Station		Location	
Site	Code	Station Name	Latitudes	Longitudes
UM site	S1	Kabahunde	1°12'22.0"S	29°42'48.4"E
	S2	Buhabura	1°12'44.7"S	29°43'20.1"E
	S3	Bubuye	1°12'51.9"S	29°43'32.9"E
	S4	Safari Lodge	1°13'23.6"S	29°43'12.0"E
	S5	Giseke	1°13'08.3"S	29°43'27.9"E
LM site	S6	Rugege	1°13'37.7"S	29°43'55.3"E
	S7	Gatare	1°13'49.3"S	29°43'47.4"E
	S8	Nyagasonga	1°13'38.0"S	29°43'26.2"E
	S9	Bwidisha	1°13'29.3"S	29°43'10.1"E

Key: UM: Upper Mulehe; LM: Lower Mulehe

3.3 Sampling Design

Samples were collected during rainy and dry seasons for a period of 6 months (March–May and June – August 2020). The lake was divided into two sites namely; the upper and lower stations. Nine sampling stations were selected purposively based on accessibility, proximity to infrastructural developments, lake inflows, and outflows. From each site, 10 samples were collected twice a month at 0.3m deep below the water surface between 6:00 & 11:00 hours. In total, 54 samples were collected for the determination of nutrient concentration levels in both wet and dry seasons.

3.4 Methods of Data Collection

3.4.1 In-Situ Measurement of Physical Parameters

Electrical conductivity, DO, pH, turbidity, and water temperature were measured on-site during sampling. A DO meter (DO 5510 M.R.C model) was used to measure DO and water temperature, while a water-resistant hand-held pH meter and a conductivity meter were used to measure pH and EC, respectively. A turbidity meter was used to measure the turbidity (2100P, HACH). All measurements were made in triplicate, and the average results were reported.

3.4.2 Determination of Nutrients in Water Samples

The concentration of TN was determined using the Hach Method 10072 standards. The contents of one TN Persulphate Reagent Powder Pillow were added to each of the two vials using a funnel, and any reagent that got on the lip or tube threads was wiped off. Two (2) mL of the sample were placed in one vial, and 2 mL of the kit's deionized water was placed in the other vial. Both vials were sealed and shaken vigorously for at least 30 seconds to ensure thorough mixing. Following that, vials were introduced into the reactor, the lid closed, and the reactor was heated for exactly 30 minutes. Using finger cots that had been cooled to room temperature, the hot vials were withdrawn from the reactor. The caps from the digested vials were removed, and each vial was filled with the contents of one Total Nitrogen (TN) Reagent Powder Pillow. After 15 seconds, the tubes were capped and shaken. At 410 nm, spectrometric measurements were taken. A UV spectrophotometer was used to record the TN concentration in a sample.

To determine total phosphorus, the HACH Method 8190 method was utilized in accordance with APHA (2017) criteria. Polyphosphates were changed to orthophosphates by sulfuric acid digestion during persulfate digestion, and organic phosphorus was transformed into orthophosphates as well. Following the ascorbic acid technique provided by the American Public Health Association (APHA) (2017), the resultant orthophosphate ion (PO4) was examined. At 880 nm, spectrometric measurements were taken. The absorbance of standards was plotted against phosphorus concentrations to create a standard curve. Direct reading from the UV spectrophotometric machine was used to determine the TP concentration.

To assess NH_3-N concentration, 1ml of phenol solution, 1ml sodium nitroprusside solution, and 2.5ml of the oxidizing solution were added to 25ml in a 50-ml Erlenmeyer flask, with vigorous mixing after each addition. The mixture was covered with plastic wrap and set aside for at least 1 hour at room temperature (22 to 27°C) in dim light to develop colour. At 640 nm, the absorbance was measured. The NH_3-N concentration in the samples was determined by measuring the absorbance at 640 nm using the DR 6000 Spectrophotometer.

To determine NO_3-N concentration, the contents of one pillow Nitraver 6 were injected into 25ml of the sample in a mixing cylinder. To dissolve the powder, the mixture was covered with a palm, held tightly, and inverted several times. For NO_2-N determination, the contents of one Nitraver 3 reagent powder pillow were added to 25ml of the sample in a mixing cylinder using the same process as for NO_3-N determination. For SRP, 50ml of filtered water sample was combined with ammonium molybdate to create molybdo-phosphoric acid in a dry 125-ml Erlenmeyer flask. At an 880 nm wavelength, the spectrophotometer measured the colour intensity corresponding to the concentration of phosphate in the sample (APHA, 2017). The concentration of SRP was measured using a UV Spectrophotometer.

3.4.3 Determination of Water Quality Index

The WQI was calculated based on the relevance of nine physico-chemical parameters in water quality analysis. Physical parameters (i.e., pH, temperature, DO, turbidity and EC) and nutrient parameters (i.e., NO_2-N, NO_3-N, NH_3-N and SRP) were selected for quantification of WQI. The mean value of each station under investigation was used as the value for each parameter used. The WHO (2011, 2018) and the Uganda National Bureau of Standards (UNBS, 2014) standards for drinking water were used in this study. The relative weights (RW) were calculated by dividing the weight for each variable by the sum of the weights for all variables (Equations 1 - 4). The Weighted Arithmetic Index Method (Brown et al., 1972) was used for the computation of WQI as modified by Saturday et al. (2021).

$$WQI = \frac{\sum QnWn}{\sum Wn} \tag{1}$$

Where:

Qn = quality rating of nth water quality parameter

Wn = the unit weight of the nth water quality parameter.

