Water Science

ORIGINAL ARTICLE

Open Access

Assessment of variability in physicochemical water parameters of Lake Nyabihoko, Western Uganda

Abraham Atuhaire[1*], Alex Saturday[2] and Ruhiiga Musigi[2]

Abstract

This study evaluates the spatial and seasonal variations in the physicochemical water quality parameters of Lake Nyabihoko. To assess the physicochemical quality, fifty-four (54) water samples were collected from nine sampling stations during the wet and dry seasons. On-site measurements included water temperature, dissolved oxygen (DO), turbidity, electrical conductivity (EC), and pH. Additionally, parameters such as hardness, alkalinity, chloride, calcium, magnesium, phosphates, and nitrates were determined. Variance analysis revealed that the mean values of all measured parameters did not significantly differ ($p > 0.05$) among the sampling stations, except for magnesium. The average values of DO, EC, turbidity, TDS, chloride, and phosphates showed significant differences between seasons, while temperature, pH, hardness, alkalinity, calcium, magnesium, and nitrates did not. The lake's water quality index (WQI) was calculated according to WHO (Guidelines for drinking-water quality: incorporating the first and second addenda, 2022) standards for drinking water, using the mean value for each parameter at each station, month, and season. WQI values ranged from 82.9 to 88.8, with an overall mean of 86.1, placing the water in the "very poor" category according to WQI classification. Seasonal variation was evident, with the WQI higher in the wet season (81.0) than in the dry season (76.8). The study recommends implementing a community catchment management plan and proper monitoring by local authorities to prevent further deterioration of water quality, thereby protecting public health and livelihoods in the vicinity of the lake.

Keywords Water quality, Water quality index, Lake Nyabihoko

Introduction

Worldwide, freshwater sources are important to both natural ecosystems and human development. They are essential for agriculture, industry, and human existence. Lakes, which contribute approximately 50% of the Earth's surface, house four times more water than rivers and are critical natural resources [3]. They provide abundant ecosystem services to humans directly through provisioning (e.g., water and fish) and indirectly through cultural, regulating, and maintenance services [10].

Nevertheless, anthropogenic activities like urbanization, industrialization, and agriculture affect surface water quality. Globally, 2.1 billion people lack access to safe water; of these, 844 million lack access to essential drinking water [32]. The rate of contamination of lake water in Africa is high due to anthropogenic activities [15]. An estimated 102 million people were reported to be still using unsafe water in sub-Saharan Africa [32]. Contamination from human activities exacerbates the issue, leaving millions reliant on unsafe water sources.

This article was transferred to Springer Nature after it was peer reviewed & accepted by the previous publisher.

*Correspondence:
Abraham Atuhaire
abrahamatuhaire@gmail.com
[1] Department of Natural Resources, Ntungamo District Local Government, P.O. Box 1, Ntungamo, Uganda
[2] Department of Environmental Sciences, Kabale University, P.O. Box 317, Kabale, Uganda

In Uganda, people have settled close to freshwater bodies for health and welfare benefits [23]. Population growth, intensive farming practices, and infrastructure development have led to increased water abstraction and external nutrient loading in natural freshwater ecosystems. Agricultural practices often lead to increased concentrations of nutrients and total solids, while industrial activities increase concentrations of toxic chemicals and heavy metals in surface water. Most industries in Uganda use conventional manufacturing technologies and lack efficient wastewater treatment facilities [1]. In addition, the increased cost of wastewater treatment has led to higher levels of contaminants in natural water sources [27]. Therefore, raw and harmful substances, such as heavy metals, are discharged into surrounding water bodies. Leachate from urban solid waste landfills, garages, car wash bays, and mining waste dumps is another source of pollution. As a result, freshwater bodies have undergone significant changes in their chemical and physical properties, often exhibiting a notable transition from clear to turbid. Due to suspended sediments and dissolved matter, such water sources are unfit for current and future uses.

Saturday et al. [23] reported that high levels of pollutants in the lake ecosystems may make the water unfit for drinking, recreation, and fishing. Additionally, excess nutrients (phosphorus and nitrogen) may trigger massive algal blooms, a phenomenon known as eutrophication, which harms aquatic life. Consequently, interventions are necessary to effectively conserve the aquatic environment. In addition, a systematic understanding of the ecosystem functions that govern the lake as a water source and habitat for aquatic and benthic organisms is required. Regular monitoring of water chemistry in lakes is essential, as various factors contribute to declines in water quality in specific bodies of water. The most significant public health risk today is water pollution. Unhealthy water conditions are estimated to contribute to approximately 80% of all human diseases [7]. In the Ankole subregion, Lake Nyabihoko is the primary source of drinking water and the habitat for flora and fauna. Nevertheless, human activities such as infrastructure development along the lake shore, business centers, agricultural activities, and fishing influence the lake's physicochemical characteristics. Human efforts will likely lead to changes in the physicochemical properties of Lake Nyabihoko. This could ultimately lead to a deterioration in water quality. To date, no studies have recorded the water quality status in Lake Nyabihoko, particularly in the context of seasonal and spatial variations. Understanding these parameters is critical for assessing the lake's suitability for drinking, fishing, agricultural, and ecological purposes, as well as for informing sustainable management practices. Therefore, this study assessed the variability in the physicochemical parameters of Lake Nyabihoko in western Uganda to determine its water quality status.

Materials and methods

Study area

Lake Nyabihoko is located in Uganda's Ntungamo district between latitudes (0° 54′ 0″ S, 0° 55′ 0″ S) and longitudes (30° 06′ 0″ E, 30° 09′ 0″ E) with an average altitude of 1359 m above sea level (Fig. 1). The lake is long and narrow, with a total surface area of about 6 km^2 and is surrounded by gently sloping hills. The area receives an average of 900 mm of rainfall per year, with two primary wet seasons: mid-September to November and March to May, which are also the periods with the highest rainfall. June to July is the dry season, while December to February are the wetter months, with a milder season periodically broken up by sporadic showers. The district's average annual temperature is 26 °C, with a mean annual minimum of 14.5 °C. High temperatures are recorded between January and February and June and August, coinciding with dry season periods. Depending on the season and current weather, relative humidity can range from 93–85% in the morning to 60–45% in the afternoon. Agriculture is a significant economic activity in the lake catchment, where livestock such as cattle, goats, and sheep are raised. Crops such as bananas, beans, maize, groundnuts, millet, and vegetables are also grown. The lake waters are used for fishing, irrigation, and recreational activities on the lake islands.

