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Assessment of Physicochemical Parameters in Relation with Ecology of *Bagrus bayad* (Fabricius, 1775, Bagridae) in Lake Albert, Ituri, Democratic Republic of the Congo (DRC)

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Abstract

The objective of this study is to assess the water quality of Lake Albert based on its physico-chemical characteristics in relation with *Bagrus bayad* ecology in the province of Ituri in the Democratic Republic of the Congo. The study undertaken between December 2019 and November 2020 in six stations (Drigi, Kicha ya Drigi, Grand Bale, Ingbokolo, Njerere and Songa Tabu) allowed the measurement of physical parameters such as pH, electrical conductivity (EC) and temperature (T), Turbidity, Total Dissolved Solids (TDS), as well as the following chemical parameters Sulphates (SO_4^{2-}), Chlorides (Cl^-), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Hydrotimetric Titer or Total Hardness (TH), Ammonium (NH_4^+), Nitrates (NO_3^-), Nitrites (NO_2^-), Phosphates (PO_4^{3-}) and Fluorides (F^-), Potassium (K^+), Sodium (Na^+), Biological Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), and Dissolved Oxygen (DO).

The annual mean values are compared with the standards for the survival of aquatic organisms. Multivariate statistical analysis including Principal Component Analysis (PCA) and Hierarchical Ascending Classification Hwaswere also applied to all measured parameters. The lake water is slightly basic with an average pH of 7.2 ± 0.4. It is slightly mineralized and less hard with an average conductivity of 96.9 ± 46.3 µS/cm and an average total hardness of 54.8 ± 12.3 mg/Nutrients pollution is a major indicator of the water quality of the stations studied. A strong correlation is reported between electrical conductivity and the following parameters: pH, NO_3^-, NO_2^-, SO_4^{2-}, TH, Cl^-, HCO_3^- and Ca^{2+}. The typology is mainly governed by this conductivity, which allows us to classify the stations according to their physico-chemical quality. The lake water is subject to organic pollution in the 6 stations studied at Lake Albert. The physico-chemical parameters considered in this survey were within the limits of aquatic life and biodiversity in the aquatic ecosystem, particularly for the survival and reproduction of aquatic species. The results suggest that, although the physico-chemical parameters are within the limits of aquatic life, they are subject to strong variations over time. Organic pollution index varied from 4.5 (Slight pollution) to 5 (Null pollution). Changes in land use and land cover around the basin and pollution from Lake Albert's tributary rivers may be fatal to the life of biodiversity in the long term.

Subject Areas

Hydrology

Keywords

Physico-Chemistry, Water Quality, Lake Albert

1. Introduction

Lake ecosystems are an indispensable part of human existence including the flora and fauna. Additionally, they have immense importance in terms of ecological, economic, and aesthetic values. Surface water quality has deteriorated due to the increase in population, industrialization, and anthropic activities. The contaminations in the lake water are mainly due to natural geogenic and anthropic activities including domestic, industrial, and municipal effluents and agricultural runoff (Mekonnen & Hoekstra, 2015 [1]; Yu *et al.*, 2016 [2]). The lake ecosystems are under intense degradation for the last couple of decades and thus depict the degradation of the civilization within the lake basins (Gophen, 2012 [3]; Khadka *et al.*, 2021 [4]). These factors are governing the distribution of fish in the lake and other diversity. Understanding the controlling factors of water quality is helpful for fish ecology (Li *et al.*, 2019 [5]; Torres *et al.*, 2019 [6]).

The chemical characteristics of lake water reflect not only the water quality of the lake but also the characteristics and changes in the ecological environment of the lake basin (Qiao *et al.*, 2017 [7]; Ramesh *et al.*, 2018 [8]). Studies of the chemical composition and distribution patterns in Lakes can more fully reveal the source chemical in the lake water, the relationship between the lake and the natural environment and the influence of human activities (Tripathiipathe *et al.*, 2014) [9]. As global environmental problems intensify scholars increasingly leasing focused on Lake chemistry problems (Rodolfo *et al.*, 2018) [10].

