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Water quality characteristics of Lake Tanganyika in Burundi and Lake Victoria in Uganda

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ABSTRACT

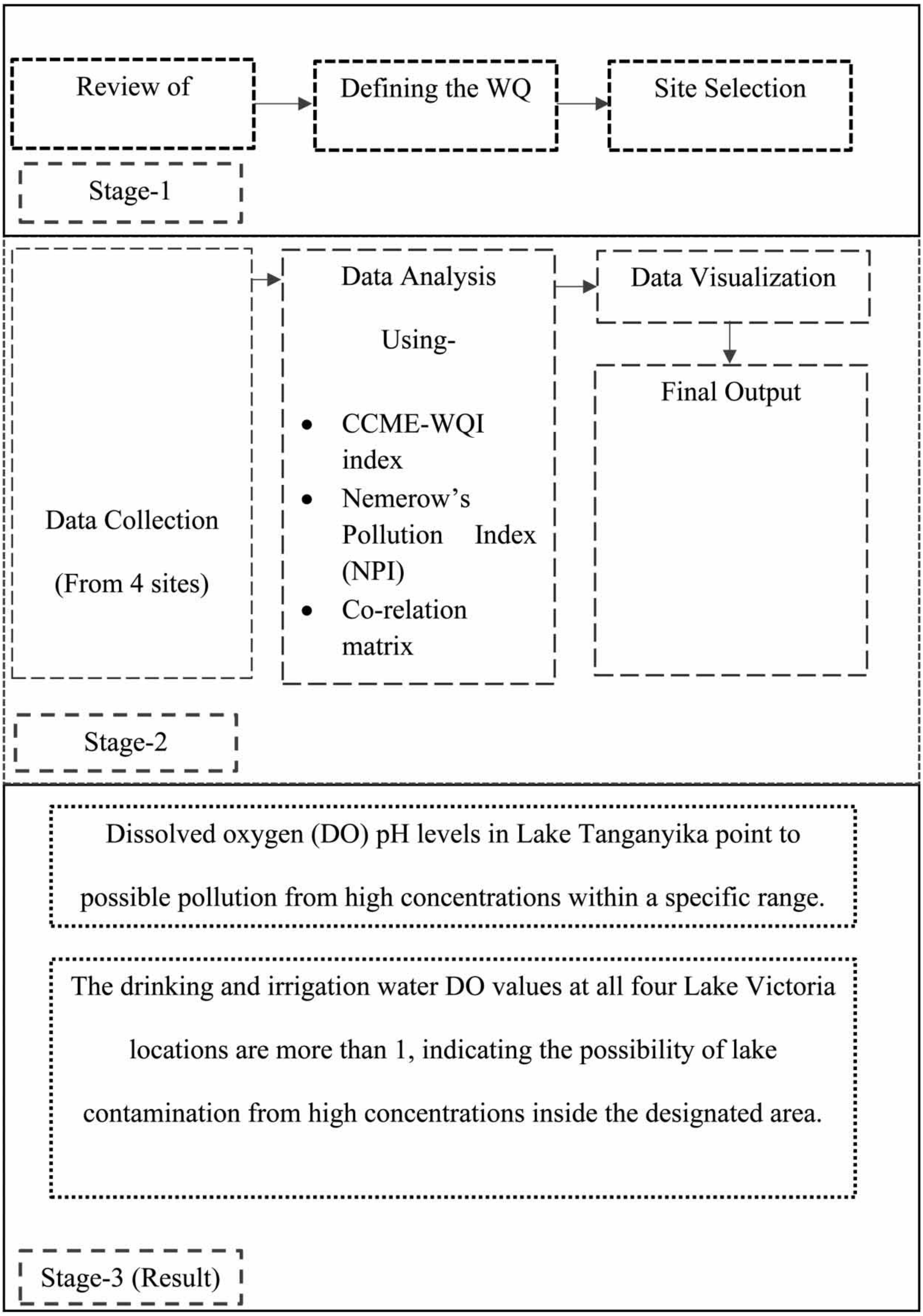
Water is necessary for all biological life and industrial, municipal, agricultural, and residential processes. It is challenging to imagine living without water. Unfortunately, human and natural activities are causing the sources of useable water to become contaminated. Despite having enormous and unique natural water resources, Africa has experienced unprecedented environmental pollution because of the abuse of these resources. Additionally, population increase and urbanization brought by technological advancements have significantly worsened water pollution in Africa. The significant causes of pollution for surface waterways are untreated effluents released into the environment by humans and machines. It is still being determined if the emission goals set by several African countries for surface water discharge have been fulfilled. Wells and boreholes are essential sources of drinking water for Africans. However, because of their location in sterile areas, the natural water quality of these groundwater sources could be better. The primary sources of water pollution in Africa include agricultural activities, mining, roadside discharges, trash from companies and workshops, landfills, and e-waste. Oil leaks are a severe problem in oil-rich African countries. Lake Tanganyika is East Africa's most significant freshwater reservoir, while Lake Victoria is the second-deepest lake in the world.

Key words: correlation, Lake Tanganyika, Lake Victoria, Nemerow's pollution index, water quality index

HIGHLIGHTS

- Evaluate scientific findings on water quality in the lakes on the African continent.
- Identify the principal contaminants of surface water.
- Pearson Correlation is used to identify the relationship among the water parameters.

GRAPHICAL ABSTRACT



Dissolved oxygen (DO) pH levels in Lake Tanganyika point to possible pollution from high concentrations within a specific range.

The drinking and irrigation water DO values at all four Lake Victoria locations are more than 1, indicating the possibility of lake contamination from high concentrations inside the designated area.

INTRODUCTION

Water quality is the main factor restricting aquatic ecosystems' productivity, particularly fish resources. Physical, chemical, and biological traits impact a pelagic habitat's health (Venkatesharaju *et al.* 1970; Watson & Lawrence 2003). The environment (atmospheric, terrestrial, and aquatic) has been subjected to an increasing strain of industrial and human activities since the start of the 21st century. The effects of these activities have been felt quickly. Any substance released into the environment, whether anthropogenically or naturally occurring, that has adverse biological effects is considered a pollutant (Lumami *et al.* 2020). Water's physical, chemical, and biological characteristics are referred to as its quality when discussing the presence of life in general and human activity in particular. The intended uses of water determine its quality, and each of these uses has some degree of effect on the quality of the water. Water supplies are severely threatened by pollution brought on by human activity and improper agricultural riverbank drainage (Rahman *et al.* 2021). According to research by Wang *et al.*, more than 350,000 recognized compounds and 70,000 unidentified chemicals have been produced and used on the global market (2020). These dangerous pollutants may enter aquatic environments via various pathways, including gaseous emissions, solid waste, and liquid waste (Le *et al.* 2022). Waste management has become a public health and environmental issue in urban areas as urbanization increases in many developing countries, making rubbish disposal a worldwide issue (Lu *et al.* 2019; Mahadevan *et al.* 2020; Long-Ling *et al.* 2021). Despite having 16% of the world's population and about 9% of the world's freshwater resources, more research needs to be done on African pollution (Behailu *et al.* 2016). Large cyanobacterial blooms that have appeared off the coast of various lakes show that East Africa's blue water quality has changed significantly over the past 40 years. The local fish population is extinct as a result of poor water quality.

Poor agricultural techniques that expedited the deposition and sedimentation of nutrient-dense soil particles have also been connected to the collapse (Verschuren *et al.* 2002; Wandiga & Madadi 2009). Agricultural activities, mining, roadside runoff, industrial and workshop waste, landfills, and electronic waste are significant sources of water pollution in Africa (Bruce & Limin 2021). Citation analysis, or scientometrics, is one of the new scientific methodologies used to track scientific activity and manage research. Scientometrics is a quantitative research tool for analyzing scientific productivity and scientific policy, as well as a scientific strategy for protecting water resources and preventing pollution (Bruce & Limin 2021). Several prior types of research have used statistical approaches to evaluate the parameters of surface water quality, physicochemical characteristics, and toxicity across a range of times. Since water quality variation is a continuous process, updated water quality data are needed for evaluation. Therefore, in response to the detrimental effects of water pollution and the need for a clear picture of the status of research, this study aims to evaluate scientific findings on water quality in the African continent lakes over the previous years. It is worth noting that the zone study on Lake Tanganyika is specifically in Burundi and Uganda for Lake Victoria.