Selection of study sites

The lake was divided into three study sites: upper, middle, and lower. Nine sampling stations were selected from these sites based on the extent and type of human activities around the lake. The upper Nyabihoko site included Pelcan (UN1), Kobukamba (UN2), and Rukomo (UN3). The middle Nyabihoko site encompassed Kasinga (MN1), Mutumo Island (MN2), and Mwamba Island (MN3). The lower Nyabihoko site featured Katoma (LN1), Kateko Island (LN2), and Omukirimirire (LN3) stations. The geographical locations of the sampling stations in Lake Nyabihoko are shown in Table 1.

Water sampling and preparation

A total of 54 water samples were collected monthly from nine stations during the wet season (March–May 2023) and the dry season (June–August 2023). Before collection, bottles were labeled and rinsed four times with lake water to remove any potential contamination. Sample collection using polythene plastic bottles took place from 6:00 am to noon. The bottles were submerged at a depth

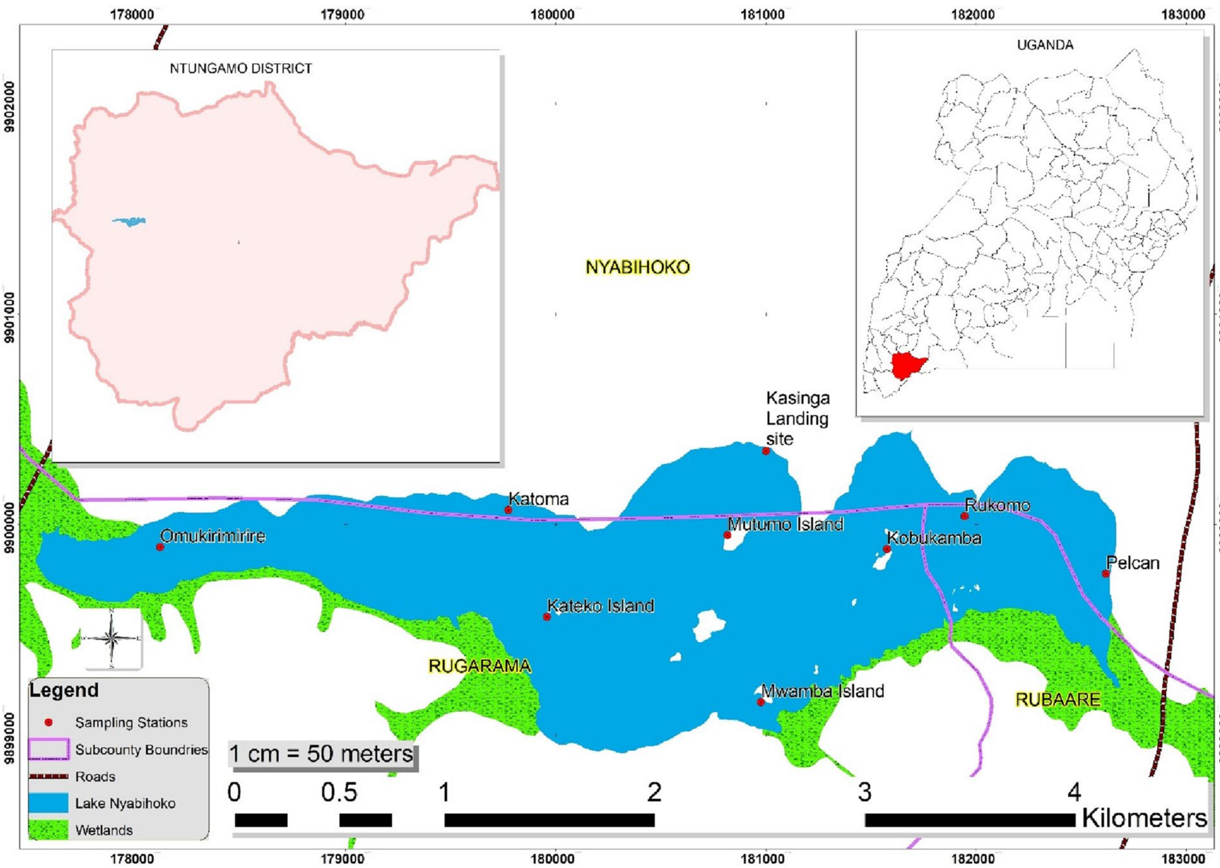

Fig. 1 Map of the study area, along with sampling stations

Table 1 Sampling site location

Study site	Station code	Station name	Location		Description
			Latitude	Longitude	
Upper Nyabihoko	UN1	Pelcan	0° 54′ 20.58″ S	30° 08′ 54.92″ E	This lake section receives runoff from Millennium Pelcan Beach and the hotel
	UN2	Kobukamba	0° 54′ 16.75″ S	30° 08′ 21.25″ E	The station is near the developed island
	UN3	Rukomo	0° 54′ 11.69″ S	30° 08′ 33.22″ E	This is located adjacent to a wetland area with limited human activities
Middle Nyabihoko	MN1	Kasinga Landing site	0° 54′ 01.58″ S	30° 08′ 02.68″ E	The station is near the landing site where fishing canoes are anchored
	MN2	Mutumo Island	0° 54′ 14.58″ S	30° 07′ 56.73″ E	The station is near the developed island
	MN3	Mwamba Island	0° 54′ 40.42″ S	30° 08′ 01.85″ E	The station is near the developed island and cleared lakeshore
Lower Nyabihoko	LN1	Katoma	0° 54′ 10.65″ S	30° 07′ 23.03″ E	Cattle grazing and crop cultivation with irrigation
	LN2	Kateko Island	0° 54′ 27.22″ S	30° 07′ 28.96″ E	The station is near the intact island
	LN3	Omukirimirire	0° 54′ 16.34″ S	30° 06′ 29.51″ E	This is located adjacent to farmlands for livestock

of 0.3 m. Samples were transported in an ice-cool box to the National Water and Sewage Corporation (NWSC) Laboratory in Mbarara within 24 h for further analysis. In the laboratory, samples were stored at 4 °C until analysis to ensure accuracy. All parameters were determined according to Standard Methods for the Examination of Water and Wastewater [21].