Lake Albert, located in the Ituri Province, DR Congo, is one of the most important ecosystems. The major aspects of the lake are its economic and social values in addition to its ecological importance. Despite providing various ecological servicing es, economic and aesthetic values, the lake basin is vulnerable to various natural and anthropic activities due to its location in the geologically fragile zone. Beadle (1981) [11] argues that there is no doubt that fish are driven by their physicochemical surround physiologically optimal areas optimal. Therefore, analysis of the physiochemical parameters is necessary to understand the ecological and environmental pathways of Lake Albert. The conservation of freshwater lakes has immense importance for the sustainability of human livelihoods and the natural environment. As per our best knowledge, there is little scientific publication on the Lake Albert to date about the ecology of the fish *Bagrus bayaj* (Linda *et al.*, 2005) [12]. Therefore, an evaluation of the water quality is an urgent need because the riparians population used the water for various needs and there is runoff from the watershed which contributes disturbed the water quality in Lake Albert in DRC side.

Thus, the objective of this study was to determine the physicochemical properties of the surface water of the lake for the ecological understanding of fish species *Bagrus bajad*. The findings of the study could be used as recommendations to manage surface water to preserve ecological sustainability in Lake Albert, DRC.

2. Material and Methods

2.1. Description of the Sampling Sites

The sampling sites in the lake were selected randomly according to the input of effluent from the watershed and other anthropogenic activities around the shoreline of the lake, as well as fish specimens from December 2010 to December 2020 including rainy and dry seasons. Six fixed stations (**Figure 1**) were used to collect water samples monthly. The choice of these areas was done according to fishermen who reported that they are mainly the potential fishing zones of the studied species (*Bagrus bajad*). The same sites also helped to collect specimens that helped for the reproduction and diet studies of the same fish species.

Each sampling area is described as follows: Drigi: is located in the South Bahema sector, at 500 m from the bank, receives waters from Drigi River, with an average depth of 4 m; aquatic macrophytes are dominated by Papyrus, Eicchornia, *Fragmites spp*; the bottom is sandy-muddy; the fauna is characterized by the presence of some individuals of hippos, sporadic crocodiles, turtles, possibly some

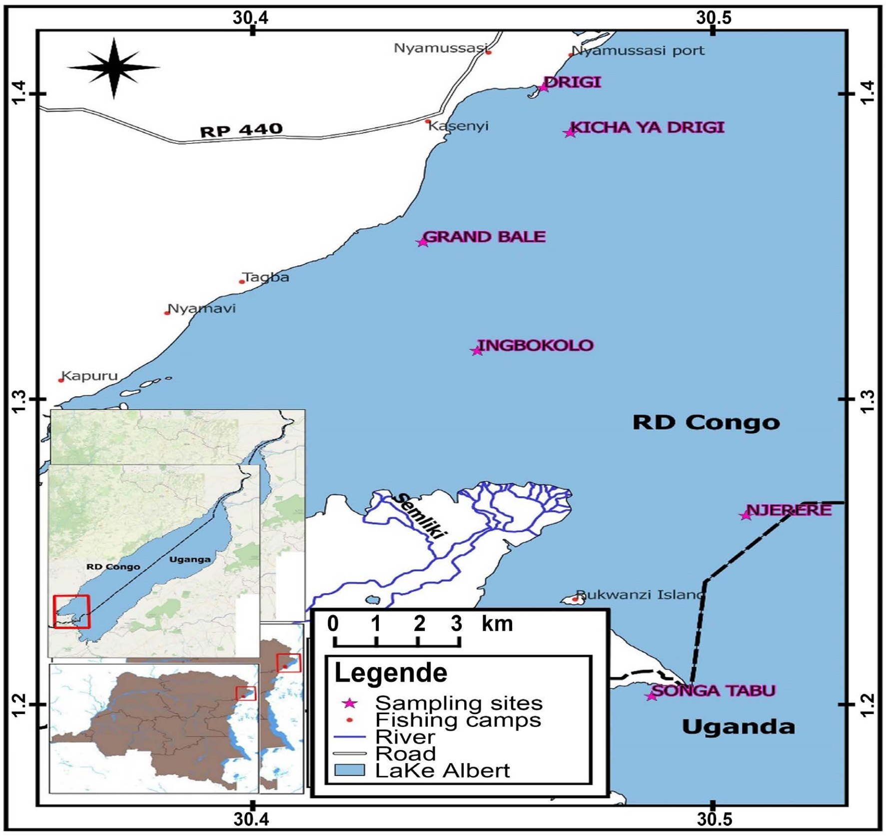

Figure 1. Sampling sites localization in Lake Albert in DRC side.