Water quality in East Africa lakes

In recent research, *Escherichia coli* counts were reported by Niyoyitungiye *et al.* (2020), and the average count in Tanganyika Lake was 1,350 CFU/100 ml. During the rainy season, people who lived near Lake Tanganyika and drank its water for domestic use reported an epidemic of waterborne cholera, which was also proof of fecal contamination. Additionally, as urbanization grows and toxic effluents from big towns are released, Lake Tanganyika's water quality and productivity continuously change (Wetzel 2001). In Lake Tanganyika, the transparency of the waters varies significantly from one location to another, according to Niyoyitungiye *et al.* (2019), with values obtained ranging from 110 to 210 cm and a general mean of 162.38 to 30.44 cm when the temperature values recorded from 27 to 28 °C and a general mean of 28 °C. TDS readings ranged from 440.86 to 453.59 mg/l, having a mean overall of 447.141 mg/l and pH readings were in the 8.5–8.88 range, with an average of 8.76–0.12. The average BOD concentration across all research locations was 9.513.18 mg, ranging from 5 to 15 mg/l, while the overall mean was 34.2520, and the COD value varied from 15 to 75 mg/l and 77 mg/l. The investigation's DO content measurements varied from 7.162 to 7.71 mg/l, with a mean across the board of 7.375 and 17 mg/l. According to earlier research, the total phosphorus (TP) readings here varied from 0.69 to 1. 71 mg/l, with a mean of 1.21 mmol. Chlorophyll values varied from 0.15 to 0.45 mg/l and 47 mg/l.

Compared to Buhungu *et al.* (2017)'s findings, Lumami *et al.* (2020)'s COD, BOD_5, suspended matter, and ammoniacal N values were relatively high. It has been shown that anthropogenic activities, such as human habitation and associated activities, substantially influence the phosphorus load into the lake waters by high phosphorus concentrations in the soils around Lake Victoria, especially near the beaches. Climate change has made it even more important to save water. Water systems like Lake Victoria face several challenges. Human activities that lead to chemical pollution, such as using phosphate detergents in laundry, car washes, and agricultural sediments, are current problems. Human waste is one of the main contributors to water contamination in East Africa. The effluents from untreated city sewers significantly imperil the long-term ecological conservation of

Lake Victoria. Some studies suggest that pesticides are present at the top of the food chain, which is potentially worrying. It is a challenging scientific effort to determine the amounts of these wastes, the breakdown of the goods they create, their impact on the environment and life, and the best techniques to control how they are distributed in the ecosystem.

Sources of pollution

Numerous studies have shown that various factors contribute to water contamination in Lake Tanganyika in Burundi and Lake Victoria in Uganda. When Nkurunziza *et al.* (2018) assessed the water quality of Lake Tanganyika, they found sources of contamination include home wastewater, agricultural runoff, and industrial discharge. Similarly, Ssebugere *et al.* (2016) evaluated the water quality of Lake Victoria and discovered that untreated sewage, agricultural practices, and industrial effluents were among the sources of contamination. In their 2019 study on anthropogenic influences on Lake Tanganyika's water quality, Bizimana and Ntakimazi identified significant pollution causes such as deforestation, mining, and using fertilizers. Namuganga & Nakayiwa (2017) examined the water quality of Lake Victoria and pinpointed the sources of contamination, which include urbanization, farming methods, and industrial operations. These resources shed essential light on the causes of water pollution in Lake Tanganyika and Lake Victoria, emphasizing the demand for efficient management plans and environmental protection measures.

MATERIALS AND METHODS

Study area profile

Eastern Africa has some of the world's most abundant water sources. The two most notable water systems and bodies of water in East Africa are as follows: Lake Victoria, the largest lake in Africa, is also the second-largest freshwater lake in the world, and Lake Tanganyika, the largest freshwater reservoir on the continent and the second-deepest lake in the world. Water distributes very differently throughout the region. The region is divided into four main aridity zones: moist sub-humid, which is mainly found in Uganda, Rwanda, and some areas of Burundi; dry sub-humid, which is mainly found in western Tanzania and some areas of Uganda; semi-arid, which is primarily found in Tanzania; and arid, which is mainly found in Kenya. The western half of East Africa, which includes Burundi, Rwanda, and Uganda, is considered to have a rain surplus. At the same time, large portions of Kenya are thought to have a significant water deficit (Figure 1).

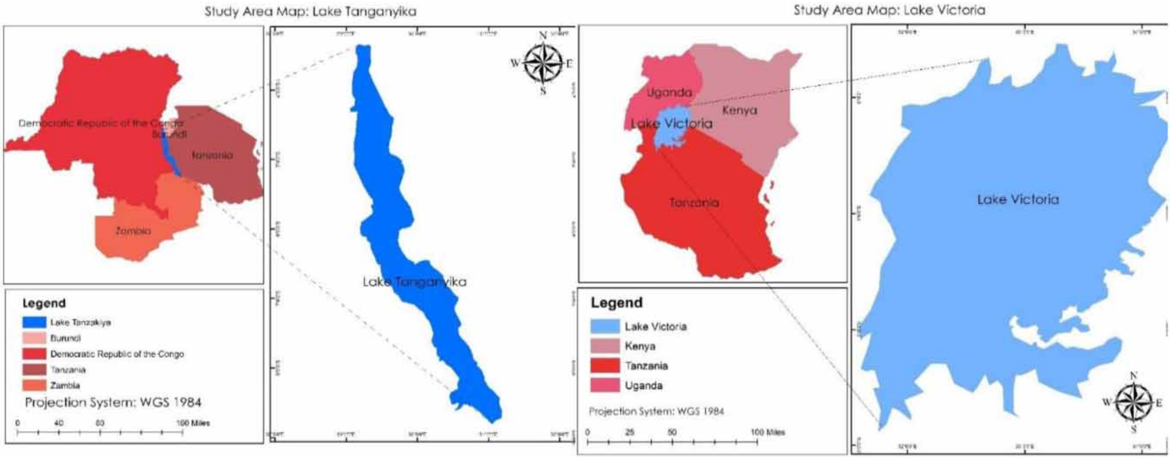


Figure 1 | Location map of the study area.

Data collection techniques

Several crucial indicators must be examined to evaluate the water quality features of Lake Tanganyika in Burundi and Lake Victoria in Uganda. Temperature, levels of dissolved oxygen (DO), pH, turbidity, total dissolved solids (TDS), nutrients (such as nitrogen and phosphate), chlorophyll-a, bacterial indicators (such as *E. coli*), and heavy metal concentrations are a few of these. The biological balance and general health of the lakes and any possible dangers to aquatic life and public health must be understood using these metrics. Some non-critical metrics may also be examined in addition to these essential parameters, like conductivity, Secchi depth, ammonia, nitrate concentrations, total suspended solids (TSS), and phosphate concentrations. This extra information on water clarity, ion concentration, particular nutrient levels, and suspended particles provided by these non-critical characteristics will help us comprehend the water quality of the lakes more thoroughly.

Four locations close to Lake Tanganyika and Lake Victoria had water samples taken. Apiece Lake's four stations took water samples at around 1,000 ml each. The locations for Lake Tanganyika were Kajaga, Nyamugari, Rumonge, and Mvugo. On the other hand, the locations for Lake Victoria were Masaka, Entebbe, Jinja, and Busia. The four sites on Lake Tanganyika and Lake Victoria have been chosen considering the surrounding population, industries, agricultural activities, and sewage treatment plants effluents to identify the contribution to the pollution observed in these waters lakes. Four separate sites for 2 years, 2021–2022, saw the collection of water samples, each measuring around 1,000 ml (Figure 2).