The water temperature, dissolved oxygen, EC, and pH were measured in situ using a portable Hach (HQ4Od) Multimeter kit. Turbidity was also measured using a Hach 2100P turbidity meter, and results were recorded in Nephelometric turbidity units (NTU). Total alkalinity and calcium were determined by titration. Total hardness was determined by the calculation method by computing it from the results of separate calcium and magnesium using the formula;

$$Hardness\ (CaCO3/L) = 2.497Ca + 4.118\ Mg \quad (1)$$

The atomic absorption spectrometric method was used to determine magnesium, and phosphate was determined using the persulfate digestion method. The colorimetric approach was used to analyze chloride.

Water quality index estimation

The water quality index (WQI) for this study was calculated using the WHO [34] standard values for drinking water. The measured mean value of each parameter at a given station/month/season under study was used. The weighted arithmetic index approach was used to determine the WQI because it is user-friendly and combines data from numerous water quality parameters into a mathematical equation that depicts the water's ecological state [14]. It also shows the significance of each parameter in evaluating and controlling water quality and can be used to define whether a water source is fit for human use.

The WQI was computed through three steps. Step 1: Calculate the unit weight (Wn) factors for each parameter by using the formula by Saturday et al. [23]

$$Wn = K/Sn \quad (2)$$

where Wn is the unit weight for the nth parameter. The unit weight (Wn) of each parameter is proportional to the weightage of each parameter; n is the number of water quality parameters. Sn is the standard permissible value for the nth parameter and K is the proportionality constant. Step 2 Calculate the sub-index (Qn) value using the formula.

$$Qn = [(Vn - Vi) \div (Vs - Vi)] \times 100 \quad (3)$$

where Vn is the observed value and Vi is the ideal value. Step 3 Combining step 1 and step 2, WQI is calculated as

$$WQI = \Sigma QnWn/\Sigma Wn \quad (4)$$

Table 2 Water quality index classification

WQI	Water quality status	Possible use
0–25	Excellent	Drinking, irrigation, and industrial use
26–50	Good	Drinking, irrigation, and industrial use
51–75	Poor	Irrigation and industrial use
76–100	Very poor	Irrigation
Above 100	Unfit for human consumption or fish culture	Requires proper treatment before use

Source: Siriwardhana et al. [24]

where Qn is the quality rating for the n^{th} water quality parameter and Wn is the unit weight for the nth water quality parameter.

Statistical analysis

The data were entered into Microsoft Excel version 2013. It was then imported into Minitab 19 for statistical analyses and inference. In Minitab, the data were first tested for parametric assumptions underlying the corresponding statistical tests, including normality and constant error variance. To assess variation in physicochemical parameters in water across the different sampling stations, a one-way analysis of variance (ANOVA) was conducted. In cases of significant variation in the stations' physicochemical parameters, Tukey's post hoc test for multiple comparisons was used to identify the least statistically significant differences between station pairs. To analyze seasonal variation, a two-sample independent t-test was conducted for each physicochemical parameter. Based on the water quality categories by Siriwardhana et al. [24], water quality indices (WQI) were calculated using World Health Organisation (WHO) standards [34]. The mean values of the stations under investigation were used for each variable (Table 2).

Results

Spatial variations in physical water quality parameters are summarized in Table 3. Kasinga Landing site recorded the lowest temperature of 23.27 ± 1.11 °C, while Katoma recorded the highest of 24.28 ± 1.30 °C. The electrical conductivity range of 389.3 ± 28.7 µS/cm at Omukirimirire to 431.3 ± 46.3 µS/cm at Rukomo. The mean turbidity values ranged between 30.00 NTU at Rukomo and 39.88 NTU at Kateko Island. TDS ranged from 194.75 ± 11.05 mg/L to 208 ± 16.39 mg/L at Katoma and Rukomo. Analysis of variance showed that the mean values for all the measured physical parameters did not differ significantly ($p > 0.05$) among the sampling stations (Table 3).

Table 3 Spatial distribution of physical water quality parameters in the study area

Sampling stations	Physical parameters (mean ± SD)			
	Temperature (°C)	Electrical conductivity (μS/cm)	Turbidity (NTU)	Total dissolved solids (mg/L)
Pelcan	23.68 ± 1.91	412.30 ± 32.40	39.58 ± 23.48	205.75 ± 13.89
Kobukamba	23.73 ± 1.85	408.50 ± 29.60	28.87 ± 7.44	195.33 ± 18.18
Rukomo	23.87 ± 2.09	431.30 ± 46.30	30.00 ± 11.05	208.25 ± 16.39
Kasinga Landing site	23.27 ± 1.11	404.30 ± 40.20	30.80 ± 7.24	202.20 ± 25.10
Mutumo Island	24.08 ± 1.26	393.30 ± 28.40	34.77 ± 11.90	196.25 ± 12.96
Mwamba Island	24.05 ± 1.44	399.58 ± 19.69	31.38 ± 7.63	200.83 ± 14.11
Katoma	24.28 ± 1.30	401.20 ± 40.50	38.93 ± 19.12	194.75 ± 11.05
Kateko Island	24.14 ± 1.43	392.90 ± 25.10	39.88 ± 19.59	196.17 ± 13.58
Omukirimirire	24.26 ± 1.29	389.30 ± 28.70	39.16 ± 18.09	195.50 ± 10.31
***F*-value**	**0.26**	**0.89**	**0.56**	**0.62**
***p*-value**	**0.974**	**0.535**	**0.805**	**0.757**