reptiles (snakes), and a diversity of aquatic birds. Human activity is exclusively dominated by cattle. Kicha ya Drigi: straddling the South Bahema sector (Irumu Territory) and the Bahema-Banywagi chiefdom (Djugu Territory); is located at 2 km from the bank, the bottom is sandy, a depth varying between 4 and 8 m; aquatic macrophytes appears during floods; Fauna is mostly dominated by aquatic birds); NJerere: belongs to the Bahema-Sud Sector, 1 km from Semliki delta, the sandy-muddy; the depth is 2 m average; the bottom is made of muds; aquatic macrophytes are dominated by *Papyrus spp.*, *Pennisetum spp.*, Eicchornia, etc.; fauna is composed of hippos, crocodiles, snakes and birds' diversity. The villages surrounding the Semliki delta are populated by more than 3000 inhabitants. Human activities are mainly dominated by fishing. Songa Tabu (Rukwanzi): located on the border between the DRC and Uganda, from the Semliki delta, waters are loaded with organic matter; the average depth is 3 m; the vegetation is similar to that of Njerere; the bottom is sandy-muddy; the fauna is similar to that of Njerere; Inhabitants are currently estimated at more than 500 persons, other surrounding villages had been driven out by the floods that led migration either to Uganda or to Kasenyi and Tchomya (DRC). The most frequent human activities are exclusively fishing in the spawning area and small trade in these villages. Grand Bale: Bahema-South, located 2 km from the bank; sandy-muddy bottom, aquatic macrophytes vegetation are dominated by Papyrus, Eicchornia et Fragmites; the average melting is 3 m; there may be individuals of crocodiles, hippos, a diversity of birds, turtles etc.; human activities are exclusively dominated by fishing. Ingbokolo: belongs to Bahema-Sud sector, 4 km from the bank; the average depth is 4 m; the bottom is sandy; aquatic macrophytes vegetation is dominated Fragmites, Eicchorrnia; some birds are observed; limited human actions impact because the site is located far from villages.

2.2. Sampling and Sample Collection Methods

To avoid contamination, non-powder vinyl clean gloves and masks were used during sample collection and laboratory work, and distilled deionized water was used for the analysis. The sterilized sampling bottles were rinsed with the lake water thrice before taking the original samples. All water samples were taken from a depth of ~15 cm from the water surface. The sampling bottles were labelled and transported to the laboratory. Until the laboratory analysis, all the samples were kept in the refrigerator at 4˚C (Mbalassa *et al.*, 2014) [13].