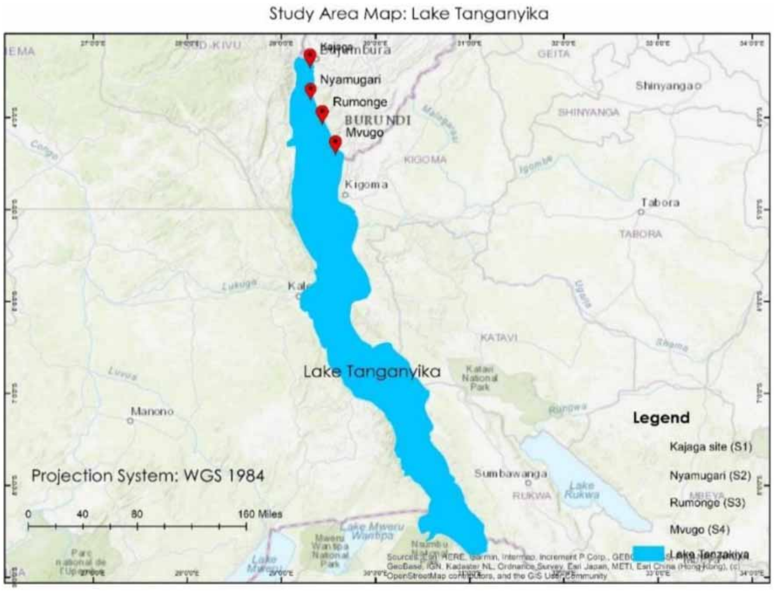


Figure 2 | Collected water sample location of Lake Tanganyika in Burundi.

The collection of samples took place 12 times between December 2021 and November 2022, each time with a 30-day gap. During the low tidal period, water samples were taken at each midstream location and a depth of around 10–20 cm. The collected samples were used to calculate the 5-day biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) after a part of each sample was filtered with Whatman 41 filter paper to remove suspended materials (COD). After sampling, an alkaline potassium iodide solution was added to shield the water samples from fungi or other pathogens. The bottles were transported to the laboratory in an airtight container, correctly labeled, and stored in the refrigerator, pending further inspection (Figure 3).

The procedure of determining parameters

It is essential to carefully consider several aspects when choosing the parameters to evaluate the water quality features of Lake Tanganyika in Burundi and Lake Victoria in Uganda. First, examining previous research on evaluations of water quality in comparable lakes or places might offer insights into frequently evaluated characteristics. Comprehending the local circumstances, terrain, hydrology, and human activity is essential. Based on their knowledge and experience, consulting with experts, scientists, and stakeholders in water resource management can provide helpful insight. Additionally, considering regulatory standards and guidelines established by national or international organizations aids in identifying the criteria to be monitored.

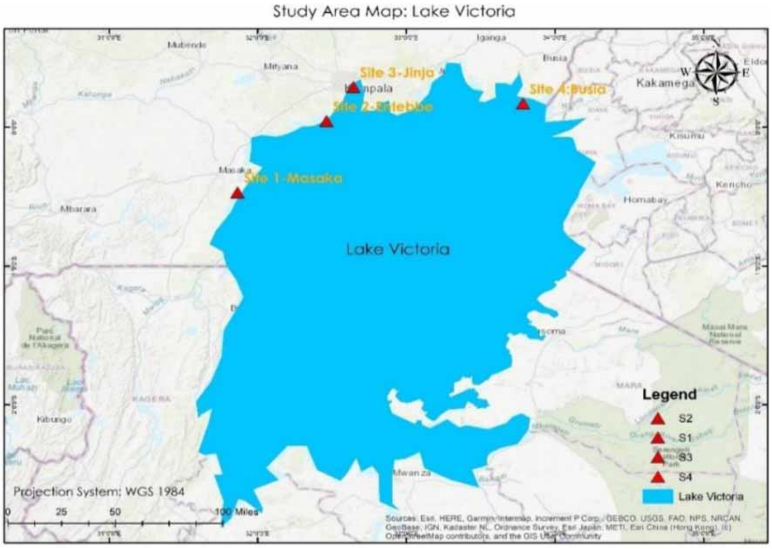


Figure 3 | Collected water sample location of Lake Victoria in Uganda.

Primary issues include nutrition loading, chemical pollution, DO levels, pH, temperature, and particular contaminants that must be addressed. The chosen metrics can be tested feasibly by assessing the resources and laboratory capabilities. Last but not least, providing parameters for trend analysis and long-term monitoring enables measuring changes in water quality over time. These methods can be used to pick parameters for evaluating the characteristics of the water quality of Lake Tanganyika and Lake Victoria in a thorough and educated way.

Parameters of Lake Tanganyika

Schedule and frequency of measurements

During 2021 and 2022, the water quality characteristics were observed in four sites (S1 of Masaka, S2 of Entebbe, S3 of Jinja, and S4 of Busia) (Table 1). Each parameter was measured yearly, with data being gathered for both years. Temperature (T, °C), transparency (Tr), pH, TDS, turbidity (Turb), phosphate (PO_4^{3-}), electrical conductivity (EC), total hardness (TH), TSS, TP, chloride (Cl^-), DO, fecal coliforms (FC), COD, and BOD_5 were among the parameters measured. Counts per 100 milliliters (counts/100 ml), microsiemens per centimeter (S/cm), milligrams per liter (mg/l), centimeters (cm), or nephelometric turbidity units (NTU) were the units of measurement for each parameter. By highlighting temporal fluctuations and possible contamination indicators, this extensive dataset offers valuable insights into the water quality features of Lake Tanganyika in Burundi and Lake Victoria in Uganda.

For the investigation of the physicochemical water quality, 20 significant parameters have been chosen. Temperature (T, °C), transparency (Tr, cm), potential of hydrogen (pH), total dissolved solids (TDS, mg/l), turbidity (NTU), NO_3^- (mg/l), NH_4^+ (mg/l), NO_2^- (mg/l), total nitrogen (TN), total alkalinity (TA), PO_4^{3-} (mg/l), EC, total hardness (TH, mg/l), TSS (mg/l), TP (mg/l), Cl^- (mg/l), FC (counts/100 ml), and DO (mg/l) of the water samples were *in-situ* measured with devices, together with a mercury thermometer, a glass electrode pH meter, and an EC meter. TH of the water has assessed by titration using an EDTA conjoining Eriochrome Black-T indicator after water depth was measured using a meter scale (AHPA 2005).

Through titration using a bromocresol green-methyl red indicator, it was determined to be $CaCO_3$, respectively, using a DO meter with a luminescent DO probe. TSS was obtained by filtration in a gravimetric manner and then dried in an oven (Radojevic & Bashkin 1999). A TDS meter was used to measure the TDS concentration quickly. By using the 5-day dilution procedure, BOD_5 was calculated (Klein & Gibbs 1979). Using a micro-digestion reactor and the colorimetric approach, the United States Environmental Protection Agency (USEPA) assessed COD (Jirka & Carter 1975). Each analysis was done three times, with the mean value being used.

Parameters of Lake Victoria

Water quality index

Many nations throughout the globe use the CCME-WQI index to evaluate their water quality (Lumb *et al.* 2006; Sharma & Kansal 2011) (Table 2). The key benefit of this index is that many variables may be added to the