Table 4 Spatial distribution of chemical parameters in the study area

Sampling stations	Chemical parameters (mean ± SD)								
	DO	pH	Hardness	Alkalinity	Chloride	Calcium	Magnesium	Phosphates	Nitrates
Pelcan	6.76 ± 0.31	8.04 ± 0.23	181.2 ± 24.6	110.17 ± 11.44	3.65 ± 2.63	75.84 ± 10.16	47.94 ± 4.64	2.62 ± 1.99	0.31 ± 0.23
Kobukamba	6.57 ± 0.53	8.10 ± 0.23	194 ± 19.90	108.67 ± 9.67	2.84 ± 1.79	78.95 ± 9.72	51.51 ± 4.64	1.84 ± 0.57	0.28 ± 0.18
Rukomo	6.33 ± 0.56	7.95 ± 0.23	200 ± 29.6	117.25 ± 17.85	3.05 ± 2.35	77.28 ± 10.49	49.1 ± 4.64	1.78 ± 0.88	0.31 ± 0.29
Kasinga	6.45 ± 0.51	8.03 ± 0.22	209.5 ± 17.21	105.5 ± 11.45	3.09 ± 2.18	83.00 ± 7.53	53.49 ± 4.64	1.93 ± 0.57	0.27 ± 0.19
Mutumo Island	6.60 ± 0.39	8.17 ± 0.23	176.67 ± 13.84	106.25 ± 13.13	3.13 ± 1.76	73.34 ± 7.92	48.01 ± 4.64	2.28 ± 1.16	0.40 ± 0.21
Mwamba Island	6.42 ± 0.44	8.09 ± 0.25	187.5 ± 12.01	109.25 ± 9.67	3.03 ± 1.97	74.92 ± 4.75	49.1 ± 4.64	1.98 ± 0.70	0.31 ± 0.22
Katoma	6.73 ± 0.44	8.04 ± 0.25	165.2 ± 29.8	105.83 ± 21.78	2.92 ± 1.68	75.2 ± 29.9	41.81 ± 4.64	2.69 ± 1.84	0.33 ± 0.21
Kateko Island	6.06 ± 0.51	8.1 ± 0.19	173 ± 27.7	96.83 ± 18.62	3.43 ± 2.26	72.72 ± 13.99	46.57 ± 4.64	2.88 ± 2.03	0.34 ± 0.21
Omukirimirire	6.51 ± 0.38	7.99 ± 0.20	179.7 ± 34.8	104.33 ± 12.50	3.45 ± 2.10	70.01 ± 10.92	42.73 ± 4.64	2.58 ± 1.68	0.30 ± 0.23
***F*-value**	**1.29**	**0.09**	**1.96**	**0.84**	**0.1**	**0.46**	**2.65**	**0.53**	**0.19**
***p*-value**	**0.271**	**0.999**	**0.074**	**0.576**	**0.999**	**0.875**	**0.018**	**0.826**	**0.991**

Spatial variations in chemical water quality parameters are summarized in Table 4. The mean DO ranges from 6.06 ± 0.51 mg/L to 6.76 ± 0.31 mg/L at Kateko Island and Pelcan, respectively. For pH, the highest mean value of 8.17 ± 0.23 was recorded at Mutumo Island, while the lowest mean value of 7.95 ± 0.23 was recorded at Rukomo. Total hardness varied between 165.2 ± 29.8 and 209.5 ± 17.21 mg/L at Katoma and Kasinga Landing sites, respectively. The highest mean alkalinity of 117.25 ± 17.85 mg/L was recorded at Rukomo, and the lowest mean alkalinity of 96.83 ± 18.62 mg/L was recorded at Kateko Island (Table 4). The mean chloride values ranged from 2.84 ± 1.79 to 3.65 ± 2.63 mg/L at Kobukamba and Pelcan, respectively. The highest mean calcium of 83.00 ± 7.53 mg/L was recorded at the Kasinga Landing site, and the lowest mean calcium of 70.01 ± 10.92 mg/L was recorded at Omukirimirire. The highest mean phosphates of 2.88 ± 2.03 mg/L were recorded at Kateko, and the lowest mean phosphates of 1.84 ± 0.57 mg/L were at Kobukamba. The mean concentration of nitrates varied between 0.27 ± 0.19 mg/L at the Kasinga Landing site and 0.40 ± 0.21 mg/L at Mutumo Island. One-way ANOVA showed that the mean values of the measured chemical parameters were not significantly different across the sampling stations ($p > 0.05$), except for magnesium (Table 4). Tukey's pairwise post hoc comparisons indicated that the sampling stations Kasinga Landing site, Kateko Island, Kobukamba, Mutumo Island, Mwamba Island, Pelcan, and Rukomo did not differ significantly in magnesium concentration. In contrast, the Kasinga Landing site recorded a significantly higher magnesium concentration than both Katoma and Omukirimirire (Table 5).

Table 5 Tukey's pairwise comparisons for magnesium concentration among the different sampling stations

Sampling stations	Mean ± SD
Kasinga Landing site	53.49 ± 5.14[a]
Kateko Island	46.57 ± 7.77[ab]
Katoma	41.81 ± 7.20[b]
Kobukamba	51.51 ± 4.92[ab]
Mutumo Island	48.01 ± 2.97[ab]
Mwamba Island	49.10 ± 3.53[ab]
Omukirimirire	42.73 ± 6.19[b]
Pelcan	47.94 ± 5.78[ab]
Rukomo	49.10 ± 5.53[ab]

Means that share similar superscript letters are not significantly different

The mean water temperature for the dry season (23.62 ± 0.13 °C) was less than that of the wet season (24.24 ± 0.37 °C). However, further analysis showed that the mean measured temperatures were not significantly different between sampling seasons ($p > 0.05$). The mean electrical conductivity for the dry season (386.5 ± 3.7 μS/cm) was less than that of the wet season (420.8 ± 6.8 μS/cm). Statistically, the mean EC values significantly differed between sampling seasons ($p < 0.05$). The mean turbidity for the dry season (39.7 ± 3.7 NTU) was higher than that of the wet season (29.91 ± 0.78 NTU), and the mean turbidity values were significantly different between sampling seasons ($p < 0.05$). The mean concentration of TDS in the wet season (206.0 ± 3.3 mg/L) was higher than in the dry season (192.89 ± 1.9 mg/L). Statistically, the mean TDS values differed significantly between sampling seasons ($p < 0.05$) (Fig. 2).

