



# Spatio-temporal variations in physicochemical water quality parameters of Lake Bunyonyi, Southwestern Uganda

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Received: 18 February 2021 / Accepted: 21 May 2021

Published online: 03 June 2021

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## Abstract

The current study was carried out to examine the spatial and temporal variations of physicochemical water quality parameters of Lake Bunyonyi. The observations were made on the surface water of Lake Bunyonyi for 1 year to determine the water quality. The basic 12 variables used to determine the quality of water were measured monthly at nine stations. Water temperature, dissolved oxygen (DO), turbidity, electric conductivity (EC), pH and Secchi depth (SD) were measured in the field, while parameters like total nitrogen (TN), total phosphorus (TP), nitrite-nitrogen ( $\text{NO}_2\text{-N}$ ), nitrate-nitrogen ( $\text{NO}_3\text{-N}$ ), soluble reactive phosphorus (SRP) were determined following APHA 2017 standard guidelines for physicochemical analysis. Taking into account standard guidelines for drinking water by the Uganda National Bureau of Standards (UNBS) and the World Health Organization (WHO), the water quality index (WQI) was used to determine the water quality. Temperature, DO, pH, turbidity and EC did not differ significantly among the study stations ( $p > 0.05$ ) but showed significant temporal variations among the study months ( $p < 0.05$ ). Likewise, TN, TP,  $\text{NO}_2\text{-N}$ ,  $\text{NO}_3\text{-N}$  and SRP did not differ significantly among the study stations ( $p > 0.05$ ) but showed significant temporal variations among the study months ( $p < 0.05$ ). The WQI values ranged from 28.36 to 49 across and from 28.2 to 56.2 between study months with an overall mean value of 36.9. The measured water quality variables did not exceed the UNBS and WHO standards for drinking water in all months and at all stations. According to these values, the water quality of Lake Bunyonyi generally belongs to the 'good' class in terms of drinking water quality based on the WQI classification. The study findings are fundamentally important for policy makers in setting guidelines for effective lake management.

**Keywords** Spatio-temporal variability · Water quality · Water quality index · Lake Bunyonyi

## Abbreviations

WHO	World Health Organization
APHA	American Public Health Association
Turb	Turbidity
NTU	Nephelometric turbidity unit
WQI	Water quality Index
USEPA	The United States Environment Protection Agency
SD	Secchi depth transparency

DO	Dissolved oxygen
NWSC	National Water and Sewage Cooperation

## 1 Background

Although water is a vital element in human life, it is most threatened worldwide [21, 48]. Globally, anthropogenic activities, namely rapid urbanization, industrialization, extensive use of agrochemicals such as chemical fertilizers,

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herbicides and pesticides and the unrelenting population growth, have resulted in the deterioration of water quality of freshwater bodies [37, 41]. High levels of pollutants such as persistent organic chemicals in the lake ecosystems may make the water unfit for recreation, swimming/ bathing, drinking and fishing, while excess nutrients (nitrogen and phosphorus) massive algal blooms that result in eutrophication and its associated effects on aquatic life [29, 41, 48, 55, 56]. Thus, aquatic environments require appropriate maintenance through interventions that require systematic knowledge of the ecosystem functions controlling the lake as a source of water and a habitat for both aquatic and benthic organisms. Since many factors are responsible for the deterioration of water quality in a given water body, the need for periodic monitoring of the lakes' water chemistry is absolute [18].

The physicochemical water quality characteristics of any lake are influenced principally by natural and anthropogenic factors. The natural factors include relief, rainfall, weathering, geology and inputs from the catchment and atmosphere, mixing of riverine freshwater from rivers and saline water and climate variability. The disturbance from the catchment area due to pollution emanating from domestic sewage, agricultural activities and industrial settings are the anthropogenic factors. Agricultural run-off is an important source of freshwater pollution and has profound effects on aquatic ecosystems, and human health through the drinking water supply [15].

In Uganda and elsewhere in the world, it is historical that people have lived close to freshwater bodies because of health and well-being benefits. According to McDougall et al. [24], over 50% of the global population live within 3 km of freshwater body. Nevertheless, population increase, intensive farming practices and infrastructure developments have contributed to excessive water withdrawal while increasing the level of external nutrient loading in the remaining natural freshwater systems. As a result, major changes in the physical and chemical characteristics of freshwater bodies have occurred, often showing a significant shift from clear water to the turbid state.

In Kigezi, Lake Bunyonyi is the main source of drinking water, the harbour for faunal and floral biodiversity, and livelihood support [42]. Nevertheless, the Lake's physicochemical characteristics are influenced by anthropogenic activities such as infrastructural developments on the lake's 29 islands, campsites and business centres, agricultural activities and fish caging. All the above-mentioned anthropogenic activities are likely to cause spatio-temporal changes in the physicochemical characteristics which may cause eutrophication and subsequently water quality deterioration.

Although some studies have been undertaken to assess the status of Lake Bunyonyi [11, 42, 54] none have

illustrated the spatio-temporal variability in physicochemical water quality characteristics of the Lake. Therefore, the need to conduct a comprehensive study to improve understanding of spatio-temporal variations of physicochemical water quality characteristics of Lake Bunyonyi was necessary. The results will contribute to a better understanding of the lake's ecosystem responses and ultimately support its sustainable management.

## 2 Materials and methods

### 2.1 Study area

The study was conducted on Lake Bunyonyi which is shared by the districts of Kabale and Rubanda in South-western Uganda (Fig. 1). Geographically, Lake Bunyonyi is located between 1.2953° S and 29.9133° E and an average altitude of 1973 m above sea level. The lake is long and narrow with a total surface area of 56 km<sup>2</sup> with an average depth of 40 m [19]. The climate of the study area is warm and temperate influenced by altitude and latitude. It is characterized by a bimodal rainfall distribution with the long rainy season occurring between March and May. The short rains occur between October and November while June to August is driest. The mean annual rainfall ranges from 800 to 1000 mm. The temperature in the lake catchment ranges from 23.7 °C in March to 24.8 °C in August [42]. Lake Bunyonyi catchment is a high potential and densely populated area with extensive subsistence farming where crops such as sweet potatoes, beans, sorghum, Irish potatoes and vegetables are grown. On a small scale, fishing and aquaculture are carried out in the lake water [19]. Thus, the livelihood activities of the people in the lake catchment largely depend on the health of the lake ecosystem.

### 2.2 Sample collection, preparation and storage

Sampling was done monthly for 1 year (October 2019 to September 2020) from nine stations (Table 1) giving a total of 108 samples. Water samples were collected (between 6: 00 and 12 noon) by dipping 1 L polyethene plastic bottles below the surface of the water (0.3 m). The sampling stations were selected in the three study sites that varied in extent and type of human activities in the lake and the lake peripheral. Nyombe (U1), Ndarura (U2) and Kariko (U3) stations were located in the upper Bunyonyi site; Harutinda (M1), Akampene (M2) and Mugyera (M3) stations were located the middle Bunyonyi site, whereas Heisesero (L1), Rugarambiro (L2) and Hamukaka (L3) stations were located in the lower Bunyonyi site. Before the actual collection of samples, the sampling bottles were labelled