Table 1 | Water sample data of Lake Tanganyika

	Kajaga site (S1)			**Nyamugari site (S2)**			**Rumonge site (S3)**			**Mvugo site (S4)**		
Parameters	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**
T (°C)	28.9	27.8	28.35	27.6	28.2	27.9	28.5	29.7	29.1	27.9	29.6	28.75
Tr (cm)	191.4	211.2	201.3	110.7	131.6	121.15	162	177	169.5	144	181	162.5
pH	8.86	8.86	8.86	8.89	8.89	8.89	8.71	8.85	8.78	8.9	8.7	8.8
TDS (mg/l)	453.58	443.55	448.56	455.89	443.11	449.5	448.94	441.12	445.03	447.8	441.1	444.45
Turb (NTU)	28.15	59.35	43.75	32.77	29.95	31.36	46.37	38.92	42.64	26.86	37.23	32.04
NO_3^- (mg/l)	1.20	1.09	1.14	1.08	1.17	1.12	1.07	1.02	1.04	1.12	1.06	1.09
NH_4^+ (mg/l)	0.71	0.78	0.74	0.51	0.67	0.59	0.91	0.63	0.77	0.87	0.58	0.72
NO_2^- (mg/l)	0.09	0.07	0.08	0.11	0.05	0.08	0.08	0.06	0.07	0.09	0.4	0.06
TN (mg/l)	2.51	2.05	2.28	2.01	2.03	2.02	2.42	2.11	2.26	2.38	2.19	2.28
TA (mg/l)	259.20	161.34	210.27	261.12	198.21	229.66	153.22	187.53	170.37	225.3	198.7	212
PO_4^{3-} (mg/l)	1.47	1.08	1.27	1.37	1.25	1.31	1.39	1.29	1.34	1.27	1.12	1.19
EC (S/m)	479.77	487.12	483.44	459.17	463.36	461.16	448.09	398.57	423.33	412.8	389.1	400.95
TH (mg/l)	230.13	135.23	182.68	227.91	236.71	232.31	228.81	205.21	217.01	229.9	211.6	220.75
TSS (mg/l)	28.69	75.02	51.85	36.12	45.64	40.88	29.98	25.08	27.53	31.67	27.12	29.39
TP (mg/l)	1.72	1.58	1.65	1.58	1.69	1.63	0.97	0.82	0.89	0.80	0.71	0.75
Cl^- (mg/l)	0.35	0.27	0.31	0.19	0.21	0.2	0.18	0.35	0.26	0.30	0.49	0.39
DO (mg/l)	7.76	7.69	7.72	7.50	7.45	7.47	7.38	7.69	7.53	7.25	7.36	7.30
FC (counts 100 ml)	1,899	997	1,448	1,688	1,086	1,387	1,988	1,426	1,707	1,749	1,288	1,518.5
COD (mg/l)	65	77	71	28	32	30	21	31	26	17	27	22
BOD_5 (mg/l)	19	21	20	16	16.8	16.4	9	11	10	7	9.5	8.25

Table 2 | Water sample data of Lake Victoria

	S1 of Masaka			S2 of Entebbe			S3 of Jinja			S4 of Busia		
Parameters	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**	**2021**	**2022**	**Mean**
T (°C)	24.45	25.38	24.91	25.34	24.76	25.05	25.47	25.12	29.29	25.09	24.98	25.03
Tr (cm)	174.24	195.23	184.73	152.43	138.92	145.67	137.78	129.37	133.57	168.39	171.12	169.75
pH	6.65	7.72	7.18	8.02	7.68	7.85	6.98	7.01	6.99	7.68	7.02	7.35
TDS (mg/l)	157.78	62.93	110.35	267.98	389.23	328.60	289.38	303.02	296.2	298.23	324.02	311.12
Turb (NTU)	14.73	22.96	18.84	13.87	15.78	14.82	14.98	15.23	15.10	18.24	21.29	19.76
NO_3^- (mg/l)	1.08	1.25	1.16	1.27	1.02	1.14	1.09	1.21	1.15	1.12	1.07	1.09
NH_4^+ (mg/l)	0.56	0.65	0.60	0.37	0.29	0.33	0.48	0.36	0.42	0.33	0.27	0.3
NO_2^- (mg/l)	0.06	0.10	0.08	0.09	0.04	0.06	0.08	0.05	0.06	0.07	0.03	0.05
TN (mg/l)	2.47	2.26	2.36	2.37	2.46	2.41	2.57	2.34	2.45	2.28	2.09	2.18
TA (mg/l)	261.35	273.57	267.46	301.34	289.45	295.39	298.34	247.67	273.00	279.25	269.87	274.56
PO_4^{3-} (mg/l)	1.12	1.39	1.25	1.21	1.02	1.11	1.32	1.09	1.20	1.41	1.11	1.26
EC (μS/cm)	316.14	116.72	216.43	412.26	372.9	392.58	327.35	299.38	313.36	315.57	327.18	321.37
TH (mg/l)	241.12	256.37	248.74	289.16	247.92	268.54	307.29	289.99	298.64	257.98	249.76	253.87
TSS (mg/l)	32.71	25.32	29.01	39.57	28.97	32.27	37.44	32.38	34.91	28.78	29.37	29.07
TP (mg/l)	1.61	1.47	1.54	1.56	1.72	1.64	1.58	1.22	1.4	1.63	1.47	1.55
Cl^- (mg/l)	0.49	0.56	0.52	0.38	0.47	0.42	0.48	0.39	0.43	0.43	0.29	0.36
DO (mg/l)	6.52	6.58	6.55	8.49	7.92	8.20	7.12	6.98	7.05	6.95	7.02	6.98
FC (counts/100 ml)	989	1,250	1,119.5	1,568	1,382	1,475	875	799	837	1,420	869	1,144.5
COD (mg/l)	57	62	59.5	49.67	59.77	54.72	54.23	59.37	56.8	60.16	67.39	63.77
BOD_5 (mg/l)	23	29.89	26.44	28.56	39.67	34.11	25.3	38.43	31.86	27.55	37.47	32.51

CCME-WQI calculation phases. Therefore, all the water quality criteria were considered in this study. It takes a somewhat unique method compared to others, using three elements to determine the final index, as shown in Abbass (2014), and Abbas & Ali (2020). The water quality index reflects the combined impact of the water quality criteria. Many nations worldwide used the CCME-WQI index to evaluate water quality (Lumb *et al.* 2006; Sharma & Kansal 2011). Many factors may be employed in calculations; ten water quality criteria were considered:

$$\mathrm{CCME-WQI} = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \tag{1}$$

where factor 1 (F_1) is scope, factor 2 (F_2) is frequency, and factor 3 (F_3) is amplitude which is measured by the following equations:

$$F_1 = \left(\frac{\text{Number of failed parameters}}{\text{Total number of parameters}}\right) \times 100 \tag{2}$$

$$F_2 = \left(\frac{\text{Number of failed tests}}{\text{Total number of test}}\right) \times 100 \tag{3}$$

F_3 represents the amount failed test values do not meet their guidelines. F_3 is calculated in three steps.

$\text{excursion}_i = (\text{Failed Test Value}_i/\text{Objective}_j) - 1$
$\text{excursion}_i = (\text{Objective}_j/\text{Failed Test Value}_i) - 1$
Now, the normalized sum excursion or nse is calculated as:
$\text{nse} = (\text{Sum of excursion}/\text{Total number of tests})$
The last step is the calculation of F_3

$$F_3 = \left(\frac{\text{nse}}{0.01\ \text{nse} + 0.01}\right) - 1 \tag{4}$$

The calculation of CCME-WQI value in each station has been determined by the first equation to produce a value between 0 and 100. Then, water quality is ranked in the following categories (Table 3):

Table 3 | Classification of water in respect of CCME-WQI

CCME-WQI value	Quality
95–100	Excellent water
80–94	Good water
60–79	Fair water
45–59	Marginal water
0–44	Poor water

Pearson correlation was utilized in the research to analyze the correlations between the physicochemical properties of water samples. These connections can reveal the source of the solutes and the process that produced the unquestionably present water (Parizi & Samani 2013):

$$r = \frac{n\sum xy - \sum x \cdot \sum y}{\left[\sqrt{[n}\sum x^2\left(\sum x\right)^2\right] \cdot \left[\sqrt{[n}\sum y^2\left(\sum y\right)^2\right]} \tag{5}$$

where r is the indicator of correlation by Pearson, $\sum xy$ is the number of values or scores in pairs, $n\sum xy$ is the sum of x and y's results, $\sum x$ is the summation of the x values, $\sum y$ is the summation of the y values (or y scores), $\sum x^2$ is the summation of squares of x values, $\sum y^2$ is the summation of squares of y standards, $(n\sum x)^2$ is the square of the summation of x values, and $(n\sum y)^2$ is the square of the summation of y values (Obilor & Amadi 2018; Parvez & Rana 2021).