Qn was computed using Equation (2).

$$Qn = 100\left[\frac{(Vn-Vi}{Sn-IV}\right] \qquad (2)$$

Where;

Vn = the concentration value of n^th^ variable;

Vi = the ideal value (*Vi* = 0, except for DO (Vi = 14.6 mg/L) and pH (*V*i = 7)

Sn = the standard permissible value for the n^th^ variable.

The Unit weight (Wn) was computed using Equation (3)

$$Wn = \frac{K}{Sn} \qquad (3)$$

Where;

K = the constant of proportionality was computed using Equation 4.

$$K = \frac{1}{\Sigma\frac{1}{Sn}} \qquad (4)$$

3.5 Statistical Analysis

For statistical data analysis, Statistica software (version 10) was used. The mean values of the measured parameters for the study stations were compared to the UNBS (2014) guidelines for natural drinking water sources, the WHO guidelines for drinking water quality, and the USEPA guidelines for recreational waters. To determine whether there were any significant spatial differences among physico-chemical variables, the Kruskal-Wallis test was utilized. Mann-Whitney U test was used to determine whether there were any significant differences between the dry and rainy seasons in terms of measured variables. Spearman's rank correlation analysis was used to establish whether there were significant relationships among physico-chemical water variables.

3.6 Deliverables

The results of the current study contribute to the understanding of nutrient dynamics in Lake Mulehe. The possible sources of nutrients in the lake water were identified. The potential consequences for human health including health, economic, and societal issues were also highlighted. The spatial and temporal variability in the physio-chemical water variables was quantified to facilitate the lake's water quality status. Technical recommendations to relevant authorities on water pollution control were highlighted. Besides, the information gathered contributes to the available literature for future reference in the world of academia.

4. RESULTS

4.1 Spatial Variability of Physical Parameters

DO values ranged from 6.32 ± 1.18 mg/L at Rugege to 6.84 ± 0.92 mg/L at Bubuye, with a mean of 6.55 ±1.08 mg/L. Water temperature varied from 20.90 ± 1.42 to 22.48 ± 0.81^{o}C at Rugege and Gatare stations, respectively with an overall value of 21.72 ± 1.40 ^{o}C (Table 2). The pH readings ranged between 7.34 ± 0.48 at Rugege and 8.15 ± 0.54 at Gatare with an overall mean value of 7.77 ± 0.48 (Table 3). Turbidity levels varied from 2.85 ± 0.68 to 4.39 ± 1.19 NTU at the Buhabura and Rugege stations respectively, with an overall mean value of 3.66 ± 1.29 NTU. Similarly, electric conductivity values ranged from 237.17 ± 13.69 µS/cm to 258.33 ± 51.67 µS/cm at Kabahunde and Safari Lodge stations respectively, with an overall mean of 243.65 ± 19.42 µS/cm (Table 3). Kruskal-Wallis test revealed no statistically significant differences in DO, temperature, turbidity, EC and pH values between stations ($p > 0.05$).

4.2 Spatial Variability of Nutrient Concentration

With an overall mean value of 0.141± 0.168 mg/L, the TP values ranged from 0.096 ± 0.049 mg/L to 0.165 ± 0.159 mg/L at Bubuye and Kabahunde stations respectively. SRP mean values ranged from 0.047 ± 0.016 mg/L to 0.168 ± 0.276 mg/L at the Bubuye and Kabahunde stations respectively, with an overall mean value of 0.084 ± 0.13 mg/L (Table 4). At Kabahunde and Bubuye stations, TN ranged from 0.84 ± 0.71 mg/L to 3.08 2.92 mg/L, with an overall mean value of 2.09 1.76 mg/L (Table 4). The NH3-N values at Safari Lodge and Nyagasonga stations ranged from 0.087 0.07 mg/L to 0.198 0.097 mg/L, with an overall mean value of 0.152 ± 0.076 mg/L. NO_2-N values ranged from 0.004 ± 0.003 to 0.007 ± 0.005 mg/L, with an average of 0.005 ± 0.003 mg/L (Table 4). At

Giseke and Bwidisha stations, NO_3-N values ranged from 0.017 ± 0.008 to 0.035 ± 0.034 mg/L, with an overall mean value of 0.026 ± 0.022 mg/L (Table 4). No significant differences were recorded in SRP, TP NH_3-N, TN, NO_2-N and NO_3-N levels among study stations ($p > 0.05$).

Table 3: Mean ± SD of physical parameters at different study stations (*n* = 54)

Station	Temperature (ºC)	DO (mg/L)	EC (µS/cm)	Turbidity (NTU)	pH
S1	21.78 ± 1.52	6.43 ± 1.27	237.17 ± 13.69	4.17 ± 1.70	7.54 ± 0.50
S2	21.48 ± 1.61	6.57 ± 1.32	241.33 ± 7.55	2.85 ± 0.68	7.85 ± 0.50
S3	21.48 ± 1.51	6.84 ± 0.92	247.17 ± 17.10	3.43 ± 1.25	7.79 ± 0.24
S4	22.03 ± 1.40	6.71 ± 1.77	258.33 ± 51.67	3.94 ± 2.15	7.71 ± 0.24
S5	21.75 ± 1.25	6.50 ± 0.90	241.50 ± 8.09	3.35 ± 1.05	8.10 ± 0.37
S6	20.90 ± 1.42	6.32 ± 1.18	237.67 ± 11.81	4.39 ± 1.19	7.34 ± 0.48
S7	22.48 ± 0.81	6.36 ± 0.87	243.50 ± 8.87	3.38 ± 1.27	8.15 ± 0.54
S8	21.77 ± 1.72	6.74 ± 1.08	244.00 ± 7.67	3.43 ± 1.05	7.73 ± 0.39
S9	21.83 ± 1.62	6.53 ± 0.72	242.17 ± 8.11	4.01 ± 0.80	7.72 ± 0.60
All Grps	21.72 ± 1.40	6.55 ± 1.08	243.65 ± 19.42	3.66 ± 1.29	7.77 ± 0.48