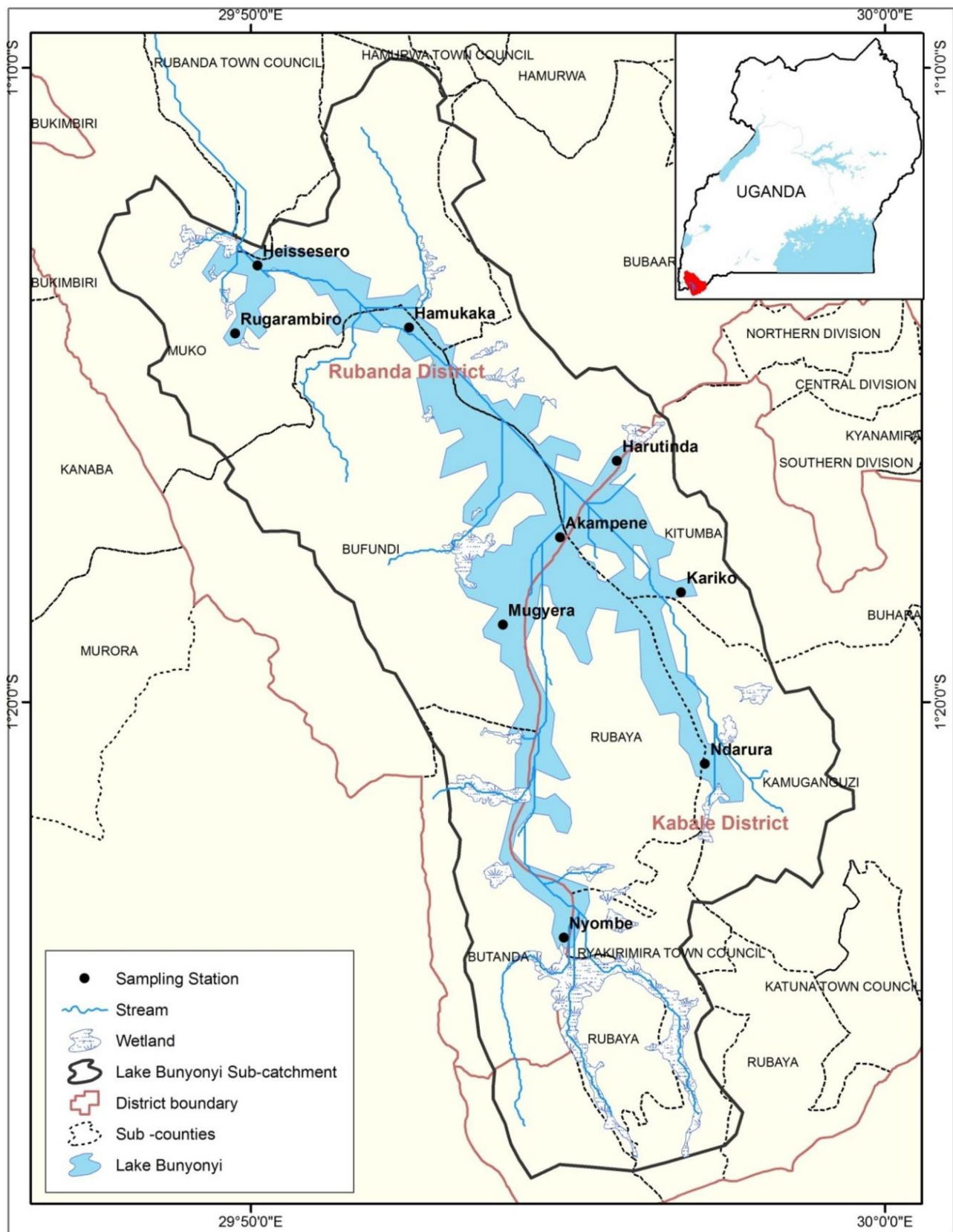


Fig. 1 Location Map of Lake Bunyonyi, Southwestern Uganda

**Table 1** Sampling site location for physicochemical parameters

Study Site	Station Code	Station Name	Location	
			Latitudes	Longitudes
Upper Bunyonyi	U1	Nyombe	1°23'50.16" S	29°55'08.80" E
	U2	Ndarura	1°20'58.55" S	29°57'25.47" E
	U3	Kariko	1°18'16.30" S	29°56'46.96" E
Middle Bunyonyi	M1	Harutinda	1°16'14.98" S	29°56'16.48" E
	M2	Akampene	1°17'37.60" S	29°55'02.47" E
	M3	Mugyera	1°19'05.62" S	29°54'09.76" E
Lower Bunyonyi	L1	Heissesero	1°13'00.32" S	29°49'53.56" E
	L2	Rugarambiro	1°14'20.11" S	29°50'04.32" E
	L3	Hamukaka	1°14'05.76" S	29°52'29.77" E

according to their station codes and rinsed with the Lake water four times to remove any possible form of contamination. All the samples were stored in the icebox with ice and then transported to the National Water and Sewerage Corporation (NWSC) Central Laboratories in Kampala for analysis within 24 h. While in the laboratory, samples were stored in the refrigerator at 4 °C before analysis.

### 2.3 Analytical methods

The physicochemical water quality parameters such as water temperature, DO, turbidity and electrical conductivity (EC), Secchi depth (SD) and pH were measured on-site. DO was measured using the DO meter (DO 5510 M.R.C model) while water temperature was measured using a temperature sensor in the DO meter. The pH and EC were measured using a water-resistant hand-held pH meter (HI8314 HANNA instruments) and using a conductivity meter (HI 9033 HANNA instruments), respectively, and the turbidity measured was using a turbidity meter (2100P, HACH). Likewise, SD was measured using Secchi disc (20 cm diameter and painted black and white alternately in a radial fashion). All measurements were taken in triplicate and the average values are reported herein.

In the laboratory, nutrient parameters such as TN and TP were determined following the standard producers described in the HACH Method 10,072 and HACH Method 8190, respectively. To determine  $\text{NH}_3\text{-N}$  concentration in the water samples, 1 ml of phenol solution, 1 ml sodium nitroprusside solution and 2.5 ml of the oxidizing solution were added to 25 ml of filtered water sample in a 50-ml Erlenmeyer flask, with thorough mixing after each addition. The mixture was covered with a plastic wrap and kept at room temperature (22 to 27 °C) in subdued light for at least 1 h for colour development. The absorbance was measured at 640 nm and  $\text{NH}_3\text{-N}$  concentrations contained in the samples were recorded directly from the DR 6000 Spectrophotometer.

To measure  $\text{NO}_2\text{-N}$  concentration in water samples, the contents of one pillow Nitraver 3 were added to 25 ml of water sample in a graduated mixing cylinder. The mixture was then covered with palm, held firmly and inverted several times to dissolve the powder. In not more than 20 min after the addition of Nitraver 3 reagent powder pillow, pink colour was observed in samples with nitrites. Between 10 min and 2 h afterwards, absorbance was measured at 543 nm at UV spectrophotometer (DR6000, HACH Laboratory Instruments). The  $\text{NO}_2\text{-N}$  concentration was directly recorded from the reading from the spectrophotometer [6]. For  $\text{NO}_3\text{-N}$  determination, the content of one pillow Nitraver 6 was added to 25 ml of water sample in a graduated mixing cylinder. The mixture was covered with palm, held firmly and inverted several times to dissolve the powder. Thereafter, the contents of one Nitraver 3 reagent powder pillow were added and a similar procedure for analysis of  $\text{NO}_2\text{-N}$  was followed. For SRP determination in the water sample, 50 mL of filtered water sample was mixed with ammonium molybdate to form molybdo-phosphoric acid in a dry 125-mL Erlenmeyer flask. The acid was reduced by ascorbic acid to a blue complex (molybdenum blue). Thereafter, the colour intensity proportional to the concentration of phosphate in the sample was measured by the spectrophotometer at a wavelength of 880 nm [6]. The SRP concentration was recorded directly from DR 6000 Spectrophotometer.

### 2.4 Water quality index estimation

The WQI was computed using the nine physicochemical parameters based on their importance in water quality analysis. These parameters are temperature, turbidity, pH, DO, EC,  $\text{NO}_2\text{-N}$ ,  $\text{NO}_3\text{-N}$ , SRP and  $\text{NH}_3\text{-N}$ . The values used for each parameter were the mean value of each station under investigation. The standards for drinking water used in this study are recommended by WHO [51, 53] and the Uganda National Bureau of Standards [47]. The selected parameters were assigned weight (AW) which varied from 1 to 4.4



based on the collective expert opinions taken from previous studies (Table 25). The average values of the AW values of the selected variables along with the reference are listed (Table 2). Thereafter, the relative weights (RW) were calculated by dividing the weight for each variable by the sum of the weights for all variables (Eqs. 1–4). The weighted arithmetic index method [9] was used for the computation of WQI.

$$WQI = \frac{\sum Q_n W_n}{\sum W_n} \quad (1)$$

where  $Q_n$  = quality rating of  $n$ th water quality parameter.  
 $W_n$  = the unit weight of the  $n$ th water quality parameter.