The chemical parameters such as electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), dissolved oxygen (DO), major cations (Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+), and the major anions (Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, HCO_3^-) were analyzed using the standard methods (APHA, 2005 [14]; Khadka *et al.*, 2021 [4]). The pH, EC, and TDS were measured in the field using a multi-parameter instrument (HANNA). BOD_5 was measured as the decrease in DO after incubation in the dark at 20˚C for five days. The BOD_5 in mg/L of DO was calculated by subtracting the mg/L of DO in incubated sample bottles from the DO in initial bottles (Olompande *et al.*, 2011) [15]. COD was calculated using potassium dichromate as an oxidant reagent (Bagalwa *et al.*, 2006) [16]. Other water samples were taken in 1l plastic bottles at the same time, for other chemical analyses. The bottles were also rinsed thrice with sample water before final collection. The samples were placed in a cooler box with ice for transportation to the laboratory. If, analyses were not done immediately; samples had to be stored in a refrigerator at 4˚C. Hydro-carbonate (HCO_3^-) was estimateperimetricallyly using 0.1 N HCl wiphenolphthaleinein and bromocresol as indicators (5%). Total hardness was determined by complexometric method using EDTA after added a tampon and Eriochrome T indicator. Calcium also was determined by complexometric method using murexide indicators. Magnesium was determined by subtracting the Total hardness and calcium. The Chloride was determined by titration with silver nitrate and potassium chromate indicator (Golterman *et al.*, 1978) [17]. The sulfate was determined using gravimetrical method. Fluoride was determined using a spectrophotometer (DR/2500 ODYSSEY at 650 nm). TSS (mg/l) were determined by filtration of 1l of water through analytical filter paper (Whatman 589, 185 μm pore size), which was dried at 105˚C and pre-weighed (APHA, 2005) [14]. The nutrients (NO_2^-, NO_3^-, NH_4^+, TP and PO_4^{3-}) were determined using a spectrophotometer at 630 nm for nitrogen and 850 nm for phosphorus (Wetzel and Likens, 2000) [18]. The concentrations of Na^+, F^-, Fe^{++}

and K^+ ions were determined by using Flame Photometer. Data were compared with UNECE (1994) [19] limit values of surface freshwater quality for the maintenance of aquatic life. Organic Pollution Index (OPI) were calculated based on BOD, nitrites, ammonium and phosphate (Gophen, 2012 [3]; Leclercq and Maquet, 1987; Mezbour *et al.*, 2018).

2.3. Statistical Data Analysis

Data analysis was done using Microsoft excel, the correlations between the parameters and different stations were done using PAlaeontological STatistics software (PAST). Results obtained were represented by use of text, graphs and statistical tables to show the interrelationships of various parameters in the stations.

A principal component analysis (PCA) was performed to evaluate the relationship between the sampling sites and the variation of the physicochemical parameters of the lake water. The resulting physicochemical parameters by sites were classified by cluster analysis (Ward's method, Euclidean distance).

3. Results

The mean physicochemical parameters of Lake Albert water are presented in Table 1. Table 2 shows the Pearson's r correlation between physicochemical parameters in different sites in the Lake Albert, DR Congo.

Table 1. Mean physicochemical parameters of Lake Albert water in six stations in DRC.

Stations	Drgi	Njerere	Spnga Tabu	Grand Bale	Licha ya Drgi	Ingbokolo	Standards
Temperature (˚C)	27.6 ± 0.6	27.6 ± 0.6	29.9 ± 1.4	29.8 ± 1.2	29.4 ± 1	28.9 ± 0.8	<37
pH	7.4 ± 0.6	7.2 ± 0.7	7.6 ± 0.6	7.1 ± 0.3	7.7 ± 0.6	6.6 ± 0.6	6.5 - 8.5
EC (µS/cm)	81.8 ± 36.2	72.2 ± 27.2	77.8 ± 32.1	77 ± 19	191.2 ± 106.2	81.5 ± 26	20 - 1500
Turbidity (NTU)	13.9 ± 11.6	32.7 ± 20.2	11.3 ± 22.7	54.8 ± 41.1	26.9 ± 15.2	23.9 ± 11.8	>5
TDS (mg/L)	40.9 ± 18.1	36.1 ± 13.6	38.9 ± 11.4	38.5 ± 9.5	95.6 ± 53.1	40.8 ± 13	≤400
TSS (mg/L)	3.8 ± 1.8	3.9 ± 1.8	9.8 ± 11.4	20.4 ± 13.3	50.7 ± 42.7	18.1 ± 4.6	20
TH (mg/L)	58.7 ± 5.9	58.7 ± 5.9	58.7 ± 5.9	34.5 ± 6.9	70.8 ± 29.3	47.4 ± 15.3	300
CaH (mg/L)	28.78 ± 7.6	28.8 ± 7.6	28.8 ± 7.6	15.6 ± 3	39.6 ± 29.1	26.6 ± 15.5	20 - 50
MgH (mg/L)	29.9 ± 1.7	29.9 ± 1.7	29.9 ± 1.7	18.8 ± 3.9	31.2 ± 0.1	20.8 ± 0.2	20 - 50
Alkalinity (mg/L)	25.2 ± 4.6	99.2 ± 38.2	99.2 ± 38.2	39.8 ± 9.3	53.8 ± 23.4	59.5 ± 37.3	−250
Sulphate (mg/L)	19.1 ± 14.4	18.2 ± 12.2	19.2 ± 7.6	18.2 ± 6.3	20.5 ± 6.6	23.1 ± 14.4	500
Chloride (mg/L)	3.0 ± 1.7	3.6 ± 1	4.8 ± 1.8	5.1 ± 2.3	5.4 ± 3.7	6.4 ± 2.1	250
Nitrite (mg/L)	0.004 ± 0.001	0.006 ± 0.006	0.008 ± 0.007	0.02 ± 0.02	0.01 ± 0.01	0.008 ± 0.007	
Nitrate (mg/L)	0.4 ± 0.2	0.2 ± 0.1	0.3 ± 0.3	0.04 ± 0.02	0.2 ± 0.2	0.2 ± 0.1	<45
Ammonium (mg/L)	0.05 ± 0.01	0.5 ± 0.09	1.3 ± 0.3	0.05 ± 0.01	1.3 ± 0.3	0.5 ± 0.6	100
Phosphore (mg/L)	0.4 ± 0.04	0.2 ± 0.04	0.3 ± 0.1	0.4 ± 0.1	0.2 ± 0.02	0.6 ± 0.2	0.6 - 1.28