Table 4: Mean ± SD of nutrients at different study stations (*n* = 54)

Station	TP (mg/L)	SRP (mg/L)	TN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)
S1	0.165 ± 0.159	0.168 ± 0.276	0.84 ± 0.71	0.132 ± 0.053	0.005 ± 0.004	0.023 ± 0.014
S2	0.096 ± 0.049	0.163 ± 0.288	2.33 ± 0.89	0.143 ± 0.082	0.005 ± 0.004	0.023 ± 0.020
S3	0.098 ± 0.031	0.047 ± 0.016	3.08 ± 2.92	0.155 ± 0.073	0.004 ± 0.003	0.028 ± 0.023
S4	0.105 ± 0.052	0.055 ± 0.018	2.80 ± 2.50	0.087 ± 0.073	0.005 ± 0.003	0.027 ± 0.031
S5	0.128 ± 0.080	0.061 ± 0.034	1.77 ± 1.55	0.143 ± 0.055	0.005 ± 0.003	0.017 ± 0.008
S6	0.112 ± 0.046	0.065 ± 0.014	1.28 ± 0.69	0.142 ± 0.069	0.007 ± 0.002	0.033 ± 0.023
S7	0.154 ± 0.146	0.074 ± 0.019	1.65 ± 1.06	0.180 ± 0.076	0.007 ± 0.003	0.020 ± 0.009
S8	0.126 ± 0.049	0.063 ± 0.023	2.55 ± 1.94	0.198 ± 0.097	0.007 ± 0.005	0.023 ± 0.028
S9	0.287 ± 0.449	0.059 ± 0.014	2.47 ± 1.94	0.185 ± 0.082	0.004 ± 0.003	0.035 ± 0.034
All Grps	0.141 ± 0.168	0.084 ± 0.131	2.09 ± 1.76	0.152 ± 0.076	0.005± 0.003	0.026 ± 0.022

4.3 Temporal Variability of Physical Parameters

The temperature varied significantly during the sampling period (H (5, N= 54) =36.15, $p < 0.05$) and values ranged from 20.24 ± 0.74 to 23.21 ± 0.54^{o}C in March and July 2020 respectively (Table 6). Similarly, the Mann-Whitney test (Table 7) revealed significant differences in temperature values between seasons ($U = 36.50$, $p < 0.05$). The dry season had a mean temperature value of 22.84 ± 0.80^{o}C, slightly higher than the values obtained in the wet season (20.61 ± 0.88^{o}C) (Table 5).

The DO values ranged from 5.43 ± 0.46 mg/L to 8.37 ± 0.74 mg/L in July and April 2020 respectively (Table 6) and significant differences were revealed over the sampling months (H (5, N= 54) = 43.72, $p < 0.05$). Between seasons, DO values differed significantly (U= 33.50, $p < 0.05$), and values were higher in the rainy season (7.3 ± 0.9 mg/L) than they were in the dry season (5.8 ± 0.5 mg/L) (Table 5). The pH values did not differ significantly during the sampling period (H (5, N= 54) =10.19, $p = 0.07$), and the values varied from 7.51 ± 0.45 to 8.01 ± 0.12. The highest mean value was recorded in April 2020 while the lowest was recorded in March 2020. Besides, there were no statistically significant variations in pH readings between seasons ($p > 0.05$) (Table 7), and the dry season registered a slightly higher pH value (7.82 ± 0.39) than that of the rainy season (7.72 ± 0.55).

The turbidity levels ranged from 2.27 ± 0.52 NTU in June to 4.91 ± 1.34 NTU in April 2020 (Table 6). The Kruskal-Wallis test found significant differences in the mean turbidity levels between sampling months (H (5, N= 54) = 32.93, $p < 0.01$). In terms of seasonal variations, the rainy season (4.55 1.05 NTU) had a higher mean turbidity value than the value obtained in the dry season (2.77 ± 0.81 NTU) (Table 5). The Mann-Whitney test (Table 7) demonstrated that turbidity values differed significantly between seasons ($U = 52.0$, $p < 0.05$).

The EC values ranged from 235.6 9.5 µS/cm in May 2020 to 261.0 39.9 µS/cm in March 2020 (Table 6) and the Kruskal-Wallis test revealed significant differences in values across sampling months (H (5, N = 54) =34.56, $p < 0.01$). Mann-Whitney test (Table 7) revealed significant differences in EC levels between seasons ($U = 881$, $p = 0.001$). The recorded EC values in the wet season (250.7 ± 25.4 µS/cm) were higher than those obtained in the dry season (236.6 4.1µS/cm) (Table 5).