$Q_n$  was computed using Eq. (2).

$$Q_n = 100 \left[ \frac{(V_n - V_i)}{S_n - IV} \right] \quad (2)$$

where  $V_n$  = the concentration value of  $n$ th variable;

$V_i$  = the ideal value ( $V_i = 0$ , except for DO ( $V_i = 14.6$  mg/L) and pH ( $V_i = 7$ ).  $S_n$  = the standard permissible value for the  $n$ th variable.

The unit weight ( $W_n$ ) was computed using Eq. (3)

$$W_n = \frac{K}{S_n} \quad (3)$$

where  $K$  = the constant of proportionality computed using Equation 4.

$$K = \frac{1}{\sum \frac{1}{S_n}} \quad (4)$$

## 2.5 Statistical analysis of data

Statistica software (version 10) was used for statistical analysis of data. The mean values of the measured parameters

for the study stations were compared to UNBS [47] guidelines for natural drinking water sources, the WHO standards for drinking water quality and the USEPA guidelines for recreational waters. One-way ANOVA was used to establish whether there were significant spatial and temporal differences in physicochemical quality characteristics. For data not normally distributed, the Kruskal–Wallis test was conducted to establish whether there existed significant differences in the physicochemical quality parameters measured. Paired samples  $t$ -test was used to establish whether there were significant seasonal variations among the measured parameters. For non-normally distributed data, the Mann–Whitney U test was used to determine whether there were significant differences in measured parameters between the dry season and wet seasons. Pearson's rank correlation analysis was performed to establish whether there existed a relationship among the measured physicochemical water quality parameters.

## 3 Results

### 3.1 Spatial variations in physicochemical water quality parameters

The values of water temperature varied from  $20.9 \pm 1.2$  to  $21.8 \pm 1.2$  °C at Ndarura (U2) and Heissesero (L1) stations, respectively (Table 3). DO concentration values varied between  $6.5 \pm 1.2$  mg/L at Mugyera station (M3) and  $7.2 \pm 1.7$  mg/L at Harutinda (M1). The pH values ranged from  $7.4 \pm 0.5$  to  $7.9 \pm 0.6$  recorded at Mugyera (M3) and Akampene (M2) stations, respectively (Table 3). Turbidity values ranged from  $2.8 \pm 0.6$  to  $4.3 \pm 1.6$  NTU at Akampene (M2) and Mugyera (M3) station, respectively. Likewise, electric conductivity values varied between  $241.1 \pm 11.1$  µS/cm and  $266.8 \pm 61.9$  µS/cm obtained at Mugyera (M3) and Harutinda (U2), respectively

**Table 2** Review of assigned weight for the physicochemical parameters

Variables	[12]	Rubio-Arias et al. [35]	Boyacio-glu [8]	Abrahão et al. [2]	Abdul Hameed et al. [1]	Kükrer & Mutlu [20]	Kangabam et al. [16]	Ravikumar et al. [34]	Meher et al. [25]	Average Values
DO	4	–	4	4	4	–	4.09	–	5	4.2
EC	2	–	–	4	2.7	–	–	3	5	3.3
Turbidity	2	3	–	4	2.4	–	2.4	–	–	2.8
PH	4	4	1	1	2.1	3	2.5	3	4	2.7
NO <sub>2</sub> -N	–	–	–	1	2.5	5	2.6	–	3	4.4
NO <sub>3</sub> -N	–	–	3	2	2	5	2	5	–	3.2
Temp	–	–	–	1	–	–	–	–	–	1.0
NH <sub>3</sub> -N	–	2	–	3	–	–	–	–	–	2.5
SRP	–	–	–	1	–	–	–	–	–	1.0

**Table 3** Mean  $\pm$  SD of physicochemical parameters at different sampling points ( $n = 108$ )

Station		Temperature ( $^{\circ}\text{C}$ )	DO (mg/L)	EC ( $\mu\text{S}/\text{cm}$ )	Turbidity (NTU)	pH	SD (m)
Nyombe	Mean	$21.2 \pm 1.3$	$6.72 \pm 1.38$	$241.8 \pm 11.5$	$3.3 \pm 1.2$	$7.5 \pm 0.5$	$0.8 \pm 0.2$
	Range	19.6–23.4	4.6–8.6	213–254	2.1–6.7	6.6–8.2	0.6–1.2
Ndarura	Mean	$20.9 \pm 1.2$	$6.75 \pm 1.38$	$243.25 \pm 7.02$	$3.0 \pm 0.6$	$7.7 \pm 0.54$	$1.0 \pm 0.3$
	Range	20.0–23.0	4.1–8.8	232–255	1.9–3.9	6.8–8.7	0.6–1.6
Kariko	Mean	$21.5 \pm 1.4$	$6.96 \pm 1.34$	$247.67 \pm 12.3$	$3.6 \pm 1.2$	$7.8 \pm 0.4$	$0.9 \pm 0.3$
	Range	19.9–23.7	3.6–8.5	233–277	2.0–5.6	7.0–8.5	0.5–1.3
Harutinda	Mean	$21.4 \pm 1.3$	$7.16 \pm 1.67$	$266.8 \pm 61.9$	$3.9 \pm 1.7$	$7.7 \pm 0.5$	$1.0 \pm 0.4$
	Range	19.6–23.5	5.0–9.9	229–422	1.8–7.1	7.1–8.7	0.5–1.8
Akempene	Mean	$21.2 \pm 1.4$	$6.76 \pm 0.98$	$243.67 \pm 8.12$	$3.3 \pm 0.8$	$7.9 \pm 0.6$	$1.1 \pm 0.4$
	Range	19.0–23.7	5.0–7.9	235–259	2.0–4.7	7.0–8.8	0.3–1.7
Mugyera	Mean	$21.1 \pm 1.4$	$6.46 \pm 1.19$	$241.1 \pm 11.1$	$4.3 \pm 1.6$	$7.4 \pm 0.5$	$1.1 \pm 0.4$
	Range	19.2–23.2	4.2–8.2	225–259	2.5–6.3	6.7–8.4	0.4–1.7
Heissesero	Mean	$21.8 \pm 1.2$	$6.93 \pm 1.25$	$245.17 \pm 8.6$	$3.3 \pm 1.0$	$7.8 \pm 0.7$	$1.2 \pm 0.4$
	Range	20.0–23.5	4.9–8.5	238–263	2.0–5.5	6.4–9.2	0.6–1.7
Rugarambiro	Mean	$21.6 \pm 1.4$	$6.9 \pm 1.34$	$245.75 \pm 7.3$	$3.5 \pm 0.9$	$7.7 \pm 0.5$	$1.1 \pm 0.4$
	Range	20.0–23.8	4.2–8.7	238–261	2.1–4.8	6.8–8.6	0.4–1.5
Hamukaka	Mean	$21.3 \pm 1.5$	$6.56 \pm 1.20$	$244 \pm 7.59$	$4.1 \pm 1.3$	$7.7 \pm 0.7$	$0.9 \pm 0.2$
	Range	20.0–23.8	3.8–7.9	235–259	2.6–6.8	6.8–8.8	0.5–1.2
All Grps	Mean	$21.3 \pm 1.3$	$6.81 \pm 1.28$	$246.57 \pm 22.9$	$3.6 \pm 1.2$	$7.7 \pm 0.6$	$1.0 \pm 0.3$
	Range	19.0–23.8	3.6–9.9	213–422	1.8–7.1	6.4–9.2	0.3–1.8

(Table 3). Secchi depth values ranged from  $0.8 \pm 0.2$  m to  $1.2 \pm 0.4$  m recorded at Nyombe (U1) and Heissesero (U3) stations, respectively. Statistically, water temperature, DO, turbidity, pH and EC and SD values showed no significant differences between study stations ( $p > 0.05$ ).