Continued

Phosphate (mg/L)	0.1 ± 0.02	0.2 ± 0.1	0.3 ± 0.1	0.2 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	
DO (mg/L)	11.3 ± 1.1	7.5 ± 2.4	7.1 ± 2.2	6.6 ± 2.3	8.3 ± 2.2	5.0 ± 1.4	6
BOD5 (mg/L)	1.9 ± 0.4	1.8 ± 0.4	1.8 ± 0.4	1.8 ± 0.3	1.8 ± 0.4	1.9 ± 0.4	0 - 50
COD (mg/L)	40.8 ± 11.5	36.8 ± 10.2	41.8 ± 16.6	42.3 ± 22.1	42.3 ± 14	50.1 ± 32.9	10 - 20
Fe (mg/L)	0.1 ± 0.1	0.6 ± 0.2	1.9 ± 3.4	5.2 ± 1	4.0 ± 1.5	5.9 ± 1.3	0.05
F (mg/L)	0.08 ± 0.05	0.1 ± 0.08	0.1 ± 0.08	0.09 ± 0.02	0.2 ± 0.2	0.1 ± 0.08	0.6 - 1.2
K (mg/L)	1.4 ± 0.3	1.6 ± 0.5	1.3 ± 0.3	3 ± 0.9	2.8 ± 1.2	1.9 ± 1.2	
Na (mg/L)	4.6 ± 0.8	3.9 ± 1.6	4.9 ± 3.5	8.2 ± 1.4	14.8 ± 6.8	9.2 ± 3.9	

Legend: STD: Standard Deviation, Standards of water quality (WHO, 2006 [20]; UNECE, 1994 [19]; Boyd and Tucker, 1998 [21]; Ali *et al.*, 2000 [22]; Karume *et al.*, 2019 [23]).

Table 2. Pearson's r correlation between physicochemical parameters in different sites in the Lake Albert, DR Congo.