Between seasons, DO values were higher in the dry season (6.83 ± 0.05 mg/L) than they were in the wet season (6.16 ± 0.08 mg/L). The wet season recorded a higher pH value (8.06 ± 0.14) than the dry season (8.05 ± 0.04). The mean hardness in the wet season (187 ± 4.5 mg/L) was higher than that of the dry season (183.3 ± 5.6 mg/L). The mean alkalinity in the wet season (108.8 ± 2.6 mg/L) was slightly higher than that of the dry season (105.5 ± 2.9 mg/L). The mean chloride concentration in the wet season (1.82 ± 0.07 mg/L) was lower than that of the dry season (4.53 ± 0.38 mg/L). The mean calcium concentration in the wet season (76.8 ± 2.6 mg/L) was higher than that of the dry season (74.6 ± 2.4 mg/L).

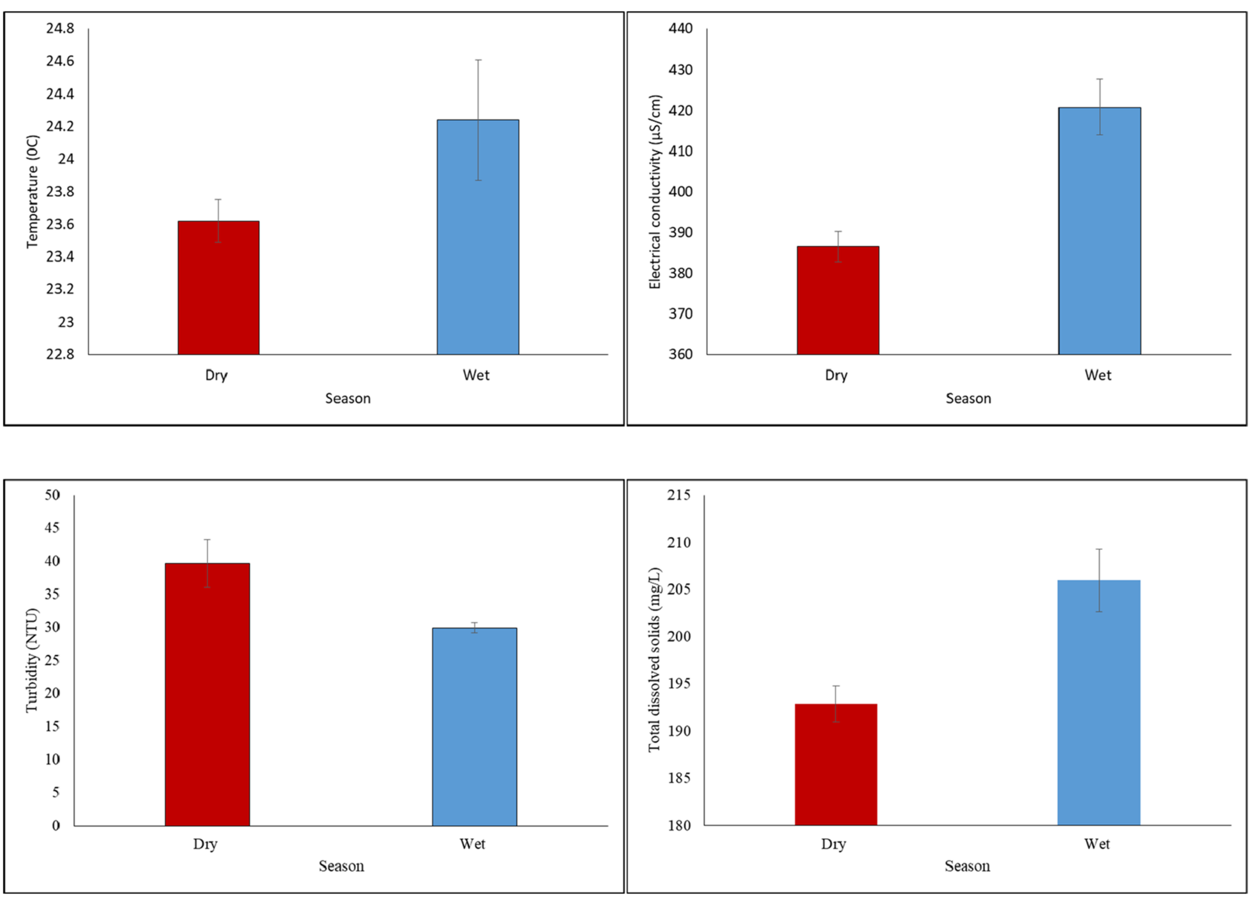

Fig. 2 Seasonal variations in physical water quality parameters

The mean concentration of magnesium in the wet season (47.43 ± 0.94 mg/L) was slightly lower than that of the dry season (48.18 ± 1.5 mg/L). The mean concentration of phosphates in the wet season (1.61 ± 0.06 mg/L) was lower than that of the dry season (2.97 ± 0.31 mg/L). The mean concentration of nitrates in the wet season (0.29 ± 0.02 mg/L) was lower than in the dry season (0.34 ± 0.05 mg/L).

Statistically, the mean values for DO, chlorides, and phosphates significantly differed between sampling seasons ($p < 0.05$) (Table 6).

The water quality index for the study area was computed using nine parameters due to their significance. These include DO, EC, TDS, pH, hardness, chloride, calcium, phosphates, and nitrates. WHO threshold values for drinking water were used to compute the water quality index (Table 7). The WQI values for the study area ranged from 82.9 to 88.8 at the Katoma and Kateko Island sampling stations, respectively, with an overall mean value of 86.1. All sampling stations recorded very poor water quality; thus, water can be used for irrigation (Table 8).