For the case of nutrients,  $\text{NH}_3\text{-N}$  values ranged between  $0.07 \pm 0.01$  mg/L and  $0.13 \pm 0.07$  mg/L obtained at Akampene (M2) and Heissesero (L1) station, respectively. TN concentration varied between  $1.0 \pm 0.7$  mg/L and  $2.9 \pm 2.1$  mg/L obtained at Nyombe (U1) and Rugarambiro (L2) stations, respectively (Table 4).  $\text{NO}_2\text{-N}$  ranged from  $0.003 \pm 0.002$  to  $0.006 \pm 0.003$  mg/L obtained at Nyombe and Rugarambiro stations, respectively (Table 3).  $\text{NO}_3\text{-N}$  concentration values ranged between  $0.02 \pm 0.02$  to  $0.03 \pm 0.03$  mg/L obtained at Harunda (U2) and Rugarambiro (L2) stations, respectively (Table 4). In addition, SRP concentration ranged from  $0.05 \pm 0.02$  mg/L at Hamukaka (L3) station to  $0.18 \pm 0.3$  mg/L at Nyombe station (U1). TP concentration ranged between  $0.08 \pm 0.04$  mg/L and  $0.21 \pm 0.17$  mg/L obtained at Kariko station (U3) and Nyombe (U1) stations, respectively (Table 4). Although the Kruskal–Wallis test revealed significant differences in  $\text{NH}_3\text{-N}$  concentration values ( $H(8, N = 108) = 29.265, p = 0.003$ ), no significant differences were recorded in TN,  $\text{NO}_2\text{-N}$ ,  $\text{NO}_3\text{-N}$ , SRP and TP concentration values between the study stations ( $p > 0.05$ ).

### 3.2 Temporal variations in physicochemical water quality variables

The values of water temperature varied between  $19.8 \pm 0.5$  to  $23.0 \pm 0.6$   $^{\circ}\text{C}$  obtained in December 2019 and August 2020, respectively (Table 5). DO values varied between  $4.4 \pm 0.5$  mg/L and  $8.4 \pm 0.7$  mg/L obtained in September and April 2020, respectively (Table 5). Likewise, pH values varied between 7.0 and  $8.5 \pm 0.1$  recorded in September and December 2020, respectively. Turbidity values ranged from  $2.2 \pm 0.3$  NTU in June to  $4.8 \pm 1.1$  NTU in April 2020. EC values ranged from  $234.7 \pm 5$   $\mu\text{S}/\text{cm}$  in July 2020 to  $266.2 \pm 58.5$   $\mu\text{S}/\text{cm}$  in January 2020 (Table 5). SD values ranged from  $0.6 \pm 0.2$  to  $1.3 \pm 0.4$  m obtained in May and June 2020, respectively (Table 4). Statistically, the mean values for the measured physical parameters were significantly different between sampling months ( $p < 0.05$ ).

Nutrients varied distinctly between sampling months.  $\text{NH}_3\text{-N}$  values ranged from  $0.07 \pm 0.01$  to  $0.14 \pm 0.1$  mg/L recorded in June and March 2020, respectively (Table 5). TN concentration ranged from  $0.6 \pm 0.4$  to  $3.8 \pm 2.1$  mg/L recorded in August and March 2020, respectively (Table 5). The  $\text{NO}_2\text{-N}$  values ranged from  $0.002 \pm 0.001$  to  $0.008 \pm 0.004$  mg/L recorded in March and August 2020, respectively.  $\text{NO}_3\text{-N}$  concentration ranged from  $0.01 \pm 0.00$  mg/L in January and September 2020 to  $0.06 \pm 0.03$  mg/L in February 2020. Likewise, SRP values in water samples varied between  $0.019 \pm 0.01$  mg/L in October 2019 to  $0.23 \pm 0.3$  mg/L in March 2020. TP values varied

**Table 4** Mean  $\pm$  SD of nutrients concentration at different sampling points ( $n = 108$ )

Station		NH <sub>3</sub> -N (mg/L)	NO <sub>2</sub> -N (mg/L)	NO <sub>3</sub> -N (mg/L)	TN (mg/L)	SRP (mg/L)	TP (mg/L)
Nyombe	Mean	0.07 $\pm$ 0.04	0.003 $\pm$ 0.002	0.023 $\pm$ 0.019	1.0 $\pm$ 0.7	0.18 $\pm$ 0.26	0.21 $\pm$ 0.17
	Range	0.01–0.15	0.001–0.007	0.01–0.07	0.2–2.1	0.01–0.73	0.04–0.48
Ndarura	Mean	0.08 $\pm$ 0.05	0.004 $\pm$ 0.003	0.02 $\pm$ 0.024	1.6 $\pm$ 1.5	0.11 $\pm$ 0.20	0.09 $\pm$ 0.06
	Range	0.01–0.23	0.001–0.007	0.01–0.08	0.2–4.4	0.01–0.75	0.03–0.20
Kariko	Mean	0.09 $\pm$ 0.06	0.005 $\pm$ 0.005	0.02 $\pm$ 0.019	2.3 $\pm$ 2.5	0.05 $\pm$ 0.02	0.08 $\pm$ 0.04
	Range	0.02–0.24	0.002–0.017	0.01–0.07	0.1–7.7	0.02–0.08	0.02–0.17
Harutinda	Mean	0.07 $\pm$ 0.02	0.004 $\pm$ 0.002	0.02 $\pm$ 0.023	2.1 $\pm$ 2.0	0.05 $\pm$ 0.02	0.08 $\pm$ 0.05
	Range	0.01–0.09	0.002–0.008	0.01–0.09	0.2–7.4	0.02–0.08	0.03–0.17
Akampene	Mean	0.07 $\pm$ 0.01	0.005 $\pm$ 0.004	0.021 $\pm$ 0.023	2.1 $\pm$ 2.8	0.09 $\pm$ 0.13	0.09 $\pm$ 0.07
	Range	0.05–0.09	0.001–0.016	0.01–0.09	0.1–10.3	0.01–0.50	0.03–0.28
Mugyera	Mean	0.09 $\pm$ 0.04	0.005 $\pm$ 0.002	0.026 $\pm$ 0.020	1.2 $\pm$ 0.8	0.05 $\pm$ 0.02	0.11 $\pm$ 0.06
	Range	0.06–0.22	0.002–0.009	0.01–0.07	0.4–2.5	0.02–0.08	0.03–0.18
Heissesero	Mean	0.13 $\pm$ 0.07	0.005 $\pm$ 0.002	0.024 $\pm$ 0.017	1.9 $\pm$ 1.3	0.05 $\pm$ 0.02	0.13 $\pm$ 0.10
	Range	0.07–0.26	0.003–0.011	0.01–0.07	0.2–4.6	0.02–0.09	0.04–0.35
Rugarambiro	Mean	0.11 $\pm$ 0.07	0.006 $\pm$ 0.003	0.03 $\pm$ 0.032	2.9 $\pm$ 2.1	0.11 $\pm$ 0.2	0.14 $\pm$ 0.13
	Range	0.07–0.32	0.001–0.014	0.01–0.09	0.5–6.8	0.02–0.74	0.02–0.52
Hamukaka	Mean	0.10 $\pm$ 0.07	0.003 $\pm$ 0.002	0.026 $\pm$ 0.025	1.7 $\pm$ 1.6	0.05 $\pm$ 0.02	0.20 $\pm$ 0.32
	Range	0.06–0.32	0.001–0.007	0.01–0.10	0.2–5.6	0.02–0.08	0.03–1.20
All Grps	Mean	0.09 $\pm$ 0.05	0.005 $\pm$ 0.003	0.041 $\pm$ 0.134	1.9 $\pm$ 1.9	0.08 $\pm$ 0.14	0.12 $\pm$ 0.14
	Range	0.01–0.32	0.001–0.017	0.01–0.09	0.1–10.3	0.009–0.75	0.12–1.20