	pH	EC	Turb	TDS	TSS	TH	CaH	MgH	Alkal	Sulfate	Chloride	NO_2	NO_3	NH_4	TP	PO_4	DO	BOD	COD	Fe	F	K	Na
pH	1																						
EC	0.52	1																					
Turb	−0.39	-0.04^{c}	1																				
TDS	0.52	1	-0.04^{c}	1																			
TSSr	0.27^{a}	0.92	0.21^{b}	0.92	1																		
TH	0.74	0.62	−0.65	0.62	0.31a	1																	
CaH	0.61	0.74	−0.59	0.74	0.48	0.96	1																
MgH	0.83	0.38	−0.64	0.38	0.02c	0.93	0.80	1															
Alk	0.14^{c}	-0.19^{c}	-0.2^{b}	−0.19c	−0.24b	0.26b	0.18c	0.33a	1														
SO_4^{2-}	−0.43	0.25^{b}	−0.3a	0.25b	0.35a	0.07c	0.30a	−0.26b	−0.12c	1													
Cl^-	−0.41	0.28^{a}	0.2b	0.28a	0.58	−0.26b	−0.03c	−0.56	0.03c	0.73	1												
NO_2^-	-0.08^{c}	0.28^{a}	0.8	0.28a	0.58	−0.49	−0.40	−0.57	−0.26b	−0.14c	0.50	1											
NO_3^-	0.61	0.06^{c}	−0.9	0.05c	−0.28a	0.72	0.58	0.82	0.09c	−0.07c	−0.57	−0.79	1										
NH_4	0.62	0.58	−0.42	0.58	0.50	0.67	0.70	0.56	0.57	0.18c	0.31a	−0.02c	0.30a	1									
TP	−0.79	−0.39	−0.05c	−0.39	−0.23b	−0.54	−0.40	−0.66	−0.46	0.65	0.37	−0.13c	−0.19c	−0.55	1								
PO_4^{3-}	0.04	0.54	0.28a	0.54	0.73	0.08	0.24c	−0.14c	0.38	0.32a	0.78	0.58	−0.50	0.67	−0.28a	1							
DO	0.61	0.16^{C}	−0.36	0.16c	−0.14c	0.48	0.33c	0.63	−0.42	−0.44	−0.81	−0.39	0.71	−0.15c	−0.28a	−0.68	1						
BOD	−0.47	-0.25^{b}	−0.41	−0.25b	−0.30a	−0.11b	−0.03c	−0.20c	−0.52	0.58	−0.01c	−0.52	0.28a	−0.49	0.85	−0.58	0.19c	1					
COD	−0.58	0.04^{c}	−0.08c	0.04c	0.27	−0.32	−0.10	−0.59	−0.28	0.89	0.82	0.14	−0.29	−0.02	0.80	0.29	−0.55	0.56	1				
Fe	−0.53	0.23^{b}	0.49	0.23b	0.57	−0.50b	−0.27	−0.76	−0.24b	0.59	0.93	0.69	−0.77	0.01c	0.45	0.66	−0.74	0.02c	0.77	1			
F	0.49	0.97	−0.01c	0.97	0.92	0.63	0.75	0.39	0.00c	0.25b	0.36	0.29c	−0.01c	0.68	−0.47	0.67	0.02c	−0.38	0.03c	0.26b	1		
K	-0.09^{c}	0.52	0.77	0.52	0.76	−0.30	−0.16a	−0.46	−0.42	0.02c	0.48	0.91	−0.75	−0.05c	−0.10c	0.56	−0.26b	−0.37	0.17c	0.70	0.51	1	
Na	0.1^{c}	0.87	0.22b	0.87	0.98	0.22	0.42b	−0.10c	−0.32a	0.49	0.66	0.55	−0.34a	0.39	−0.04c	0.69	−0.21b	−0.13c	0.43	0.67	0.86	0.76	1

Legend: a: slight correlated, b: correlated; c: strong correlated.

Water of Lake Albert was generally rather neutral with a pH varied about 7.2 ± 0.2 in all the 6 stations of collections. The high pH (slightly alkaline) was recorded at Kicha ya Drigi (7.7 ± 0.6) and the lowest (slightly acidic) were recorded at Ingbokolo about 6.6 ± 0.6. Electrical conductivity ranged from 72.2 to 191.2 µS/cm. Surface water had turbidity values varied from 11.3 - 54.8 NTU. The high value was recorded at Grand Bale and the lowest at Songa Tabu stations.

The result related to organic matter (BOD) shown in this study revealed too that its values are very weak, aroud 1.8 mg/L. Total dissolved solids were high in surface water in the samples collected which ranged from 36.1 - 95.6 mg/L. The concentration of DO in the lake varied from 5 - 11 mg/L, indicating oxygenated water.