Across the study months, WQI values ranged from 61.1 to 96 in March and May 2023, respectively, with an overall mean of 79. Most of the sampling months recorded very poor water quality, except for March, which also recorded poor water quality (Table 9). Between seasons, the dry season recorded the lowest WQI of 76.8,

Table 6 Seasonal variations in chemical water quality parameters in the study area

Parameter	Sampling season	Mean ± SD	*T*-value	DF	*p*-value
DO	Dry	6.83 ± 0.05	7.48	52	0.000
	Wet	6.16 ± 0.08			
pH	Dry	8.05 ± 0.04	−0.06	52	0.954
	Wet	8.06 ± 0.14			
Hardness	Dry	183.3 ± 5.6	−0.52	52	0.607
	Wet	187.0 ± 4.5			
Alkalinity	Dry	105.5 ± 2.9	−0.83	52	0.409
	Wet	108.8 ± 2.6			
Chloride	Dry	4.53 ± 0.38	7.07	52	0.000
	Wet	1.82 ± 0.07			
Calcium	Dry	74.6 ± 2.4	−0.60	52	0.550
	Wet	76.8 ± 2.6			
Magnesium	Dry	48.18 ± 1.5	0.43	52	0.669
	Wet	47.43 ± 0.94			
Phosphates	Dry	2.97 ± 0.31	4.29	52	0.000
	Wet	1.61 ± 0.06			
Nitrates	Dry	0.34 ± 0.05	0.90	52	0.371
	Wet	0.29 ± 0.02			

Table 7 Relative weight of parameters for WQI determination with WHO standards

Parameters	WHO standards (Sn)	Relative weight (Wn)
Temperature	25	0.10327545
Dissolved oxygen	6	0.43031438
Electrical conductivity	1500	0.00172126
Total dissolved solids	600	0.00430314
pH	8.5	0.30375133
Chloride	250	0.01032755
Calcium	300	0.00860629
Magnesium	30	0.08606288
Nitrates	50	0.05163773

Table 8 Change in the WQI values across the study stations

S/N	Sampling stations	WQI	Status
1	Pelcan	84.3	Very poor
2	Kobukamba	87.5	Very poor
3	Rukomo	85.2	Very poor
4	Kasinga Landing site	87.1	Very poor
5	Mutumo Island	87.9	Very poor
6	Mwamba Island	87.5	Very poor
7	Katoma	82.9	Very poor
8	Kateko Island	88.8	Very poor
9	Omukirimirire	83.6	Very poor
Overall WQI		**86.1**	Very poor

Table 9 Change in the WQI values during sampling months

S/N	Sampling months	WQI	Status
1	March	61.1	Poor
2	April	85.8	Very poor
3	May	96.0	Very poor
4	June	76.2	Very poor
5	July	75.7	Very Poor
6	August	78.9	Very poor
Overall WQI		**79.0**	Very poor

Table 10 Seasonal change in the WQI values

S/N	Sampling seasons	WQI	Status
1	Wet season	81.0	Very poor
2	Dry season	76.8	Very poor
Overall WQI		**78.9**	Very poor

indicating very poor water quality. During the wet season, a WQI value of 81 falls under the poor water quality category (Table 10).

Discussion

Spatial variability of physicochemical water parameters

Contrary to the hypothesis, the results showed no significant differences in the physical parameters across sampling stations. This may be attributed to the potentially homogeneous human activities conducted in all sampling stations and uniform hydrological events, which result in similar impacts on water quality [19]. Previous studies [19, 20, 33] reported that variability in factors such as human activities, biological activity, precipitation, and runoff, among others, would cause differences in water quality across locations. Physical parameters can vary from one region to another, depending on local environmental conditions, land use, and waterbody characteristics [35]. However, the observed lack of significant difference may be attributed to a lack of significant variations in human impact through waste disposal and vegetation decline, which would otherwise lead to higher values of physical water parameters. Hence, there is no significant variation among the different sampling stations.

Analysis of variance showed that chemical parameters (alkalinity, pH, hardness, chloride, calcium, phosphates, dissolved oxygen, and nitrates) were not significantly different among the sampling stations. This might be because these areas experience similar anthropogenic interferences, which makes the impact magnitude uniform [18, 19]. Secondly, the locational proximity may weaken their geospatial variability and, hence, lower the likelihood of water quality differences among the sampling stations. However, the mean magnesium concentration differed significantly among the sampling stations,the Kasinga Landing site recorded the highest concentrations, followed by Katoma and Omukirimirire. This variation in magnesium levels could be attributed to potential natural phenomena, such as groundwater discharge into the lake [8], rather than to human factors. For example, it has been reported that the magnesium concentration in water can vary significantly based on environmental and geological factors, including groundwater from aquifers, which can have varying levels of magnesium depending on the mineral composition of the surrounding soil and rocks [12]. For example, regions with dolomite and magnesium-rich limestone can have groundwater with higher magnesium content [5], leading to variability in water magnesium levels. The Kasinga Landing site could have natural magnesium sources, such as soil, which could release magnesium into water through soil erosion.

Seasonal variability of physicochemical water parameters

This study found that most water physicochemical parameters differed significantly across months, with the dry months recording higher concentrations than the wet months. This may be attributed to several environmental factors, such as precipitation, lake circulation, and groundwater interactions that affect physical parameters such as temperature, turbidity, and sediment distribution, and human factors like agricultural cycles, which affect water quality through increased nutrient runoff and higher pollution loads [19]. Changes in these parameters are often driven by seasonal variations, weather patterns, and anthropogenic activities [19, 20]. The different months of the year exhibit variations in environmental and weather conditions, such as temperature, precipitation, runoff, and evapotranspiration [17], which in turn affect hydrological processes and water quality. Saturday et al. [22] reported similar findings in a study on Lake Mulehe in South-Western Uganda, citing timely changes in weather conditions that affect the activity levels of aquatic organisms, such as algae, bacteria, and other plants; the decomposition rate of organic materials; and nutrient cycles.

Although this study hypothesized that seasonality would significantly influence physicochemical parameters, it found that the mean values for total dissolved solids and electrical conductivity were significantly higher in the wet than in the dry season. This might be attributed to erosion and deposition of materials during the wet season, aquatic vegetation, and colloidal particle accumulation, leading to more turbid water than in the dry season [28]. This study further established that the mean turbidity during the dry season was higher than during the wet season, due to lower water levels [28]. Other parameters, including temperature, were not significantly different between seasons, although the dry season recorded lower temperatures than the wet season. These outcomes may be most controlled by the natural environment rather than by human activities' impacts on water. Although human activities enhance pollution, resulting in lower water quality, the level of human impacts in the study area may not be significant, resulting in lower water quality; the level of human impacts in the study area may not be significant enough to warrant significant differences among the seasons. These findings contradict previous studies [22, 36], which reported significant variations between the dry and wet seasons in Lakes Mulehe and Naivasha, respectively.