Table 5: Seasonal variability of physical parameters

Variables	Season	
	Wet season	Dry season
Temperature (^{o}C)	20.61 ± 0.88	22.84 ± 0.80
DO (mg/L)	7.32 ± 0.92	5.79 ± 0.54
EC (µS/cm)	250.74 ± 25.44	236.56 ± 4.14
Turbidity (NTU)	4.55 ± 1.05	2.77 ± 0.81
pH	7.72 ± 0.55	7.82 ± 0.39

Table 6: Mean ± SD of physical parameters across sampling months (*n* = 54)

Months	Temperature (^{O}C)	DO (mg/L)	EC (µS/cm)	Turbidity (NTU)	pH
Mar	20.24 ± 0.74	7.01 ± 0.26	261.00 ± 39.92	4.19 ± 0.59	7.51 ± 0.45
Apr	20.83 ± 0.96	8.37 ± 0.74	255.67 ± 3.84	4.91 ± 1.34	8.01 ± 0.12
May	20.76 ± 0.89	6.58 ± 0.42	235.56 ± 9.48	4.56 ± 1.08	7.64 ± 0.79
Jun	22.27 ± 0.93	6.22 ± 0.32	237.33 ± 4.18	2.27 ± 0.52	7.76 ± 0.09
Jul	23.21 ± 0.54	5.43 ± 0.46	234.67 ± 5.00	2.98 ± 0.93	7.82 ± 0.45
Aug	23.03 ± 0.61	5.71 ± 0.54	237.67 ± 2.69	3.05 ± 0.77	7.88 ± 0.52
All Grps	21.72 ± 1.39	6.55 ± 1.08	243.65 ± 19.42	3.66 ± 1.29	7.77 ± 0.48

Table 7: Mann-Whitney (*U)* test results for physical parameters between sampling seasons (*n* = 54, α = 0.05)

	Rank Sum Wet	Rank Sum Dry	U	Z	p-value	Z adjusted	p-value	Valid N Wet	Valid N Dry	2*1sided exact p
Temperature	414.50	1070.50	36.50	-5.67	0.00	-5.67	0.00	27.00	27.00	0.00
DO	1073.50	411.50	33.50	5.72	0.00	5.72	0.00	27.00	27.00	0.00
EC	990.50	494.50	116.50	4.28	0.00	4.29	0.00	27.00	27.00	0.00
Turbidity	1055.00	430.00	52.00	5.40	0.00	5.40	0.00	27.00	27.00	0.00
pH	785.50	699.50	321.50	0.74	0.46	0.74	0.46	27.00	27.00	0.46

4.4 Temporal Variability of Nutrient Concentration

The amounts of nutrients in the samples fluctuated dramatically over the study months. TP mean values in June 2020 varied from 0.05 ± 0.01 mg/L to 0.23 ± 0.2 mg/L in March 2020 (Table 6). The Kruskal-Wallis test revealed statistically significant variations in mean TP levels across sampling months (H (5, N= 54) =36.46, $p > 0.001$). In June 2020, SRP mean values ranged from 0.04 ± 0.01 mg/L to 0.23 ± 0.3 mg/L while in March 2020, SRP mean values ranged from 0.04 ± 0.01 mg/L to 0.23 ± 0.3 mg/L. The wet season had a slightly higher mean SRP value of 0.12 ± 0.18 mg/L than the dry season, while the dry season had a mean value of 0.051 ± 0.02 mg/L (Table 8). According to the Mann-Whitney test (Table 10), the mean SRP values did not differ substantially between seasons ($U = 171.50$, $p > 0.05$).

Significant differences in the mean TN levels were recorded across sampling months (H (5, N= 54) = 30.98, $p < 0.001$). The mean TN values ranged between 0.64 ± 0.40 mg/L to 3.77 ± 2.06 mg/L recorded in July and March 2020 respectively (Table 6). Besides, a significant difference in TN mean values between seasons were recorded ($U = 127.50$, $p < 0.05$) and the dry season recorded a higher mean value of 1.18 ± 0.97 mg/L in comparison with the rainy season (2.99 ± 1.91 mg/L) (Table 8).

The NO_2-N mean values in May and July 2020 ranged from 0.003 ± 0.002 mg/L to 0.009 ± 0.001 mg/L respectively, with significant variations across the study months (H (5, N= 54) =17.39, $p = 0.004$). The dry season (0.01 ± 0.004 mg/L) had higher mean NO_2-N values than those recorded in the rainy season (0.004 ± 0.002 mg/L) (Table 8), with statistically significant variations between the seasons ($p < 0.05$). NH_3-N mean values ranged from 0.07 ± 0.01 mg/L to 0.19 ± 0.09 mg/L in June and March 2020 respectively (Table 6). The rainy season (0.16 ± 0.07 mg/L) recorded a slightly higher NH_3-N mean value (0.16 ± 0.07 mg/L) than taken in the dry season (0.14 ± 0.06 mg/L) (Table 7). The Mann-Whitney (*U*) test (Table 10) revealed no statistically significant seasonal changes in mean NH_3-N values ($U = 305.50$, $p = 0.31$).

NO_3-N values varied from 0.01 mg/L to 0.004 mg/L in June and July 2020 respectively with the highest mean value of 0.05 mg/L to 0.03 mg/L reported in March 2020. Seasonally, the wet season (0.02 ± 0.03 mg/L) exhibited a higher NO_3-N content than that recorded in the dry season (0.014 ± 0.01 mg/L) (Table 8). There were statistically significant differences in mean NO_3-N values (Table 9) between seasons ($U = 128$, $p > 0.05$) (Table 10).