Alkalinity was higher in both Njerere and Songa Tabu (99.2 mg/L) and low value was recorded at Drgi (25.2 mg/L). Variation of alkalinity is probably due to an external phenomenon occurring in the site during the period of sampling and must be follow-up in the future. But the high levels of carbonates and hydrogen carbonates was attributed to presence of carbonaceous rock in the lake Albert basin. Chloride levels were low in both the six sampling sites with a mean of 4.7 ± 0.7 mg/L. Fluoride levels were low in all the sampling sites in the Lake Albert which ranged from 0.11 ± 0.06 mg/L. Sulphate levels were ranging from 18.2 ± 12.2 mg/L and 23.1 ± 14.4 mg/L.). The study showed that the concentration of PO_4^{3-} was in the range of 0.1 - 0.3 mg/L. The results revealed that NH_4^+ contents in Lake Albert were found to vary from 0.05 - 1.3 mg/L. The results revealed that the concentration of NO_3^- in the Lake Albert was in the range of 0.07 - 0.56 mg/L.

The Organic Pollution index is present in Figure 2.

Organic pollution index varied from 4.5 (Slight pollution) to 5 (Null pollution). Figure 2 reveals that the sites Songa Tabu and Kicha ya Drigi have a slight pollution index while Drigi and Grand Bale have null pollution index.

The hierarchical clustering for different sites in the Lake Albert water in DRC side shown that there is similarity between some sampling sites as presented in Figure 3.

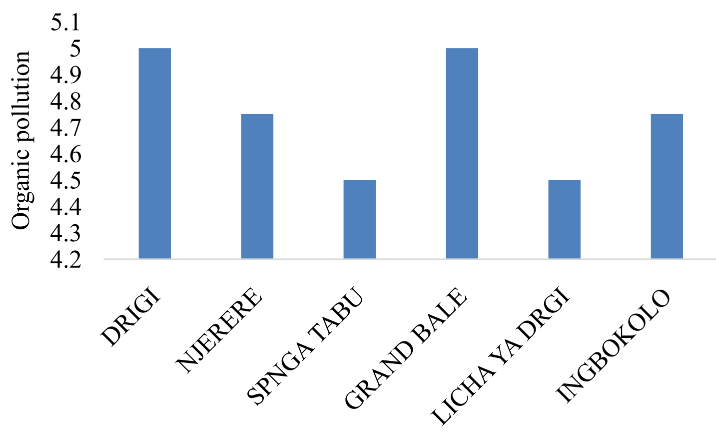

Figure 2. Organic Pollution of different sites.

The observations corresponding to the Grand Bale site are projected to the right of the factorial plane (B) whose waters are characterized by low mineralization and high anthropisation. On the other hand, the observations corresponding to the Njerere, Songa Tabu and Kicha ya Drigi sites are projected to the left of the factorial plane (A), with waters characterized by low mineralization and anthropisation for Drigi and waters characterized by high mineralization and low anthropisation for Ingbokolo (**Figure 4**).