The findings of this study showed that the mean values of water parameters, including pH, hardness, alkalinity, calcium, magnesium, and nitrates, were not significantly different across seasons. Seasonality can directly or indirectly influence water quality through its effects on temperature, precipitation, and biological and human activities [29]. Such impacts can subsequently affect local environmental conditions, land use, and water body characteristics. The lack of significant variation in chemical water parameters indicates that seasonal variations in attributes such as temperature, precipitation (runoff and evaporation), biological activity, and human activities were perhaps not sufficiently concentrated or intensified to warrant significant impacts on water quality. These findings contradict the observations of Umer et al. [30], who reported higher levels of chemical parameters, such as chlorides, during the wet season, attributed to frequent runoff and evaporation. In addition, the areas do not appear to have sources discharging higher levels of these chemical elements, resulting in significant concentrations in the water. Previous studies by Tyagi and Malik [29] and Verma and Saksena [31] on the concentrations of such elements in water often depend on the source, e.g., rocks or waste disposed of in areas linked to the water source.

Higher levels of turbidity may be attributed to high biological activity, including the decomposition of organic materials and runoff from agricultural fields into the lake [9, 16]. Higher magnesium levels above the permissible limits may be attributed to potential geological sources, such as ground aquifers supplying higher magnesium levels from lower rock layers [2]. Similar observations were made by Bwire et al. [4], who also reported exceeding the World Health Organisation thresholds for turbidity and magnesium.

Water quality index estimation

The study found that all sampling stations recorded very poor water quality, which cannot be used for irrigation unless treated. All sampled stations recorded very poor WQI due to low water quality, resulting from variable contaminant levels in the areas. Waste materials that are deposited in water result in lower-quality water [13]. The WQI scores generally indicate that Mutumo, Mwamba, and Kateko have very high WQI scores, indicating poor water quality. This implies that such degraded stations with contaminated water resources cannot support diverse aquatic life as they have a reduced ability to harbour biodiversity [11]. Soman et al. [25] reported that the continuous degradation of water resources, including rivers and lakes, lowers water quality, thereby reducing drinking water availability and harming aquatic biodiversity. It was further noted that the WQI was high during the wet season, likely due to increased water pollution from runoff. These findings concur with previous studies, such as Kiwanuka et al. [6] and Teshome [26], which reported seasonal variations in WQI, although the wet-season studies recorded higher WQI values.

Conclusion

The measured physical water parameters showed no variation among the sampling stations. This indicates that the physical water quality is relatively consistent throughout the lake. The concentrations of all measured physical parameters are significantly affected by seasonal variations, except for temperature, which did not vary considerably across sampling seasons. The tested chemical water quality parameters, except for magnesium, showed no variation among the sampling stations. Hardness, alkalinity, and pH showed higher mean values in the wet season, while other parameters, such as dissolved oxygen, chloride, magnesium, phosphates, and nitrates, were higher during the dry season. Based on the WQI results, the lake's water quality is classified as very poor for drinking; therefore, it can be used for irrigation. However, the study emphasises the need for local authorities to regularly monitor human activities in the Lake Nyabihoko sub-catchment to maintain physicochemical parameters within acceptable limits.

However, this study has certain limitations that should be considered when interpreting the results. Excluding microbiological indicators, such as *E. coli*, restricts the assessment of fecal contamination and related health risks. Similarly, focusing solely on physicochemical parameters may overlook pollutants such as heavy metals and other emerging contaminants. Furthermore, the 6-month monitoring period limits understanding of long-term trends and broader seasonal dynamics. Future research should therefore include microbiological analyses, extend monitoring durations, and cover larger areas to gain a more complete understanding of water quality in tropical agricultural catchments.

Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Atuhaire Abraham. The first draft of the manuscript was written by Atuhaire Abraham and all authors commented on previous versions of the manuscript.

Funding

The authors received no specific funding for this work.

Data availability

Upon reasonable request, the corresponding author will provide the data collected.

Declarations

Competing interests

The authors declare that they have no competing interests.

Received: 30 April 2025 Accepted: 3 November 2025
Published online: 02 February 2026

References

1. Angiro C, Abila PPO, Omara T. Effects of industrial effluents on the quality of water in Namanve stream, Kampala Industrial and Business