Nemerow's pollution index (NPI)

The Nemerow pollution index (NPI) is a measurement of pollution created by the following equation can be used to determine the NPI, one of the simplified pollution indices:

$$\text{NPI} = \frac{Ci}{Li} \tag{6}$$

Ci is the revealed concentration of the ith parameter, and Li is the allowable limit of the ith parameter. Ci and Li must have the same unit in the previous at the above equation. The NPI value represents overall pollution as a single parameter. In NPI, there are no units. Li values are shown in the table for various applications and water quality parameters. The presence of impurities in the water necessitates treatment before use when the NPI value is more significant than 1.0. NPI greater than 1 signifies an excess concentration, and the particular parameters can potentially contribute to the pollution of water bodies situated (Nemerow 1971). There are already many indices available for evaluating the quality of water. The current study used NPI to assess marsh water quality and pinpoint the physicochemical elements that cause water pollution. Nemerow developed a detailed pollution index called NPI (Rathod *et al.* 2011). If the NPI value is greater than 1, the particular perimeter and its presence in excess amount or concentration have the potential to pollute the water bodies. The pollution index is one of the best resources for analyzing and disseminating data (basic environmental information) to the general public, technicians, managers, and decision-makers (Caeiro *et al.* 2005) (Table 4).

Table 4 | Standard values of water quality parameters

Parameter	Unit	WHO (Drinking)	WHO (Irrigation)
pH	N/A	8.5	8.5
DO	mg/l	5	–
NO_3^-	mg/l	10	–
TH	mg/l	500	–
TDS	mg/l	1,500	2,000
EC	µs/cm	2,000	2,000

Source: WHO (2011).

ANALYSIS AND FINDINGS

Water quality index

The study found that WQI ranged between 49.61 (Kajaga site) and 42.67 (Rumonge site) with an average of 46.05 in the study area for Lake Tanganyika where it ranged between 41.21 (Masaka) and 36.76 (Jinja) with an average of 38.93 in the study area for Lake Victoria (Table 5).

Table 5 | Classification of water in respect of CCME-WQI for Lake Tanganyika

Stations	WQI value	Quality
Kajaga	49.61	Marginal water
Nyamugari	46.79	Marginal water
Rumonge	42.67	Poor water
Mvugo	45.13	Marginal water

The water quality index of Lake Tanganyika and Lake Victoria were introduced using important physicochemical parameters where four sites were considered from each lake. The table values of WQI are presented where the values of both lakes were >35 to >50 for every station. The sequence of the WQI value was Kajaga site > Nyamugari site > Mvugo site > Rumonge site in Lake Tanganyika, whereas, in Lake Victoria, the order was Masaka site > Busia site > Entebbe site > Jinja site. High values were found in Lake Tanganyika, and most of the station's water quality was in 'Marginal Water', where only one station had a value less than 45 and had 'Poor Water' quality (Table 6).

Table 6 | Classification of water in respect of CCME-WQI for Lake Victoria

Stations	WQI value	Quality
Masaka	41.21	Marginal water
Entebbe	38.57	Poor water
Jinja	36.76	Poor water
Busia	39.16	Poor water

On the other hand, only one station (Masaka site) had 'Marginal Water' in Lake Victoria, where the majority of values were lower, and the quality of the water was 'Poor' in three stations. WQI readings below a certain point signal an increase in water pollution. This could result from rising anthropogenic and agricultural activity, industrialization, and various pollutants accumulating in the lake water over time (Figure 4).

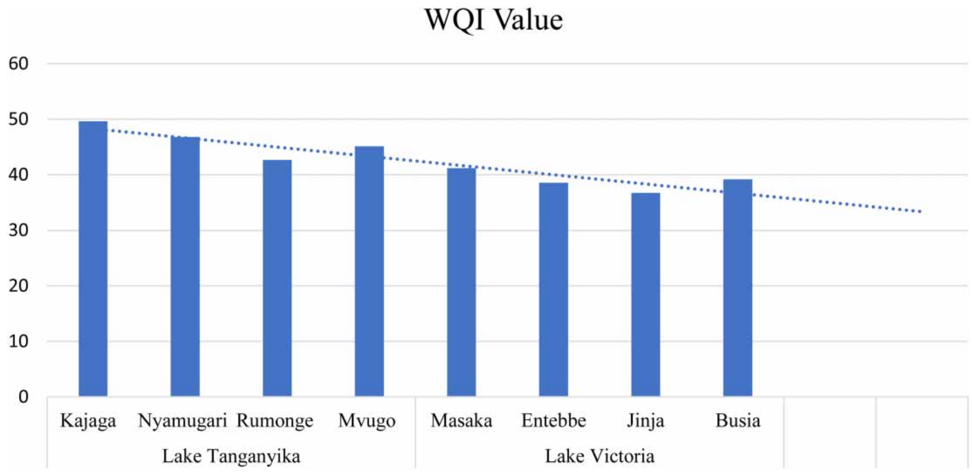


Figure 4 | Values for Lake Tanganyika and Lake Victoria.

Nemerow's pollution index

The NPI Index calculation reveals that the pH value for drinking water and irrigation at all four sites at Lake Tanganyika is greater than 1. It means that the lake may become contaminated due to its presence in excess or concentration and the specific perimeter. For DO, the pH value for drinking water and irrigation at all four sites at Lake Tanganyika is greater than 1. It means that a lake might become contaminated if it were present in an excessive amount or concentration and within a certain perimeter (Table 7).

According to the NPI calculation (Table 8), all four sites at Lake Victoria have DO values greater than 1 for irrigation and drinking water. It means that its presence in excess or concentration and the specific perimeter have the potential to contribute to lake pollution.

Based on the NPI calculation, it is found that Lake Victoria is in much better condition than Lake Tanganyika (Figures 5 and 6).

Table 7 | Calculated NPI values for Lake Tanganyika

Parameter	S1 (Drinking)	S1 (Irrigation)	S2 (Drinking)	S2 (Irrigation)	S3 (Drinking)	S3 (Irrigation)	S4 (Drinking)	S4 (Irrigation)
pH	1.04	1.04	1.05	1.05	1.03	1.03	1.04	1.04
DO	1.54	–	1.49	–	1.49	–	1.46	
NO_3^-	0.11	–	0.11	–	0.10	–	0.11	
TH	0.37	–	0.46	–	0.43	–	0.44	
TDS	0.30	0.22	0.30	0.22	0.30	0.22	0.30	0.22
EC	0.24	0.24	0.23	0.23	0.21	0.21	0.20	0.20

Table 8 | Calculated NPI values for Lake Victoria

Parameter	S1 (Drinking)	S1 (Irrigation)	S2 (Drinking)	S2 (Irrigation)	S3 (Drinking)	S3 (Irrigation)	S4 (Drinking)	S4 (Irrigation)
pH	0.84	0.84	0.92	0.92	0.82	0.82	0.86	0.86
DO	1.31	–	1.64	–	1.41	–	1.40	–
NO_3^-	0.12	–	0.11	–	0.12	–	0.11	–
TH	0.50	–	0.54	–	0.60	–	0.51	–
TDS	0.07	0.06	0.22	0.16	0.20	0.15	0.21	0.16
EC	0.11	0.11	0.20	0.20	0.16	0.16	0.16	0.16