Table 8: Seasonal variability of nutrient levels

Variables	Seasons	
	Wet season	Dry season
NH_3-N	0.16 ± 0.09	0.14 ± 0.06
NO_2-N	0.004 ± 0.002	0.01 ± 0.004
NO_3-N	0.04 ± 0.03	0.01 ± 0.01
TN	2.99 ± 1.91	1.18 ± 0.97
SRP	0.12 ± 0.18	0.05 ± 0.02
TP	0.18 ± 0.22	0.11 ± 0.08

Table 9: Mean ± SD of nutrient concentration across sampling months (n = 54)

Months	TP (mg/L)	SRP (mg/L)	TN (mg/L)	NH_3-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)
Mar	0.27 ± 0.35	0.23 ± 0.30	3.77 ± 2.06	0.19 ± 0.09	0.004 ± 0.002	0.05 ± 0.03
Apr	0.08 ± 0.01	0.07 ± 0.00	2.67 ± 1.57	0.17 ± 0.09	0.004 ± 0.002	0.03 ± 0.02
May	0.17 ± 0.12	0.05 ± 0.01	2.54 ± 2.03	0.12 ± 0.05	0.003 ± 0.002	0.03 ± 0.02
Jun	0.05 ± 0.01	0.04 ± 0.01	2.23 ± 0.91	0.07 ± 0.01	0.006 ± 0.005	0.01 ± 0.00
Jul	0.16 ± 0.12	0.06 ± 0.02	0.64 ± 0.39	0.18 ± 0.04	0.009 ± 0.001	0.01 ± 0.00
Aug	0.11 ± 0.02	0.06 ± 0.03	0.67 ± 0.46	0.18 ± 0.04	0.005 ± 0.003	0.02 ± 0.00
All Grps	0.14 ± 0.17	0.08 ± 0.131	2.09 ± 1.76	0.15 ± 0.08	0.005 ± 0.003	0.03 ± 0.02

Table 10: Mann-Whitney (*U)* test results for physical parameters and nutrients between sampling seasons (*n* = 54, α = 0.05)

	Rank Sum Wet	Rank Sum Dry	U	Z	p-value	Z adjusted	p-value	Valid N Wet	Valid N Dry	2*1sided exact p
NH_3-N	801.50	683.50	305.50	1.01	0.31	1.02	0.31	27.00	27.00	0.31
NO_2-N	577.00	908.00	199.00	-2.85	0.00	-2.87	0.00	27.00	27.00	0.00
NO_3-N	979.00	506.00	128.00	4.08	0.00	4.28	0.00	27.00	27.00	0.00
TN	979.50	505.50	127.50	4.09	0.00	4.10	0.00	27.00	27.00	0.00
SRP	935.50	549.50	171.50	3.33	0.00	3.33	0.00	27.00	27.00	0.00
TP	868.50	616.50	238.50	2.17	0.03	2.17	0.03	27.00	27.00	0.03

4.5 The Relationship between Physical Parameters and Nutrient Levels

To establish whether there were significant relationships between physical parameters and nutrient levels observed in Lake Mulehe, Spearman's correlation was used (Table 11). The water temperature had a negative significant correlation with NO_3-N ($r = -0.520$, $p < 0.05$), TN ($r = -0.612$, $p < 0.05$) and SRP ($r = -0.342$, $p < 0.01$) (Table 11). The DO level was significantly positively correlated with NO_3-N ($r = 0.388$, $p < 0.05$), TN ($r = 0.623$, $p < 0.05$), and SRP ($r = 0.381$, $p < 0.05$) but significantly negatively correlated with NO_2-N ($r = -0.395$, $p < 0.05$). The EC was significantly positively correlated with NO_3-N ($r = 0.390$, $p < 0.05$), TN ($r = 0.456$, $p < 0.05$) and SRP ($r = 0.520$, $p < 0.05$) while turbidity was significantly positively correlated with NO_3-N (r = 0.427, $p < 0.05$), SRP ($r = 0.502$, $p < 0.05$) and TP ($r = 0.347$, $p < 0.05$). The NH_3-N was significantly positively correlated with NO_2-N (*r* = 0.269, *p* < 0.05), SRP (*r* = 0.364, *p* < 0.05), and TP (*r* = 0.391, *p* < 0.05) but significantly negatively correlated with NO_2-N (*r* = -0.395, *p* < 0.05).

The analysis among physical parameters revealed that water temperature had a negative significant correlation with DO (*r* = -0.619, *p* < 0.05), turbidity (*r* = -0.515, *p* < 0.05), EC (*r* = -0.462, *p* < 0.05) while DO was significantly positively correlated with turbidity (*r* = 0.515, *p* < 0.05) and EC (*r* = 0.726, *p* < 0.05). Besides, the EC values were significantly positively correlated with turbidity (*r* = 0.323, *p* < 0.05) and pH (*r* = 0.369, *p* < 0.05). Among physical parameters, water temperature recorded a significant negative correlation with DO (*r* = -0.619, p 0.05), turbidity (*r* = -0.515, *p* < 0.05), and EC (r = -0.462, *p* <0.05), while the DO had a significant positive correlation with turbidity (*r* = 0.515, p < 0.05) and EC (*r* = 0.726, *p* <0.05).

Furthermore, turbidity ($r = 0.323$, $p < 0.05$) and pH ($r = 0.369$, p 0.05) were both significantly positively linked with EC values.