**Table 5** Mean  $\pm$  SD of physicochemical parameters in the different sampling months ( $n = 108$ )

Months		Temp	DO	EC	Turbidity	pH	SD
Oct	Mean	20.1 $\pm$ 0.6	7.8 $\pm$ 0.4	242.4 $\pm$ 4.6	4.8 $\pm$ 1.2	7.2 $\pm$ 0.6	0.9 $\pm$ 0.1
	Range	19.0–21.1	7.1–8.7	232.0–247	3.2–6.8	6.4–8.5	0.6–1.0
Nov	Mean	21.1 $\pm$ 1.2	7.8 $\pm$ 0.7	257.6 $\pm$ 3.9	4.2 $\pm$ 1.5	7.8 $\pm$ 0.1	1.0 $\pm$ 0.3
	Range	20.0–23.7	7.0–8.7	250.0–263	2.9–7.1	7.6–8.0	0.5–1.4
Dec	Mean	19.8 $\pm$ 0.5	8.2 $\pm$ 0.7	237.0 $\pm$ 2.2	3.6 $\pm$ 1.1	8.5 $\pm$ 0.1	1.1 $\pm$ 0.3
	Range	19.0–20.8	7.3–9.7	234.0–241	2.7–6.2	8.2–8.7	0.5–1.4
Jan	Mean	22.2 $\pm$ 0.8	7.6 $\pm$ 0.4	266.2 $\pm$ 58.5	3.2 $\pm$ 0.5	8.1 $\pm$ 0.5	1.2 $\pm$ 0.3
	Range	21.2–23.2	7.1–8.6	243.0–422	2.7–4.0	7.4–8.8	0.8–1.7
Feb	Mean	21.1 $\pm$ 0.8	6.7 $\pm$ 0.4	245.6 $\pm$ 5.6	3.8 $\pm$ 1.1	7.3 $\pm$ 0.3	0.8 $\pm$ 0.4
	Range	20.2–22.3	5.9–7.2	240.0–255	2.2–6.2	6.8–7.8	0.5–1.7
Mar	Mean	20.2 $\pm$ 0.7	7.0 $\pm$ 0.3	261.8 $\pm$ 42.4	3.9 $\pm$ 0.5	7.5 $\pm$ 0.4	0.7 $\pm$ 0.1
	Range	19.3–22.0	6.6–7.3	241.0–371	3.2–4.4	6.8–8.0	0.5–0.9
Apr	Mean	20.8 $\pm$ 1.0	8.4 $\pm$ 0.7	255.6 $\pm$ 3.9	4.8 $\pm$ 1.1	8.0 $\pm$ 0.1	0.8 $\pm$ 0.2
	Range	20.1–23.3	7.5–9.9	248.0–261	3.3–6.9	7.8–8.1	0.5–1.0
May	Mean	20.6 $\pm$ 1.0	6.6 $\pm$ 0.4	235.4 $\pm$ 9.4	4.4 $\pm$ 1.1	7.6 $\pm$ 0.8	0.6 $\pm$ 0.2
	Range	19.6–22.7	6.0–7.1	213.0–244	3.3–6.7	6.6–8.8	0.3–0.9
Jun	Mean	22.0 $\pm$ 0.9	6.2 $\pm$ 0.3	237.2 $\pm$ 4.1	2.2 $\pm$ 0.3	7.8 $\pm$ 0.1	1.3 $\pm$ 0.4
	Range	20.9–23.8	5.6–6.7	228.0–242	1.8–2.6	7.6–7.9	0.8–1.8
Jul	Mean	22.7 $\pm$ 1.1	5.4 $\pm$ 0.5	234.7 $\pm$ 5	2.9 $\pm$ 0.9	7.8 $\pm$ 0.4	1.2 $\pm$ 0.4
	Range	20.3–23.8	4.9–6.2	225.0–240	2.1–5.1	7.0–8.7	0.6–1.6
Aug	Mean	23.0 $\pm$ 0.6	5.6 $\pm$ 0.4	237.7 $\pm$ 2.7	2.9 $\pm$ 0.7	7.9 $\pm$ 0.5	1.2 $\pm$ 0.2
	Range	21.8–23.7	5.0–6.4	233.0–242	1.9–4.2	7.5–9.2	0.9–1.6
Sept	Mean	22.2 $\pm$ 0.8	4.4 $\pm$ 0.5	247.8 $\pm$ 1.7	2.6 $\pm$ 0.2	7.0 $\pm$ 0.0	1.3 $\pm$ 0.2
	Range	21.1–23.5	3.6–5	245.0–250	2.4–3.0	7.0–7.1	0.9–1.5
All Grps	Mean	21.3 $\pm$ 1.3	6.8 $\pm$ 1.3	246.6 $\pm$ 22.8	3.6 $\pm$ 1.2	7.7 $\pm$ 0.5	1.0 $\pm$ 0.3
	Range	19.0–23.8	3.6–9.9	213.0–422	1.8–7.1	6.4–9.2	0.3–1.8

from  $0.05 \pm 0.01$  mg/L in June 2020 to  $0.27 \pm 0.2$  mg/L in March 2020 (Table 5). Statistically, the mean values for all the nutrient parameters were significantly different between sampling months ( $p < 0.05$ ).

### 3.3 The relationship between physicochemical water quality parameters

The Pearson's correlation was computed to establish whether there existed significant relationship among physicochemical parameters measured in Lake Bunyonyi (Table 7). Water temperature had a positive significant correlation with SD ( $r = 0.367$ ;  $p < 0.01$ ) but with a negative significant correlation with DO ( $r = -0.046$ ,  $p < 0.01$ ), turbidity ( $r = -0.416$ ,  $p < 0.01$ ),  $\text{NO}_2\text{-N}$  ( $r = -0.290$ ;  $p = 0.02$ ); and  $\text{NO}_3\text{-N}$  ( $r = -0.323$ ,  $p = 0.001$ ) and TN ( $r = -0.329$ ,  $p = 0.001$ ) (Table 6). TP had a positive significant correlation with  $\text{NO}_3\text{-N}$  ( $r = 0.335$ ,  $p < 0.01$ ),  $\text{NH}_3\text{-N}$  ( $r = 0.279$ ,  $p = 0.003$ ), SRP ( $r = 0.5502$ ,  $p < 0.01$ , TN ( $r = 0.198$ ,  $p = 0.040$ ) but significantly negatively correlated with SD ( $r = -0.217$ ;  $p = 0.024$ ) (Table 6). Likewise, DO levels were significantly positively correlation with turbidity ( $r = 0.508$ ;  $p < 0.05$ ) and pH level ( $r = 0.342$ ,  $p < 0.01$ ), turbidity ( $r = 0.483$ ,  $p < 0.01$ ),  $\text{NO}_2\text{-N}$

( $r = 0.329$ ,  $p < 0.01$ ) but significantly negatively correlated with SD ( $r = -0.268$ ,  $p < 0.01$ ). Besides, the TN values were significantly positively correlated with turbidity ( $r = 0.245$ ,  $p = 0.010$ ),  $\text{NH}_3\text{-N}$  ( $r = 0.255$ ,  $p = 0.008$ ),  $\text{NO}_3\text{-N}$  ( $r = 0.571$ ,  $p < 0.01$ ) but significantly negatively correlated with temperature ( $r = -0.329$ ,  $p < 0.01$ ), pH ( $r = -0.210$ ,  $p = 0.029$ ) and SD ( $r = -0.255$ ,  $p = 0.004$ ).