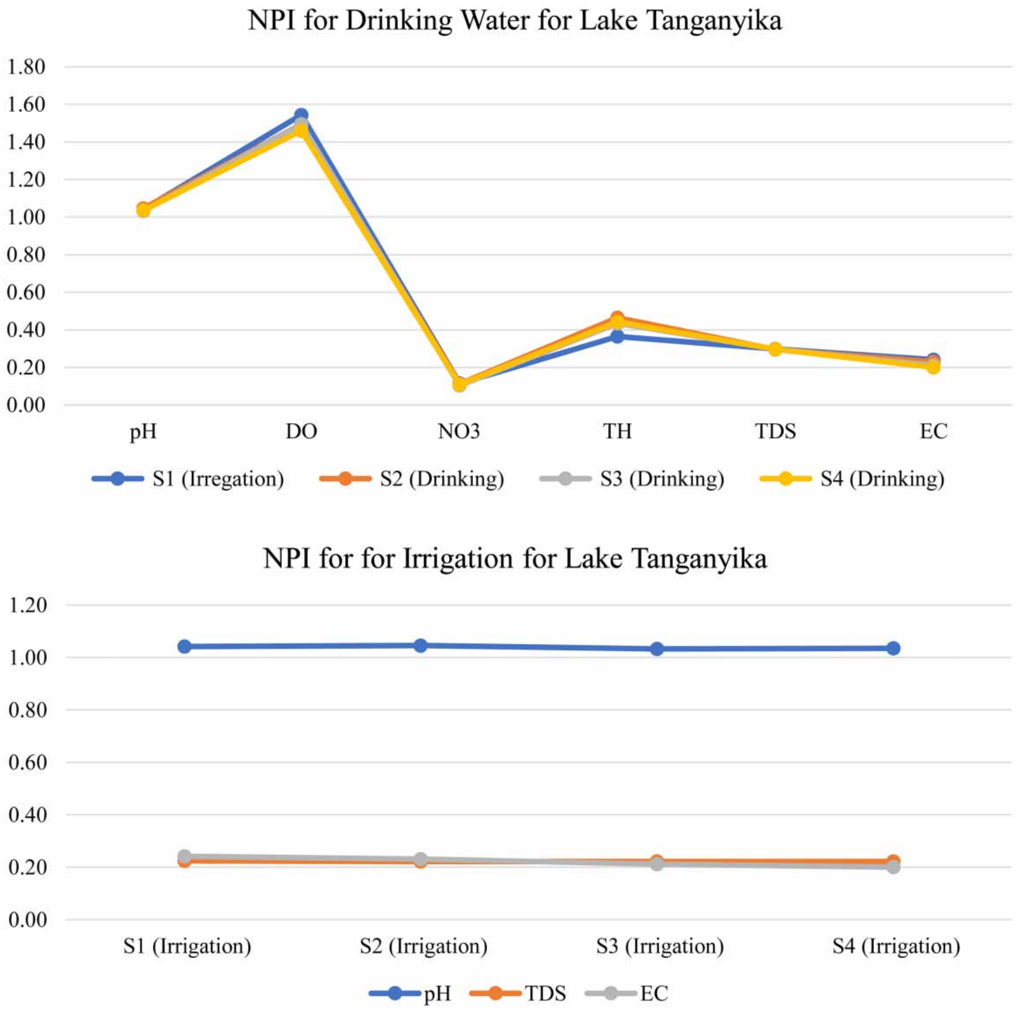


Figure 5 | NPI values (irrigation and drinking water) for water at Lake Tanganyika.

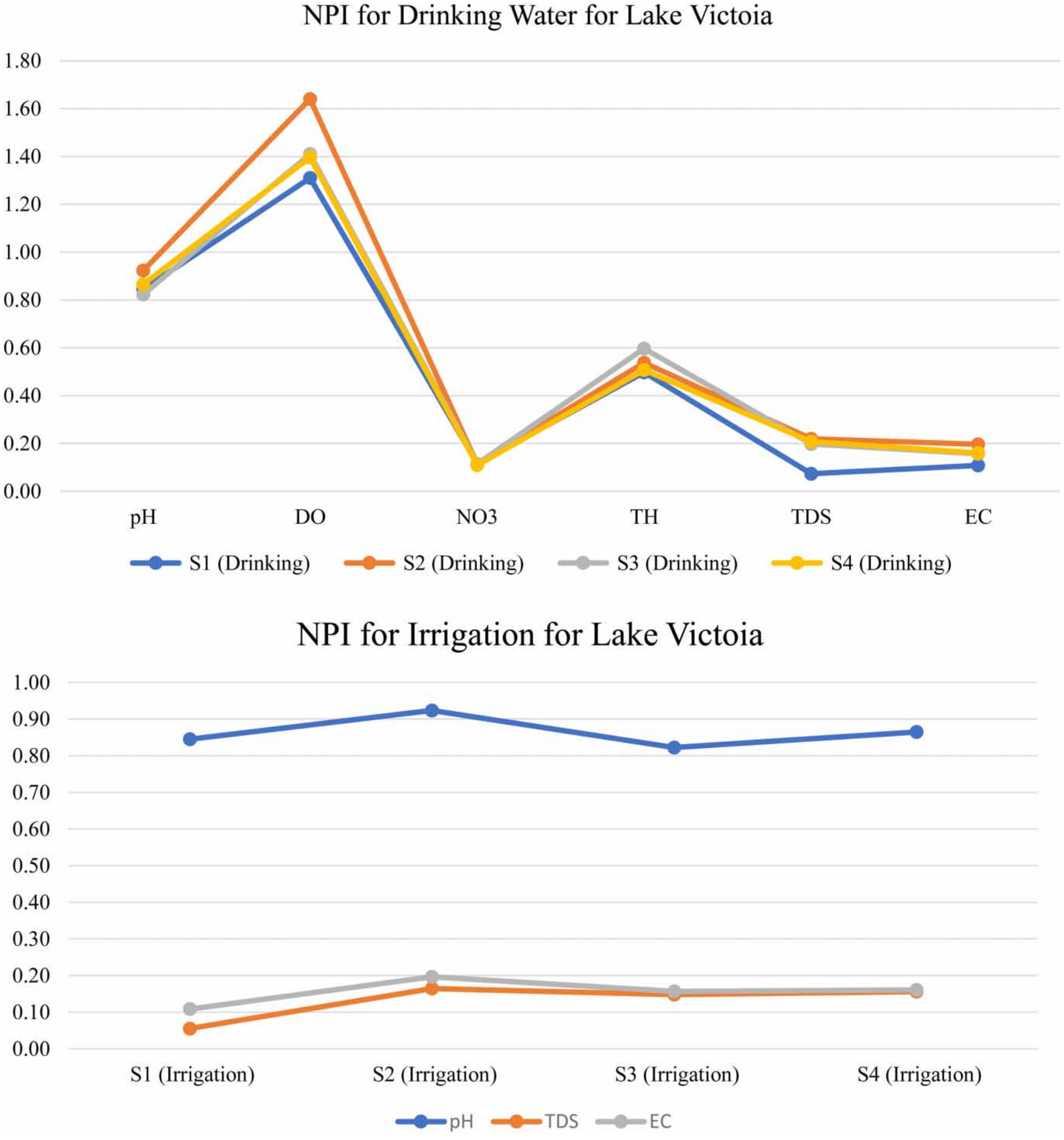


Figure 6 | NPI values (irrigation and drinking water) for water at Lake Victoria.

Correlation matrix

The correlation coefficients (r) for all computed constraints and the p values indicate the degree of significance. Temperature and pH level have a very significant negative association ($r = -0.600$, $p = 0.01$), according to the Lake Tanganyika correlation table. On the other hand, EC and temperature exhibited a very high negative association ($r = -0.624$, $p = 0.01$). TSS and TP likewise exhibit a substantial negative connection ($r = -0.596$, $p = 0.01$; $r = -0.581$, $p = 0.01$) with water temperature, similar to the preceding two components. Contrarily, Cl^- has a substantial positive connection ($r = 0.692$, $p = 0.01$) with temperature. There was no apparent relationship between temperature and other variables for Lake Tanganyika. For Lake Victoria, there was, however, no apparent relationship between temperature and other variables. Transparency (Tr) and turbidity level have a significant positive association ($r = 0.616$, $p = 0.01$), according to the Lake Tanganyika correlation table. On the other hand, transparency (Tr) and turbidity revealed a high negative connection ($r = -0.624$, $p = 0.01$). Similar to the primary component, there is a significant negative association between transparency (Tr) and TH ($r = -0.721$, $p = 0.05$). The transparency (Tr) and COD have a significant positive association ($r = 0.688$, $p = 0.01$). For Lake Tanganyika, there was no more obvious relationship between turbidity and the other variables. The correlation chart for Lake Victoria, on the other hand, demonstrates a significant inverse relationship between the levels of TDS and transparency (Tr) ($r = -0.740$, $p = 0.05$). Contrarily, there was a significant positive association between turbidity and transparency (Tr) ($r = 0.076$, $p = 0.05$). Similar to the preceding components, there was a significant negative association between the transparency (Tr), EC, and TSS ($r = -0.645$, $p = 0.01$; $r = -0.615$, $p = 0.01$, respectively). Additionally, there is a significant positive association between COD and turbidity ($r = 0.688$, $p = 0.01$).