Table 11: Spearman correlation matrix for Physical parameters and nutrients in Lake Mulehe ($n = 54$)

	Temp	DO	EC	Turbid	pH	NH_3-N	NO_2-N	NO_3-N	TN	SRP	TP
Temp	1.000	-0.619	-0.462	-0.515	0.188	-0.064	0.266	-0.520	-0.612	-0.342	-0.237
DO		1.000	0.726	0.515	0.238	0.010	-0.395	0.388	0.623	0.381	-0.045
EC			1.000	0.323	0.369	0.211	-0.252	0.390	0.456	0.520	-0.030
Turbid				1.000	-0.006	0.256	-0.236	0.427	0.222	0.502	0.347
pH					1.000	0.047	0.067	-0.068	-0.062	0.079	-0.231
NH_3-N						1.000	0.269	0.189	-0.107	0.364	0.391
NO_2-N							1.000	-0.097	-0.180	0.100	-0.004
NO_3-N								1.000	0.398	0.392	0.304
TN									1.000	0.085	-0.087
SRP										1.000	0.401
TP											1.000

4.6 Water Quality Index

The WQI was computed using the values of nine physicochemical variables (Table 12) that were chosen because of their significance in water quality analysis. The mean value of the stations under investigation was utilized for each variable. The WQI values were calculated using WHO threshold limit values (WHO, 2011, 2018), except for SRP and NH_3-N values derived from the Uganda National Bureau of Standards (UNBS, 2014) (Table 12). The WQI values in the lake ranged from 36.0 to 74.7 at the Safari Lodge and Nyagasonga stations respectively with an overall mean value of 58.7 (Table 13). Except for the Safari Lodge station, which reflected that water from Lake Mulehe is good for drinking, recreation, and domestic purposes due to physicochemical factors, the recorded WQI range values lie between the "Poor” and "Good" class (Table 13).

Table 12: Relative weight of parameters WQI determination

Variables	WHO/UNBS standards	Relative weight (Wn)
DO (mg/l)	6	0.023
EC (µS/cm)	250	0.001
Turbidity (NTU)	5	0.028
pH	8.5	0.016
NO_2-N (mg/L)	0.9	0.155
NO_3-N (mg/L)	11	0.013
NH_3-N (mg/L)	0.2	0.696
SRP (mg/L)	2.2	0.063

Table 13: Change in the WQI values across the study stations

S/N	Station		WQI	Status
	Name	Code		
1)		S1	52.0	Poor
2)		S2	55.6	Poor
3)		S3	59.5	Poor
4)		S4	36.0	Good
5)		S5	55.9	Poor
6)		S6	55.2	Poor
7)		S7	68.9	Poor
8)		S8	74.7	Poor
9)		S9	70.3	Poor
Mean value			**58.7**	**Poor**

The water quality index is a measurement of water quality on a scale. As shown in Table 1, a WQI of 0 to 25 indicates "Excellent" water quality, 25 to 50 indicates "Good" water quality, 51 to 75 indicates "Poor" water quality, 76 to 100 indicates "Very poor" water quality, and >100 indicates that the water is "Unsuitable" for drinking (Noori et al., 2019).

5 DISCUSSION

5.1 Variability in Physical Water Quality Parameters

DO values recorded in the present investigation were greater than 2 mg/L. According to Keister et al. (2020), these values do not cause stress to aquatic animals and ecosystems, and can only produce minor changes in communities through direct organism mortality and a reduction in sensitive species population increase. Tiémoko et al. (2020) reported a DO content range of 4.6 to 7.7 mg/L for Lake Taabo and Kossou, which is consistent with the current study. DO is a wide indicator of water quality in the aquatic ecosystem, and it is affected by a variety of parameters including microbial activity, temperature, organic matter content, pressure, and sampling time (Das Kangabam & Govindaraju, 2019; Mutlu, 2019). Furthermore, DO concentration has been linked to the distribution and abundance of particular algae species (Saturday et al., 2022), and its presence is required for the survival of complex sorts of biological life in water (Lung'ayia et al., 2022).

In other related studies, Tibihika et al. (2016) and Saturday et al. (2021) reported the overall mean water temperatures of Lake Bunyonyi of 22°C and 21.3 ± 1.4°C, respectively, which are closely related to the present study findings. Low temperatures recorded in the lake's ecosystem were attributed to the water mass that enters Lake Mulehe through River Nyamunyuka which drains from the hills of Kanaba Sub-County in Kisoro District. Besides, the lake is situated between steep hills which limits the amount of sunlight heating the surface waters of the lake.

Water temperature was found to be within the WHO recommended limit of 25°C (WHO, 2008). Tibihika et al. (2016) and Saturday et al. (2021) reported overall mean water temperatures of 22°C and 21.3 ± 1.4^{o}C, respectively for Lake Bunyonyi, similar to the current study findings. The water mass that reaches Lake Mulehe through River Nyamunyuka, which descends from the slopes of Kanaba Sub-County in Kisoro District, is responsible for the low temperatures recorded in the lake habitat.

The EC values recorded in the present study did not exceed the WHO maximum permissible limits of 2500 μS/cm stated in global national drinking water guidelines. Therefore, the study findings correctly show that the water in Lake Mulehe is not highly ionized and has a low ionic concentration. Since EC is a function of total dissolved solids (ions concentration), high EC values at the Safari Lodge station can be attributed to high levels of total dissolved solids, whereas low EC values at the Kabahunde station imply untainted lake environment. The rising EC levels of the lake could be a result of surface runoff from agricultural activities and garbage from disposal sites near the stream. Additionally, previous studies have linked surface runoff, effluents, minerals, and salts from municipal runoff after heavy rainfall to greater levels of electrical conductivity in receiving freshwater bodies (Lung'ayia et al., 2022; Saturday et al., 2021).