### 3.4 Water quality index

The WQI used to assess the water quality was prepared using values of the nine physicochemical variables selected based on their importance in water quality. They include; temperature, turbidity, pH, DO, EC,  $\text{NO}_2\text{-N}$ ,  $\text{NO}_3\text{-N}$ , SRP and  $\text{NH}_3\text{-N}$ . The values used for each variable were the mean value of the stations under investigation. The threshold limit values by WHO [51], [53] except for SRP and  $\text{NH}_3\text{-N}$  values derived from Uganda National Bureau of Standards [47] were used for computation of the WQI values (Table 8). The WQI values (Table 7) in the Lake varied from 28.36 to 49.4 obtained at Harutinda and Heisesero stations, respectively. Based on the WQI classification, the recorded WQI range values fall under the 'good'

**Table 6** Mean  $\pm$  SD of nutrient concentration in the different sampling months ( $n = 108$ )

Months		$\text{NH}_3\text{-N}$	$\text{NO}_2\text{-N}$	$\text{NO}_3\text{-N}$	TN	SRP	TP
Oct	Mean	$0.08 \pm 0.08$	$0.008 \pm 0.003$	$0.02 \pm 0.01$	$1.5 \pm 1.4$	$0.019 \pm 0.01$	$0.1 \pm 0.10$
	Range	0.01–0.24	0.006–0.017	0.01–0.03	0.4–4.6	0.010–0.03	0.02–0.28
Nov	Mean	$0.08 \pm 0.02$	$0.004 \pm 0.002$	$0.01 \pm 0.01$	$1.1 \pm 1.0$	$0.104 \pm 0.39$	$0.11 \pm 0.17$
	Range	0.05–0.12	0.002–0.007	0.01–0.03	0.1–2.7	0.02–0.74	0.02–0.52
Dec	Mean	$0.08 \pm 0.01$	$0.008 \pm 0.004$	$0.02 \pm 0.02$	$1.9 \pm 2.1$	$0.047 \pm 0.01$	$0.11 \pm 0.05$
	Range	0.07–0.09	0.005–0.016	0.01–0.08	0.1–6.8	0.037–0.06	0.05–0.17
Jan	Mean	$0.07 \pm 0.02$	$0.004 \pm 0.001$	$0.01 \pm 0.00$	$0.8 \pm 1.6$	$0.07 \pm 0.01$	$0.17 \pm 0.07$
	Range	0.05–0.11	0.002–0.005	0.01–0.01	0.2–5.0	0.055–0.08	0.1–0.35
Feb	Mean	$0.09 \pm 0.03$	$0.005 \pm 0.002$	$0.06 \pm 0.03$	$3.7 \pm 2.7$	$0.15 \pm 0.21$	$0.13 \pm 0.03$
	Range	0.07–0.18	0.003–0.008	0.02–0.09	1.7–10.3	0.056–0.7	0.10–0.17
Mar	Mean	$0.14 \pm 0.10$	$0.004 \pm 0.002$	$0.05 \pm 0.03$	$3.8 \pm 2.1$	$0.227 \pm 0.3$	$0.27 \pm 0.2$
	Range	0.07–0.32	0.001–0.008	0.01–0.10	1.5–7.4	0.058–0.75	0.11–1.2
Apr	Mean	$0.14 \pm 0.09$	$0.004 \pm 0.002$	$0.03 \pm 0.02$	$2.7 \pm 1.6$	$0.074 \pm 0.0$	$0.08 \pm 0.01$
	Range	0.06–0.32	0.001–0.007	0.01–0.08	0.6–5.6	0.07–0.08	0.06–0.10
May	Mean	$0.11 \pm 0.05$	$0.003 \pm 0.002$	$0.03 \pm 0.02$	$2.5 \pm 2.0$	$0.049 \pm 0.01$	$0.17 \pm 0.12$
	Range	0.07–0.22	0.001–0.006	0.01–0.07	1.2–7.7	0.041–0.06	0.09–0.47
Jun	Mean	$0.07 \pm 0.01$	$0.006 \pm 0.005$	$0.01 \pm 0.00$	$2.2 \pm 0.9$	$0.039 \pm 0.01$	$0.05 \pm 0.01$
	Range	0.06–0.09	0.001–0.014	0.01–0.02	0.5–3.8	0.032–0.05	0.04–0.06
Jul	Mean	$0.08 \pm 0.02$	$0.004 \pm 0.001$	$0.01 \pm 0.00$	$0.8 \pm 1.1$	$0.023 \pm 0.01$	$0.05 \pm 0.02$
	Range	0.04–0.10	0.002–0.006	0.01–0.02	0.1–3.6	0.009–0.03	0.04–0.08
Aug	Mean	$0.08 \pm 0.03$	$0.004 \pm 0.003$	$0.02 \pm 0.01$	$0.6 \pm 0.4$	$0.110 \pm 0.15$	$0.15 \pm 0.12$
	Range	0.02–0.10	0.001–0.007	0.01–0.02	0.1–1.4	0.046–0.5	0.09–0.45
Sept	Mean	$0.07 \pm 0.01$	$0.002 \pm 0.001$	$0.01 \pm 0.00$	$1.0 \pm 0.5$	$0.059 \pm 0.08$	$0.09 \pm 0.15$
	Range	0.05–0.09	0.001–0.005	0.01–0.01	0.4–1.9	0.021–0.28	0.03–0.48
All Grps	Mean	$0.09 \pm 0.05$	$0.005 \pm 0.003$	$0.02 \pm 0.02$	$1.9 \pm 1.8$	$0.08 \pm 0.14$	$0.13 \pm 0.14$
	Range	0.01–0.32	0.001–0.017	0.01–0.10	0.1–10.3	0.009–0.75	0.02–1.2



**Table 7** Pearson correlation matrix for physicochemical water quality variables (n = 108)

Variables	Temp	DO	pH	SD	Turb	NH <sub>3</sub> -N	NO <sub>2</sub> -N	NO <sub>3</sub> -N	TN	SRP	TP
Temp	1	− 0.500**	0.05	0.367**	− 0.416**	− 0.086	− 0.290**	− 0.323**	− 0.328**	− 0.024	− 0.126
DO		1	0.342**	− 0.268**	0.483**	0.067	0.329**	0.135	0.155	0.099	0.149
pH			1	0.096	− 0.089	− 0.087	0.131	− 0.238*	− 0.210*	0.088	− 0.064
SD				1	− 0.525**	− 0.089	0.114	− 0.384**	0.275**	− 0.125	− 0.217*
Turb					1	0.161	0.168	0.245*	0.166	0.012	0.152
NH <sub>3</sub> -N						1	− 0.067	0.252**	0.255**	0.195*	0.279**
NO <sub>2</sub> -N							1	0.167	0.086	− 0.124	− 0.054
NO <sub>3</sub> -N								1	0.571**	0.330**	0.335**
TN									1	0.169	0.198*
SRP										1	0.550**
TP											1

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

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

**Table 8** Relative weight of parameters WQI determination

Variables	WHO/UNBS standards	Assigned weight (AW)	Relative weight (Wn)
DO (mg/l)	6	4.2	0.023
EC (μS/cm)	250	3.3	0.001
Turbidity (NTU)	5	2.8	0.028
pH	8.5	2.7	0.016
NO <sub>2</sub> -N (mg/L)	0.9	4.4	0.155
NO <sub>3</sub> -N (mg/L)	11	3.2	0.013
NH <sub>3</sub> -N (mg/L)	0.2	2.5	0.696
SRP (mg/L)	2.2	1.0	0.063
Temperature (°C)	25	1.0	0.006

**Table 9** Change in the WQI values across the study stations

S/N	Station		WQI	Status
	Name	Code		
2	Nyombe	U1	30.56	Good
3	Ndarura	U2	33.01	Good
4	Kariko	U3	37.63	Good
5	Harutinda	M1	28.36	Good
6	Akampene	M2	28.74	Good
7	Mugyera	M3	37.13	Good
8	Heissesero	L1	49.40	Good
9	Rugarambiro	L2	45.42	Good
10	Hamukaka	L3	42.23	Good

class, which reflects that water from Lake Bunyonyi is good for drinking, recreation and domestic uses on account of physicochemical variables (Table 8).