According to the Lake Tanganyika correlation table, there is a significant positive association between the levels of TP and pH ($r = -0.608$, $p = 0.05$). Contrarily, there was a significant positive association between Lake Victoria pH and TA ($r = 0.623$, $p = 0.01$). Similar to the primary component, there is a significant negative association between pH level and DO ($r = 0.674$, $p = 0.01$). Furthermore, pH and FC have a substantial positive connection ($r = 0.915$, $p = 0.05$). The Lake Tanganyika correlation table shows a significant positive connection ($r = 0.673$, $p = 0.01$) between TDS and TA. Additionally, for Lake Tanganyika, there is a substantial correlation between TDS and PO_4^{3-} ($r = 0.718$, $p = 0.05$). On the other hand, TDS and NH_4^+ have a very high negative association in Lake Victoria ($r = -0.932$, $p = 0.01$). On the other hand, TDS and NO_2^- exhibit a high association ($r = -0.683$, $p = 0.05$). Similar to the previous correlation, TDS and Cl^- have a negative correlation ($r = -0.673$, $p = 0.01$). TDS and DO are, however, significantly positively associated with one another for Lake Victoria ($r = 0.586$, $p = 0.01$). The tributary has a significant navigated connection with TA and TH for Lake Tanganyika ($r = -0.752$, $p = 0.05$; $r = -0.838$, $p = 0.01$). For Lake Tanganyika, the tributary positively correlates with TSS ($r = 0.597$, $p = 0.05$). The turbidity, TN, and TSS have a significant navigated association for Lake Victoria ($r = -0.772$, $p = 0.05$; $r = -0.801$, $p = 0.01$). Additionally, the turbidity has a negative navigated correlation ($r = -0.705$, $p = 0.01$) with both TN and EC. For Lake Victoria, the tributary positively correlates with COD ($r = 0.815$, $p = 0.05$) (Tables 9 and 10).

NO_3^-, EC, and TP have a substantial positive link with each other, according to the Lake Tanganyika correlation table ($r = 0.626$, $p = 0.01$; $r = 0.692$, $p = 0.01$). NO_3^- and NO_2^- are highly correlated for Lake Victoria ($r = -0.696$, $p = 0.01$). NH_4^+ and TN have a positive association for Lake Tanganyika ($r = 0.60$, $p = 0.01$). Contrarily, NH_4^+, NO_2^-, and Cl^- are positively correlated at Lake Victoria ($r = 0.709$, $p = 0.01$; $r = 0.829$, $p = 0.01$). NH_4^+, EC, and BOD_5 are, however, inversely associated with Lake Victoria ($r = -0.748$, $p = 0.01$; $r = -0.663$, $p = 0.05$). NO_2^- and Cl^- have a positive correlation with Lake Tanganyika ($r = 0.627$, $p = 0.05$). Additionally, there is a significant association between TN and FC ($r = 0.738$, $p = 0.01$). PO_4^{3-} and FC are also correlated ($r = 0.799$, $p = 0.01$), respectively. The correlation between EC and TSS, TP, DO, COD, and BOD_5 for the same lake, however, is positive ($r = 0.692$, $p = 0.05$; $r = 0.929$, $p = 0.05$; $r = 0.581$, $p = 0.05$; $r = 0.729$, $p = 0.05$; and $r = 0.888$, $p = 0.01$, respectively). The correlation between TH, TSS, and COD, on the other hand, is adverse ($r = -0.762$, $p = 0.01$; $r = -0.715$, $p = 0.05$). Additionally, TSS and FC have a negative correlation ($r = -0.647$, $p = 0.05$). The correlation between TSS and TP, COD, and BOD_5 is, however, positive ($r = 0.606$, $p = 0.05$; $r = 0.703$, $p = 0.01$; $r = 0.728$, $p = 0.01$). Contrarily, TP has a positive correlation with both COD and BOD_5 ($r = 0.820$, $p = 0.01$; $r = 754$, $p = 0.01$, respectively). Finally, yet importantly, COD and BOD_5 have a positive correlation ($r = 0.853$, $p = 0.01$). PO_4^{3-} and Cl^- are positively linked with NO_2^- at Lake Victoria ($r = 0.708$, $p = 0.05$; $r = 0.635$, $p = 0.05$, respectively). However, the relationship between NO_2^- and BOD_5 is adverse (-0.673). Additionally, TN and COD exhibit a strong negative correlation ($r = -0.753$, $p = 0.01$). Additionally, there is a positive correlation between TA, TP, DO, and FC ($r = 0.661$, $p = 0.05$; $r = 0.735$, $p = 0.01$; and $r = 0.621$, $p = 0.05$), whereas there is a negative correlation between PO_4^{3-} and FC ($r = -0.601$, $p = 0.05$). On the other hand, for the same lake, the correlation between EC, TSS, and DO is positive ($r = 0.619$, $p = 0.05$; $r = 0.621$, $p = 0.05$). However, EC and DO have a negative correlation ($r = 0.737$, $p = 0.01$). In contrast, TH has a positive correlation with TSS and COD ($r = 0.753$, $p = 0.01$) and a negative correlation with COD ($r = -0.588$, $p = 0.05$). Additionally, TSS and COD have a negative correlation ($r = -0.812$, $p = 0.01$) as well. On the other hand, TP and FC have a positive correlation ($r = 0.643$, $p = 0.05$). Finally, DO and FC has a positive correlation ($r = 0.628$, $p = 0.05$).

Table 9 | Correlations for Lake Tanganyika

	T (°C)	Tr	pH	TDS	Turb	NO_3^-	NH_4^+	NO_2^-	TN	TA	PO_4^{3-}	EC	TH	TSS	TP	Cl^-	DO	FC	COD	BOD_5
T (°C)	1																			
Tr	0.433	1																		
pH	−0.600*	−0.317	1																	
TDS	−0.537	−0.358	0.345	1																
Turb	−0.003	0.616*	−0.330	−0.308	1															
NO_3^-	−0.408	−0.037	0.496	0.429	−0.423	1														
NH_4^+	−0.093	0.364	−0.213	−0.084	0.322	0.064	1													
NO_2^-	0.408	0.129	−0.563	−0.240	−0.038	−0.215	−0.354	1												
TN	0.285	0.382	−0.346	0.234	−0.147	0.245	0.650*	−0.006	1											
TA	−0.266	−0.416	0.544	0.673*	−0.752**	0.525	−0.522	0.040	0.033	1										
PO_4^{3-}	−0.020	−0.307	0.137	0.718**	−0.405	0.260	0.058	−0.368	0.434	0.404	1									
EC	−0.624*	0.109	0.462	0.530	0.266	0.626*	0.069	−0.421	−0.090	0.156	0.248	1								
TH	0.077	−0.721**	−0.017	0.332	−0.838**	0.196	−0.150	0.010	0.228	0.445	0.614*	−0.299	1							
TSS	−0.596*	0.295	0.383	−0.061	0.597*	0.261	0.097	−0.239	−0.431	−0.226	−0.493	0.692*	−0.762**	1						
TP	−0.581*	−0.075	0.608*	0.515	0.018	0.692*	−0.256	−0.336	−0.289	0.382	0.238	0.929**	−0.148	0.606*	1					
Cl^-	0.692*	0.528	−0.376	−0.466	−0.103	−0.128	−0.154	0.627*	0.276	0.063	−0.426	−0.567	−0.163	−0.296	−0.493	1				
DO	0.121	0.550	0.290	0.141	0.382	0.180	−0.157	−0.264	−0.058	0.042	0.205	0.581*	−0.506	0.375	0.571	−0.023	1			
FC	0.083	−0.149	−0.220	0.614*	−0.301	0.000	0.352	−0.137	0.738**	0.249	0.799**	−0.101	0.539	−0.647*	−0.237	−0.145	−0.144	1		
COD	−0.154	0.688*	0.280	0.119	0.479	0.431	0.045	−0.145	0.021	0.021	−0.126	0.729**	−0.715**	0.703*	0.651*	0.070	0.820**	−0.318	1	
BOD_5	−0.413	0.235	0.516	0.316	0.262	0.550	−0.265	−0.237	−0.318	0.232	0.023	0.888**	−0.456	0.728**	0.932**	−0.273	0.754**	−0.401	0.853**	1

*Correlation is significant at the 0.05 level (two-tailed).