Turbidity values did not surpass the maximum limit (20 NTU) for worldwide national drinking water guidelines (WHO, 2018). Nonetheless, turbidity mean values reported during the rainy season (March-May 2020) were much higher, possibly due to increased phytoplankton biomass and high surface runoff into the lake system. Saturday et al. (2021) observed turbidity mean values ranging between 2.8 ± 0.6 and 4.3 ± 1.6 NTU, which are slightly lower than the values obtained in the current study. Contrary to the present study results, Umer et al. (2020) reported a turbidity range of 28.5 to 63.0 NTU in Lake Beseka which was significantly higher than the values recorded in the present study. High turbidity in freshwater lakes prevents light from reaching the water column, delaying phytoplankton and macrophyte development and decreasing primary productivity and oxygen release (Lung'ayia et al., 2022; Saturday et al., 2022; Umer et al., 2020).

The recorded pH range (7.34 0.48 – 8.15 0.54) suggested a neutral to an alkaline state of the lake ecosystem, which was within the acceptable range (6.5 – 8.5) for aquatic species to thrive (WHO, 2018). The huge intake of fresh water from River Nyamunyuka and other minor streams that pour into the lake is possibly a response to the observed pH variations. Ongom et al. (2017), Song et al. (2020) and Muduli and Pattnaik (2020) all obtained pH ranges suggesting neutral to slightly alkaline lake conditions, which are consistent with our findings.

In contrast to the pH range stated, Niyoyitungiye et al. (2019) found that the optimal pH range below pH 6.5 affects the slow growth of some aquatic species, whilst pH values over pH 6.5 affect the ability of some organisms to maintain their salt balance, which can cause a delay in reproduction.

5.2 Variability of Nutrient Concentrations

Total phosphorus (TP) is a phosphorus measurement that includes both inorganic and organic forms. Because of its extended residence duration in lakes, TP is regarded as the most important nutrient (Radbourne et al., 2019). Opiyo et al. (2019) showed higher TP readings (3.09 0.09 mg/L) in the wet season than in the dry season, which is similar to the findings of the current study. The measured TP levels are the result of lake contamination caused by intensive agriculture in the lake sub-catchment area. Phosphorus-producing human activities have a considerable impact on freshwater ecosystems (Havens &

Nürnberg, 2004). Lake Mulehe's location, surrounded by high topography, favours nutrient enrichment due to the high velocity of run-off draining into the lake and its subsequent lengthy stay in the lake.

The spatial differences in TP levels are explained by the proximity of some stations to the lakeshore and the intensity of the nearby agricultural activities. Seasonal rainfall variability in the lake area also explained temporal variations in TP levels. This, in turn, determines the intensity of nutrient deposition, with the wet season experiencing high nutrient enrichment from high surface runoff that sweeps the various nutrients from densely farmed agricultural fields, as contrasted to the dry season, which experiences little to no rain. Saturday et al. (2021) reported an average mean value of 0.141 ± 0.168 mg/L in Lake Bunyonyi, which is consistent with the current findings. Contrary to the present study findings, Opiyo et al. (2019) found an average mean TP value of 2.9 0.08 mg/L in Lake Simbi, higher than the observed TP values in the current study, owing to multiple years of nutrient inputs from the lake sub-catchment, which is heavily irrigated.

Total nitrogen (TN) is a measure for both organic and inorganic nitrogen levels (Saturday et al., 2021). The role of nitrogen in freshwater systems is determined by the relative amount of various nitrogen forms present. Like TP, high surface run-off into Lake Mulehe is partially responsible for the observed TN levels in the lake system. Besides, the intensity of agricultural practices around the lake under study could also explain the observed spatial differences. The upper Mulehe sites recorded relative higher TN concentration levels due to runoff from agricultural activities and tourism recreation facilities that enter the lake via Bubuye and Safari Lodge stations, respectively. This backs the popular belief that agriculture in the lake watershed is a major source of nitrogen in freshwater lakes (Huang et al., 2017). Like TP, high surface runoff into Lake Mulehe is partially responsible for the observed TN levels in the lake system. Besides, the intensity of agricultural practices around the study lake could explain the observed spatial differences in TN concentration.

In contrast with the dry season which receives little or no rain, high TN values in the wet season were linked to high rainfall intensity which affects nutrient deposition through surface runoff that sweeps nutrients from crop farms and faecal matter from rural populations around the lake. Saturday et al. (2021) and Ozguven and Demir Yetis (2020) reported TN concentration content values of 1.9 ± 1.9 mg/L in Lake Bunyonyi and 4.9 ± 16.0 mg/L in Big Soda Lake Van, respectively, in similar tour study findings. Contrary to the current study findings, Zhou et al. (2020) reported an overall mean TN value of 0.88 ± 0.05

mg/L for Lake Qiandaohu, higher than the current study findings.

Ammonia–nitrogen (NH_3-N) levels were higher than the recommended limit of 0.025 mg/L for freshwater settings, over which it is harmful to freshwater life (EPA, 2001). This could be due to the fish's metabolic activity and other factors impacting orthophosphate availability, as well as cyanobacteria nitrogen fixation. Similarly, Tilahun and Ahlgren (2010) found 0.09 ± 0.08 mg/L in Ethiopia's Lake Chamo. The elevated NH_3-N content at the Nyagasonga station may be due to the demineralization of submerged macrophytes.

The range of NO_2-N values was within the WHO drinking water cutoff value of 0.9 mg/L. (WHO, 2011). As a result, Lake Mulehe's water is less prone to create health issues. The NO_2-N concentrations in Lake Bunyonyi (32.9 ± 0.7 g/L) and Lake

Tonga (0.82 ± 0.25 mg/L), respectively, were lower than those reported by Tibihika et al. (2016) and Loucif et al. (2020). Nonetheless, the NO2-N values recorded were higher than 1.3 ± 0.7 µg/L recorded by Keyombe and Waithaka (2019). Because of chemical reactions with organic compounds, the presence of nitrites in freshwater lakes can lead to the creation of nitrosamines, which can induce carcinogenic effects (WHO, 2017).