Park, Uganda. BMC Research Notes. 2020:4–9. https://doi.org/10.1186/s13104-020-05061-x.
2. Atwebembeire J, Bazira J, Kagoro G, Yatuha J, Andama M, Lejju JB. The physico-chemical quality of streams and channels draining into River Rwizi, South Western Uganda. 2018.
3. Bhateria R, Jain D. Water quality assessment of lake water: a review. Sustain Water Resour Manag. 2016;2:161–73.
4. Bwire G, Sack DA, Kagirita A, Obala T, Debes AK, Ram M, et al. The quality of drinking and domestic water from the surface water sources (lakes, rivers, irrigation canals and ponds) and springs in cholera-prone communities of Uganda: an analysis of vital physicochemical parameters. BMC Public Health. 2020;20(1):1128. https://doi.org/10.1186/s12889-020-09186-3.
5. Fellows C, Al-Hamzah A, Ihm S. Pathways to magnesium supplementation of drinking water: the saline water conversion corporation experience. Available at SSRN. 2023;4610479:16. https://doi.org/10.1016/j.ceja.2023.100574.
6. Kiwanuka M, Mutanda HE, Niyomukiza JB, Nakasagga E. Assessment of suitability of drinking water from the springs in urban slums of Kampala. Environ Challenges. 2023;10:100667.
7. Kumar R, Grover AS, Wats M. Assessment of water quality status of lakes in Haryana, India. Int J Recent Sci Res. 2018;9(7):27831–5.
8. Larroquette B. Annual performance report | Uganda (Issue February 2020). 2020.
9. LeChevallier MW, Au K-K. Water treatment and pathogen control. Iwa Publishing; 2004.
10. Li X, Tsigaris P. The global value of freshwater lakes. Ecol Lett. 2024;27(2):e14388. https://doi.org/10.1111/ele.14388.
11. Lumb A, Sharma TC, Bibeault J-F. A review of genesis and evolution of water quality index (WQI) and some future directions. Water Qual Expo Health. 2011;3(1):11–24. https://doi.org/10.1007/s12403-011-0040-0.
12. Mishra RK. Fresh water availability and its global challenge. British Journal of Multidisciplinary and Advanced Studies. 2023;4(3):1–78.
13. Mshelia YM, Lawan DM, Arhyel M, Inuwa J. Physicochemical analysis and water quality assessment of selected location in Maiduguri metropolis using weighted arithmetic water quality index. FUDMA JOURNAL OF SCIENCES. 2023;7(4):147–51.
14. Patel DD, Mehta DJ, Azamathulla HM, Shaikh MM, Jha S, Rathnayake U. Application of the weighted arithmetic water quality index in assessing groundwater quality: a case study of the South Gujarat region. Water. 2023;15(19):3512.
15. Paugy D, Levêque C, Otero O. The inland water fishes of Africa: diversity, ecology and human use. IRD Éditio; 2017.
16. Paul MJ, Meyer JL. Streams in the urban landscape. Annu Rev Ecol Evol Syst. 2001;32(1):333–65.
17. Paulding C, Randhir TO. An ecohydrological assessment of potential impacts of climate change on the herpetofauna. Sustainability and Climate Change. 2021;14(1):22–34. https://doi.org/10.1089/scc.2020.0027.
18. Ramachandra TV. Freshwater Ecology: Concepts and Environmental Applications of Limnology. Curr Sci. 2020;119(8):1376–7.
19. Raymond PA, Hartmann J, Lauerwald R, Sobek S, McDonald C, Hoover M, et al. Global carbon dioxide emissions from inland waters. Nature. 2013;503(7476):355–9.
20. Reynolds CS. The ecology of phytoplankton. Cambridge University Press; 2006.
21. Rice EW, Baird RB, Eaton AD. Standard methods for the examination of water and wastewater. ed-23rd. Washington DC: American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF); 2017.
22. Saturday A, Kangume S, Bamwerinde W. Content and dynamics of nutrients in the surface water of shallow Lake Mulehe in Kisoro District, South–western Uganda. Appl Water Sci. 2023;13(7):150. https://doi.org/10.1007/s13201-023-01953-y.
23. Saturday A, Lyimo TJ, Machiwa J, Pamba S. Spatio-temporal variations in physicochemical water quality parameters of Lake Bunyonyi, Southwestern Uganda. SN Appl Sci. 2021;3(7):684.
24. Siriwardhana KD, Jayaneththi DI, Herath RD, Makumbura RK, Jayasinghe H, Gunathilake MB, et al. A simplified equation for calculating the water quality index (WQI), Kalu River, Sri Lanka. Sustainability. 2023;15(15):15. https://doi.org/10.3390/su151512012.
25. Soman J, Kalimuthu S, Subramanian A, Valliraj G, Kumar K. Impact assessment of water quality in Sulur lake based on physico-chemical parameters. Environ Eng Manag J. 2022. https://doi.org/10.30638/eemj.2022.167.
26. Teshome FB. Seasonal water quality index and suitability of the water body to designated uses at the eastern catchment of Lake Hawassa. Environ Sci Pollut Res. 2020;27(1):279–90. https://doi.org/10.1007/s11356-019-06794-4.
27. Turibamwe E, Wangalwa R. A comparative study of two biological monitoring systems in assessing water quality: a case of river Birira, Sheema district, Uganda. Water Conserv Manag. 2020;4:7–14.
28. Turyahabwe R, Turyabanawe GL, Andama E, Othieno T, Wamono E. Spatio-temporal variations in water quality and fish assemblages in Odoponyi seasonal stream as a response to disturbance from selected agricultural landscapes in Tororo, Uganda. J Appl Sci Environ Manage. 2023;27(9):9. https://doi.org/10.4314/jasem.v27i9.2.
29. Tyagi D, Malik DS. Assessment of physico-chemical parameters and water quality index of Ram-Ganga reservoir at Kalagarh (Uttarakhand). Int J Current Res Life Sci. 2018;7:1234–9.
30. Umer A, Assefa B, Fito J. Spatial and seasonal variation of lake water quality: Beseka in the Rift Valley of Oromia region, Ethiopia. Int J Energy Water Resour. 2020;4(1):47–54. https://doi.org/10.1007/s42108-019-00050-8.
31. Verma AK, Saksena DN. Assessment of water quality and pollution status of Kalpi (Morar) River, Gwalior, Madhya Pradesh: with special reference to conservation and management plan. Asian J Exp Biol Sci. 2010;1(2):419–29.
32. Walekhwa AW, Ntaro M, Kawungezi P, Nimusiima E, Achangwa C, Mulogo Musoke D, Mugema E. Water quality of improved water sources and associated factors in Kibuku District, Eastern Uganda. Sustain Water Resources Manage. 2022;8(50):1–13. https://doi.org/10.1007/s40899-022-00604-5.
33. Wetzel RG. Limnology: lake and river ecosystems. Gulf Professional Publishing; 2001.
34. World Health Organization, WHO. (2022). Guidelines for drinking-water quality: incorporating the first and second addenda (Fourth Edition). World Health Organization. https://books.google.com/books?hl=en&lr=&id=x3RyEAAAQBAJ&oi=fnd&pg=PR2&dq=WHO,+W.+H.+(2022).+Guidelines+for+drinking-water+quality:+Incorporating+the+first+and+second+addenda.+&ots=73SojtMPc7&sig=_lw4SuBO_W3lTzB2FK8cSLNl5EU.
35. Yang C, Yang P, Geng J, Yin H, Chen K. Sediment internal nutrient loading in the most polluted area of a shallow eutrophic lake (Lake Chaohu, China) and its contribution to lake eutrophication. Environ Pollut. 2020;262:114292.
36. Yongo E, Agembe SW, Manyala JO, Mutethya E. Assessment of the current trophic state and water quality of Lake Naivasha, Kenya using multivariate techniques. Lakes & Reservoirs: Science, Policy and Management for Sustainable Use. 2023;28(1):e12422. https://doi.org/10.1111/lre.12422.

Publisher's Note