**Correlation is significant at the 0.01 level (two-tailed).

Table 10 | Correlations for Lake Victoria

	T (°C)	Tr	pH	TDS	Turb	NO_3^-	NH_4^+	NO_2^-	TN	TA	PO_4^{3-}	EC	TH	TSS	TP	Cl^-	DO	FC	COD	BOD_5
T (°C)	1																			
Tr	−0.382	1																		
pH	−0.164	0.066	1																	
TDS	0.104	−0.740**	0.128	1																
Turb	−0.179	0.760**	0.065	−0.402	1															
NO_3^-	0.177	0.127	0.373	−0.478	0.027	1														
NH_4^+	0.027	0.511	−0.239	−0.932**	0.189	0.377	1													
NO_2^-	0.061	0.344	0.350	−0.683*	0.048	0.696*	0.709**	1												
TN	0.211	−0.527	−0.141	0.028	−0.772**	−0.090	0.298	0.267	1											
TA	0.005	−0.218	0.623*	0.318	−0.291	−0.039	−0.217	0.303	0.337	1										
$PO_4{}^{3-}$	0.108	0.477	0.192	−0.468	0.437	0.344	0.423	0.708*	−0.140	0.146	1									
EC	−0.025	−0.645*	0.168	0.804**	−0.705*	−0.324	−0.748**	−0.445	0.245	0.488	−0.526	1								
TH	0.569	−0.704*	−0.044	0.265	−0.525	0.380	−0.064	0.265	0.454	0.284	0.123	0.247	1							
TSS	0.304	−0.615*	−0.085	0.279	−0.801**	0.200	−0.116	0.172	0.563	0.426	−0.154	0.619*	0.753**	1						
TP	−0.371	0.183	0.392	0.134	−0.110	−0.500	−0.094	0.050	0.255	0.661*	0.036	0.341	−0.421	−0.056	1					
Cl^-	−0.023	0.299	0.020	−0.673*	0.042	0.151	0.829**	0.635*	0.533	0.017	0.356	−0.597*	−0.111	−0.223	0.230	1				
DO	−0.023	−0.520	0.674*	0.586*	−0.527	0.104	−0.560	−0.052	0.212	0.735**	−0.381	0.761**	0.293	0.492	0.348	−0.337	1			
FC	−0.325	0.183	0.915**	0.050	−0.056	0.207	−0.162	0.335	−0.020	0.621*	0.139	0.259	−0.257	−0.067	0.643*	0.117	0.628*	1		
COD	−0.178	0.451	−0.255	−0.020	0.815**	−0.377	−0.153	−0.506	−0.753**	−0.547	0.015	−0.440	−0.588*	−0.812**	−0.192	−0.232	−0.562	−0.337	1	
BOD_5	0.027	−0.417	0.185	0.615*	0.098	−0.163	−0.663*	−0.673*	−0.346	−0.130	−0.601*	0.230	−0.034	−0.262	−0.272	−0.498	0.345	−0.045	0.407	1

*Correlation is significant at the 0.05 level (two-tailed).

**Correlation is significant at the 0.01 level (two-tailed).

CONCLUSION

The research addresses a variety of subjects, such as heavy metal pollution, BOD_5, and the evaluation of water quality. A case study on the pollutant load of effluents dumped into Lake Tanganyika in the Democratic Republic of the Congo is also included in the publication. The results of the investigations show how anthropogenic activities have an influence on water quality in various parts of Africa. The studies also highlight the necessity for efficient water quality management techniques and the need of monitoring and evaluate water quality to maintain sustainability.

The methodology employed in the investigations involves several analytical methods, including the single-factor index, principal component analysis, and the CCME-WQI. The investigations also use several tools to assess various water quality characteristics, including DO meters, TDS meters, and micro-digestion reactors. The essay stresses the necessity for ongoing efforts to monitor and control water quality in the region and offers insightful information about the present state of water pollution research in Africa. The results of the research can help in the creation of efficient water quality management plans and regulations to guarantee the sustainability of water resources in Africa.

The article displays the lake water quality data for Lake Victoria and Lake Tanganyika. Only one station had ‘Poor Water’ quality with a value below 45 at Lake Tanganyika, with the majority of stations having ‘Marginal Water’ quality. WQI readings below a certain point signal an increase in water pollution. However, three stations in Lake Victoria mainly had lower values and ‘Poor Water’ quality, while only one station (Masaka) had ‘Marginal Water’. This could be due to increased industrialization, human and agricultural activities, and other toxins accumulated in the lake water over time. The NPI reveals that the pH and DO values for irrigation and drinking water are more significant than one at all four locations close to Lake Tanganyika. It is worth noting that the highest air pressure caused the high DO level. The cause of high pH levels is chemical pollutants and environmental factors.

Additionally, the NPI >1 at Lake Victoria DO value is used for irrigation and drinking water at all four locations. Lake Victoria is in considerably better shape than Lake Tanganyika in terms of NPI. Due to human activity, the release of industrial effluents, sewage wastes, agricultural runoff, bacteriological parameters, and the determined value of WQI.

Overall, the research findings can help with the creation of efficient water quality management plans and regulations to maintain the long-term viability of Africa’s water resources. In addition to highlighting the necessity for ongoing efforts to monitor and control water quality in the area, the publication offers insightful information about the present status of water pollution research in Africa. The severity of pollution is higher in the dry season than in the rainy season. As a result, to prevent further deterioration of water quality, specific mitigating measures are necessary, such as ongoing environmental monitoring, public awareness campaigns, and the implementation of strict guidelines for river usage and maintenance.

The authors suggest several possible applications and preventative strategies based on the findings of this study on the water quality parameters of Lake Tanganyika in Burundi and Lake Victoria in Uganda. First, the study might help with the creation and application of specialized plans and regulations for managing water quality to reduce pollution from sources such as untreated effluents and industrial discharges. To encourage proper waste disposal practices, this may entail tighter restrictions, upgraded wastewater treatment facilities, and greater public awareness campaigns. The results may also help with the development of routine monitoring programmes to follow water quality indicators and quickly spot any alterations or new problems. Early intervention and cleanup measures might then be made, minimizing any possible harm to aquatic ecosystems and human health. The study might also be used as a springboard for cooperation between government organizations, academics, and local people to create sustainable methods for fishing, farming, and other lake-related activities. This could entail advocating for environmentally friendly agricultural methods, ethical fishing methods, and watershed management programmes to lessen non-point source pollution and safeguard the lakes’ water quality. Overall, putting the research findings to use might help preserve Lake Tanganyika and Lake Victoria and manage them sustainably, ensuring that both current and future generations have access to clean, healthy water supplies.

The authors suggest future study efforts in several areas to address additional gaps in our knowledge of the water quality features in Lake Tanganyika (Burundi) and Lake Victoria (Uganda). First of all, thorough research on the effects of certain pollutants, such as heavy metals, pesticides, and emerging contaminants, on the water quality of these lakes would offer invaluable information on possible dangers and risk reduction techniques.

Understanding the long-term implications on the lake ecosystems will also benefit from research on how climate change affects water quality metrics such as temperature, DO, and nutrient dynamics. To fill in more gaps in our understanding of the water quality aspects in Lake Tanganyika (Burundi) and Lake Victoria (Uganda), the authors may recommend future study efforts in a variety of areas. First of all, an in-depth investigation of how particular pollutants, such as pesticides, heavy metals, and emerging contaminants, affect the water quality of these lakes would provide essential knowledge on potential risks and risk management strategies. Research on how climate change impacts water quality parameters including temperature, DO, and nutrient dynamics will also help understand the long-term effects on the lake ecosystems.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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