The observed NO_3-N values did not exceed 11 mg/L, which is within the WHO's recommended drinking water limits (WHO, 2011). NO_3-N is a nutrient found in freshwater bodies at very low amounts but is an incredibly important source of nitrogen for protein synthesis. Inorganic nitrogen is the most common form of nitrogen in natural waters, according to Lodh et al. (2014), and it is the most necessary nutrient for hydrophytes and aquatic algae to grow swiftly. The highest NO_3-N concentration measurement (0.01 ± 0.004 mg/L) was found at the Bwidisha station, which could be attributed to farmlands nearby. Tibihika et al. (2016), Maryam et al. (2020) and Tibebe et al. (2019) obtained average NO_3-N levels of 33.8 ± 2.1 g/L, 0.46 mg/L and 0.21 mg/L respectively, slightly higher the values obtained in the current study. Although NO_3–N is an important nutrient for the growth of aquatic plants in aquatic habitats, a concentration > 90 mg/L is harmful to aquatic species (Amić & Tadić, 2018). Rain, fog, snow, decomposition of organic matter, and fertilizer application in agricultural fields are the key processes that naturally enhance NO_3-N content in lake ecosystems.

5.3 Water Quality Index of Lake Mulehe

The WQI of Lake Mulehe fell into the 'poor' category of WQI classification attributed to anthropogenic activities, rather than lithological sources. Some studies had earlier reported similar results. For instance, James et al. (2019) reported a WQI range of 51.9 to 101.1 indicative of poor water quality in the Nyando river of Kenya. Jindal and Wats (2022) reported the WQI value range of 59.7 to 83.5 at Sukhna Lake. On the contrary, Shah and Joshi (2017) reported that the water quality at Station 1 of the River Sabarmati in India was good, with a WQI ranging from 19.84 to 44.58 between 2005 and 2008. Nihalani and Meeruty (2020) found a WQI range of 30 to 50 for River Mahi and 28 to 52 for River Narmada, both of which are significantly different to the WQI range reported in the current study. Although Lake Mulehe's WQI values indicate poor quality, values in the lower lake site indicated deteriorating water quality. Pollutant influx from the upper and middle Mulehe sites to the lower site may have resulted in slightly higher WQI values. Excessive use of fertilizers and chemicals, including pesticides could have caused increased pollution at the Gatare and Nyagasonga as a result of expanded agricultural practices (such as Irish potato production).

5.4 Correlation among Physico-chemical Variables

The temperature was positively connected with NO_2-N but inversely correlated with SRP, TN, NO_3-N, and SRP, according to the correlation analysis. In Loktak Lake, India, Kangabam et al. (2017) found a significant negative relationship between temperature and NO_3-N concentration values. Saturday et al. (2021) found a substantial positive association between TN, NO_3-N, and NO_2-N levels in Lake Mulehe, Uganda.

The positive correlation between DO and turbidity had earlier been reported by Bhattrai et al.(2017) in Lake Hwajinpo, South Korea. The significant correlation between water temperature and DO levels differed slightly from those of Ali and Khairy (2016), who found an increase in DO levels when water temperatures were lower due to gas solubility, which increases when temperatures and metabolic activity of organisms are low and decreased, respectively. Temperature, DO, turbidity, NH_3-N, TP, and SRP were all favourably associated with the observed positive correlation values. Yu et al. (2020) observed a positive correlation of TN with TP and NH_3-N, but a substantial negative correlation with NO_2-N which is similar to the present study findings.

6. SUMMARY OF RESULTS, CONCLUSION AND RECOMMENDATION

6.1 Summary of the Findings

This study investigated the content and dynamics of nutrients in the surface water of Lake Mulehe in Kisoro District, South-western Uganda. In 2017, the lake transformed from clear to greenish and turbidity intensified resulting in ecosystem and water quality degradation. The lake water is indeed polluted, according to the findings. Despite its socioeconomic and ecological importance, little was known about the lake's water quality before this investigation. Results indicate that water temperature, DO, pH, turbidity, and EC did not differ significantly between study stations ($p > 0.05$) although there were significant temporal differences ($p = 0.05$) over the study months. Nutrients (TN, NO_3-N, TP, NO_2-N and SRP) did not differ substantially between study stations ($p > 0.05$) but did reveal significant differences (*p* = 0.05) between study months. With an overall mean value of 58.69, the WQI values varied from 36 to 74.7.

6.2 Conclusion and Recommendations

Both statistical analyses and WQI were used to assess the content and dynamics of nutrients in Lake Mulehe. All nutrient variables did not differ substantially between study stations but did reveal significant differences across study months. This is attributed to seasonal rainfall variability which in turn determines the intensity of nutrient deposition. The wet season experienced high nutrient enrichment from surface runoff that swept nutrients from densely farmed fields in contrast to the dry season, which experienced little rain. The WQI values varied from 36.0 (good quality) to 74.5 (poor quality), with a mean value of 58.69 (poor quality) implying the ‘poor' water category in terms of worthiness for human consumption. Nevertheless, water from Lake Mulehe can be used for recreational and agricultural activities. These findings provide a point of reference for policymakers when it comes to establishing standards for effective lake management. Since the current study focused on physicochemical water quality parameters, there is a need to assess the lake water's suitability for human consumption using faecal indicator bacteria. Besides, continuous pollution monitoring and enforcement of local regulations to reduce pollution are recommendable

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