The water quality index signifies as scale of water quality (Table 9). As indicated in Table 10, the WQI between 0 to 25 means 'Excellent' quality of water; 25 to 50 means 'Good' quality of water; 51 to 75 means 'Poor' quality of water; 76 to 100 means 'Very poor' quality of water; and > 100 means the water is 'Unsuitable' for drinking [29].

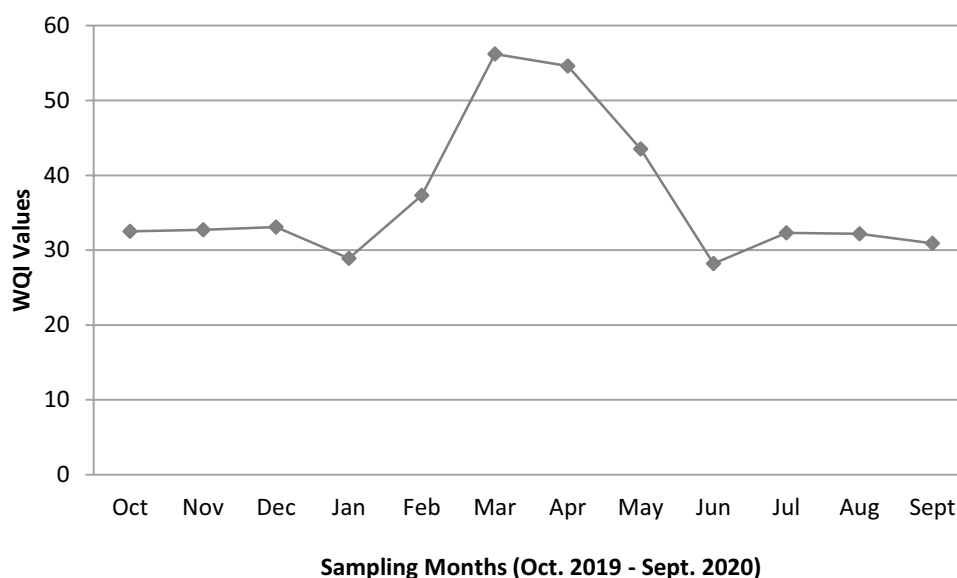
On a temporal scale, it was observed that March 2020 recorded the highest WQI value (56.2) while in July 2020, the lowest index value (28.2) was obtained (Fig. 2). Based on the WQI classification, it was observed that WQI values obtained during the sampling period fall under the 'good' category unlike the values for March and April 2020 which fell under the 'poor' category (51–75). When examined changes in the WQI values between seasons (Fig. 2), it was observed that the mean WQI value for the wet season (41.7) was higher

**Table 10** Water quality index classification

WQI	Water quality status
0–25	Excellent
26–50	Good
51–75	Poor
76–100	Very poor
Above 100	Unfit for human consumption

than the value recorded in the dry season (33.5) and both fell under the 'good' category.

**Fig. 2** Changes in the monthly WQI values at Lake Bunyonyi



## 4 Discussion

### 4.1 Variability in physical water quality parameters

The observed surface temperature values were found to be within the WHO permissible limit (25 °C) for aquatic living [50]. Similar to our findings, Tibihika et al. [42] recorded an overall mean water temperature value of  $21.3 \pm 1.4$  °C at Lake Bunyonyi. The observed somewhat low temperature was attributed to two main factors. Firstly, the water mass that enters Lake Bunyonyi through River Kagoma and other minor streams take longer to warm up. Secondly, Lake Bunyonyi is situated between steep hills with several barriers that limit the amount of sunlight heating the surface waters of the lake.

The observed DO concentrations in the current study were > 2 mg/L. These values according to Keister et al. [17] do not cause stress to aquatic organisms and ecosystems and can rarely result in changes in the communities through direct organisms mortality and reduction in the population growth of sensitive species. In the aquatic ecosystem, DO provides a broad indication of water quality and depends on many factors such as microbial activity, temperature, level of organic matter, pressure and the sampling time [10, 27]. Similar to study findings, Tiémoko et al. [43] reported a DO concentration range of 4.6 to 7.7 mg/L at Lake Taabo and Kossou. With regard to EC, the recorded values in the current study did not exceed the WHO maximum permissible limits of 2500  $\mu\text{S}/\text{cm}$  as stated in the global national regulations and standards for drinking water. Therefore, our study results rightly indicate that water in the Lake Bunyonyi was not considerably ionized and has a relatively low ionic concentration level. The observed high EC values at Harutinda station are possibly

attributed to the possible pollution from Crater Bay Cottages and Lake Bunyonyi Overland camp whereas low EC values at Nyombe station indicates an untainted aquatic environment. The turbidity range across all study stations did not exceed the maximum value (20 NTU) for the global national regulations and standards for drinking water [53]. Similar to our study results, Anjusha et al. [5] reported a mean turbidity range of 2.5–3.9 NTU, slightly lower than the values reported in the present study. On the other hand, Umer et al. [46] reported a turbidity range of 28.5 to 63.0 NTU in Lake Beseka significantly higher than recorded values in the current study attributed to the rapid expansion of the Lake water level.

Concerning pH levels, the recorded range of values reflected a neutral to a slightly alkaline aquatic environment and was within the acceptable range (6.5–8.5) for a healthy aquatic life [53]. The observed variations in pH are possibly due to the high influx of freshwater from the upper Bunyonyi site and River Kagoma that flows into the lake. Similar to the present study findings, Ongom et al. [30], Song et al. [39] and Muduli and Pattnaik [26] obtained pH ranges reflecting neutral to slightly alkaline lake conditions. According to Niyoyitungiye et al. [28], the optimal pH range below pH 6.5 influences the slow growth of some aquatic species while pH value > 6.5 affects the capacity of some organisms to preserve their salt equilibrium and can cause a stoppage in reproduction unlike the reported pH range is conducive. Concerning SD, the observed temporal variability is possibly attributed to the seasonal variations. For instance, Lake Bunyonyi experiences high runoff inflow from the catchment and increased as a result of high discharge experience in the rain season. Similar to study results, Sitoki et al. [38], Tran et al. [45], reported the SD range value of 0.8–1.7 m (Lake Kyoga) and 0.17–2.3 m

(Edward), respectively. On the other hand, Stoyneva-Gärtner et al. [40], Vundo et al. [49] and Ozguven & Demir Yetis [32] reported an SD range significantly higher than the recorded values in the present study.

## 4.2 Variability in the nutrient concentrations

TN concentration is the measure of both organic and inorganic nitrogen concentration. The role of nitrogen in freshwater bodies varies according to the relative amounts of the forms of nitrogen present. Generally, higher TN concentration values were found in the lower Bunyonyi site where run-off from agricultural land enters the lake through the Rugarambiro sampling station. This confirms the frequently experienced opinion that farm activities in the lake watershed are an important source of nitrogen in freshwater lakes [14]. Similar to our study findings, Tibihika et al. [42] and Ozguven and Demir Yetis [32] reported TN concentration values of  $103.6 \pm 8.4 \mu\text{g/L}$  in Lake Bunyonyi and  $4.9 \pm 16.0 \text{ mg/L}$  in Big Soda Lake Van, respectively. However, the observed study findings were higher than  $0.88 \pm 0.05 \text{ mg/L}$  for Lake Qiandaohu as reported by Zhou et al. [58].

In all study stations, the observed  $\text{NH}_3\text{-N}$  concentrations were greater than  $0.025 \text{ mg/L}$ , the recommended limit for freshwater environments beyond which, it acts as toxic to freshwater organisms [13]. Similar to our study results, Tilahun and Ahlgren [44] obtained  $0.09 \pm 0.08 \text{ mg/L}$  in Lake Chamo of Ethiopia. The observed high  $\text{NH}_3\text{-N}$  concentration at Heissesero is possibly due to the demineralization of submerged macrophytes. The assumption is built based on the fact that rivers that flow into the lake under study showed low  $\text{NH}_3\text{-N}$  concentration and the  $\text{NH}_3\text{-N}$  concentration in the lake did not change significantly during the rainy season.

The observed  $\text{NO}_2\text{-N}$  concentration range values were within the WHO concentration threshold of  $0.9 \text{ mg/L}$  for drinking water [51]. Thus, water from Lake Bunyonyi is less likely to cause health concerns and thus Lake Bunyonyi still meets the minimal standards to serve as a source for drinking water. The observed  $\text{NO}_2\text{-N}$  values were lower than  $32.9 \pm 0.7 \mu\text{g/L}$  and  $0.82 \pm 0.25 \text{ mg/L}$  recorded at Lake Bunyonyi, and Lake Tonga by Tibihika et al. [42] and Loucif et al. [22], respectively. On the other hand, the recorded  $\text{NO}_2\text{-N}$  values were higher than  $1.3 \pm 0.7 \mu\text{g/L}$  obtained at Lake Oubeira reported by Keyombe and Waithaka [18]. The presence of nitrites in freshwater lakes can give rise to the presence of nitrosamines by reaction with organic compounds and thus cause carcinogenic effects [52].

The observed  $\text{NO}_3\text{-N}$  concentration values did not exceed  $11 \text{ mg/L}$ ; the WHO recommended  $\text{NO}_3\text{-N}$  limits for drinking water [51]. The recorded highest  $\text{NO}_3\text{-N}$  concentration value ( $0.01 \pm 0.004$ ) at Ndarura station perhaps

emanates from farmlands around the study station. In comparison with other previous studies, Tibihika et al. [42], Maryam et al. [23] and Tibebe et al. [41] obtained the average  $\text{NO}_3\text{-N}$  values of  $33.8 \pm 2.1 \mu\text{g/L}$ ,  $0.46 \text{ mg/L}$  and  $0.21 \text{ mg/L}$  slightly higher the values obtained in the current study. In aquatic environments,  $\text{NO}_3\text{-N}$  are important nutrients necessary for the growth of aquatic plants; nevertheless, the concentration  $> 90 \text{ mg/L}$  is toxic to aquatic organisms [4]. The major pathways that naturally increase  $\text{NO}_3\text{-N}$  content in lake ecosystems are rain, fog, snow, decomposition of organic matter and fertilizer application in agricultural fields.

TP is the measure of both inorganic and organic forms of phosphorus. Due to the longer residence time in lakes, TP is considered the most critical nutrient [33]. Similar to the results of the current study, Opiyo et al. [31] reported high TP values ( $3.09 \pm 0.09 \text{ mg/L}$ ) in the wet season than in the dry season. The observed spatial variations in TP concentrations were attributed to proximity to agricultural farmlands which are the major sources of nutrients in the lake. Likewise, the variations in TP concentration during the study period are possibly attributed to seasonal changes in rainfall amounts which influence nutrient deposition intensity. The current study findings, however, disagrees with that of Opiyo et al. [31] who reported the mean average of  $2.9 \pm 0.08 \text{ mg/L}$  in Lake, respectively, higher than reported TP values in the current study. This attributed to several years of nutrients inflows from the Lake sub-catchment that experiences intense agricultural activities [31].

## 4.3 Water quality index of Lake Bunyonyi

The WQI of Lake Bunyonyi fell within the 'good' category of WQI classification across study stations. Nevertheless, the WQI values for March and April 2020 fell under the 'poor' category (51–75). Similar to our results, Shah and Joshi [36] revealed the quality of water at Station 1 of River Sabarmati of India was of good quality with a WQI range of 19.84 to 44.58 obtained from 2005 to 2008. Similarly, Nihalani and Meeruty (2020) reported a WQI range of 30 to 50 for River Mahi, and 28 to 52 for River Narmada, all of which are substantially related to the observed WQI range of the current study. In other related studies, Kükre and Mutlu [20] reported that WQI values for Saraydüzü Dam Lake ranged between 17.62 and 29.88, implying that Saraydüzü Dam Lake water belonged to the 'very good' class of WQI classification in terms of drinking water quality.

Although WQI values for stations in the lower Bunyonyi site place them into the 'good' category, the declining water quality was noticed. The recorded somewhat high WQI values are perhaps a result of containments inflow from the upper and middle Bunyonyi sites to the lower

site, thereby increasing pollutants concentration. Besides, the Heissesero station is situated adjacent to Muko Trading Centre where wastewater and surface run-off are directed into the Lake via run-off ways. The high WQI value for Hamukaka station is attributed to wastewater discharge from Bright Island and the agricultural run-off from crop fields. At Rugarambiro station, the increased agricultural practices (such as Irish potato growing) around the Lake increase pollution as a result of excessive use of fertilizers, and chemicals including pesticides.

#### 4.4 Correlation of among physicochemical variables

The correlation analysis revealed that temperature was positively correlated with DO, EC, SRP,  $\text{NH}_3\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NO}_3\text{-N}$ . The reported significant negative correlation between temperature and  $\text{NO}_3\text{-N}$  concentration values has been reported by Kangabam et al. [16] in Loktak Lake, India. Likewise, Bhatrai et al. [7] reported that DO was significantly negatively correlated with water temperature while positively correlated with turbidity, pH level, TP and TN of Lake Hwajinpo of South Korea. The results of significant correlation between surface water temperature and DO differed slightly from that of Ali and Khairy [3] who reported an increase in DO levels the period when surface water temperatures were lower due to gas solubility, which increases when temperatures and metabolic activity of organisms are low and the decreased, respectively. TP values were positively correlated with temperature, DO, turbidity,  $\text{NH}_3\text{-N}$ , TP and SRP. Similar to the study findings, Yu et al. [57] reported a positive correlation that TN positively correlated with TP and  $\text{NH}_3\text{-N}$  but significantly negatively with  $\text{NO}_2\text{-N}$ .

## 5 Conclusion

Based on the results, we conclude that the quality of water in Lake Bunyonyi is generally good for drinking as per WQI classification. This is further supported by the fact that the mean values for all the measured physicochemical variables were within WHO, UNBS and USEPA permissible limits for drinking water and recreational waters, respectively. It was evident that the obtained values for temperature, DO, turbidity, EC,  $\text{NH}_3\text{-N}$ ,  $\text{NO}_2\text{-N}$  and  $\text{NO}_3\text{-N}$  of the samples fell below the permissible levels and thus may not put both human and aquatic life at health risks. Although remarkable temporal variations were recorded among the measured physicochemical parameters, no extreme variations were recorded in all the study stations. The current study findings are fundamentally important for policymakers in setting guidelines for effective lake management. We, therefore, recommend that further studies investigate in

detail the point sources of contamination and the possible causes of high concentration of nutrients in Lake Bunyonyi be conducted.

**Acknowledgements** We would like to thank NWSC, Kampala—Uganda, for accepting us to use their laboratory facilities. We also wish to thank the communities living around Lake Bunyonyi for their support during the study.

**Authors' contributions** AS conceived and designed the study, collected and analysed data and drafted the manuscript: TJL contributed to the conception and design of the study, assisted in data interpretation and revision of the manuscript for intellectual content. JM contributed to the conception and design of the study, assisted in data interpretation and revision of the manuscript for intellectual content. SP contributed to the conception and design of the study, assisted in data interpretation and revision of the manuscript for intellectual content. All the authors read and approved the final manuscript for publication.

**Availability of data and material** All data generated and analysed during this study are included in this published article.

#### Declarations

**Competing interests** The authors declare no conflict of competing interests.

Not applicable.

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

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