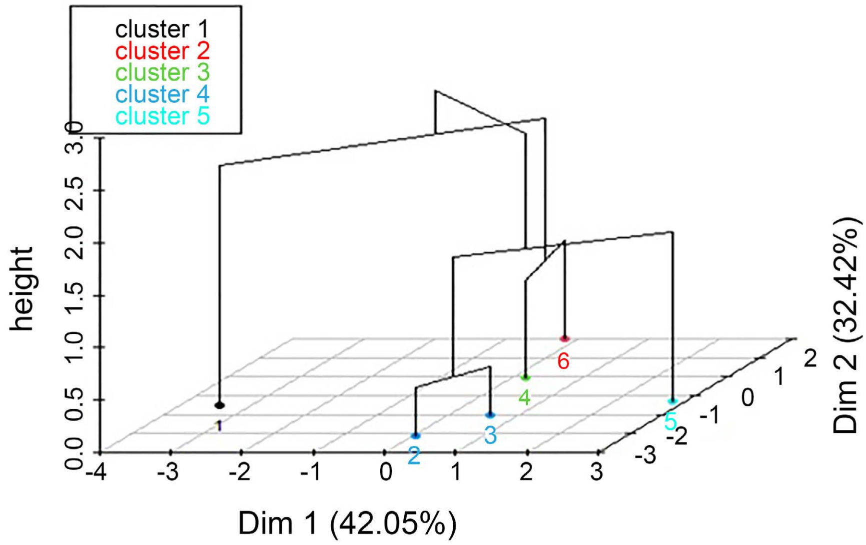

Figure 3. Cluster analysis (Ward's method) with 1: Drigi, 2: Njerere, 3: Ssonga Tabu, 4: Grand Bale, 5: Kicha ya Drigi and 6: Ingbokolo.

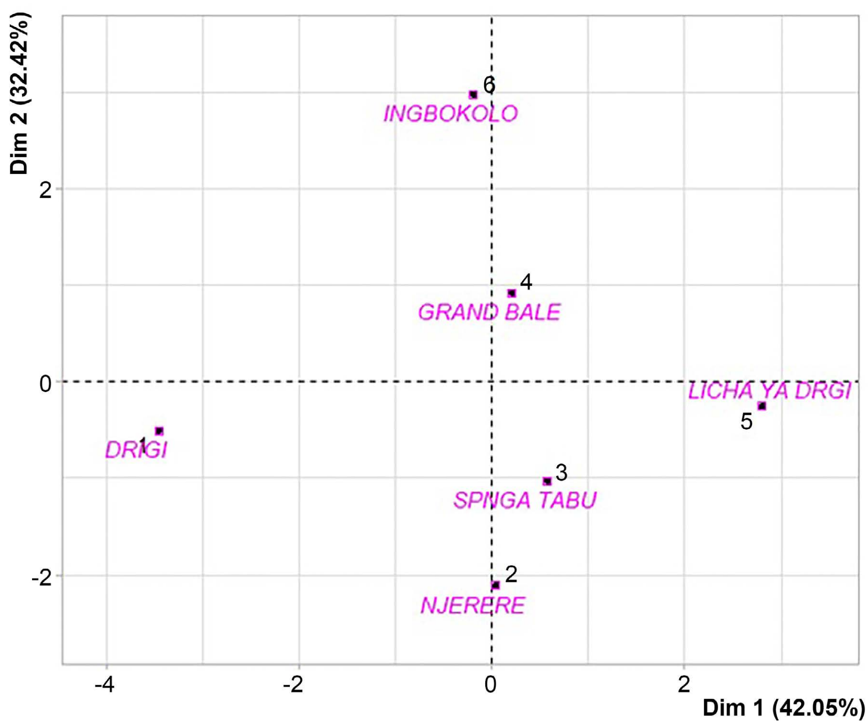

Figure 4. Principal component analysis of different sites in Lake Albert.

The result present in the analysis show the same as the one obtained with the cluster analysis. PCA analysis is in very good concordance with the result of the cluster analysis in Lake Albert. The dendrogram of the physico-chemical parameters in the different sites of Lake Albert in Figure 5 shows that there are 3 groups of similar sites. The PCA of the physicochemical parameters revealed the same results as the dendrogram presented in Figure 6.

Seasonal variation of physicochemical parameters in water quality in the different sites in the Lake Albert water are presented in the Figure 6. The pH was within the range of 6.5 - 9.5; which indicates that the water is made for fisheries and aquatic life.

4. Discussion

4.1. Water Quality of the Lake Albert

The pH was within the range of standard which indicates that the water is good for aquatic species (UNECE, 1994) [19]. The pH could be attributed to rocks in the study area that include the alkali-basalt, syenite and phonolites that have high concentration calcite minerals rich in carbonate ions (Hem, 1985) [24]. These variations are probably due to the input for watershed of runoff water coming from rivers as also observed by Olapade and Omotovin, (2012) [25] from Lake Kivu. Electrical conductivity is dependent on the type of rocks the

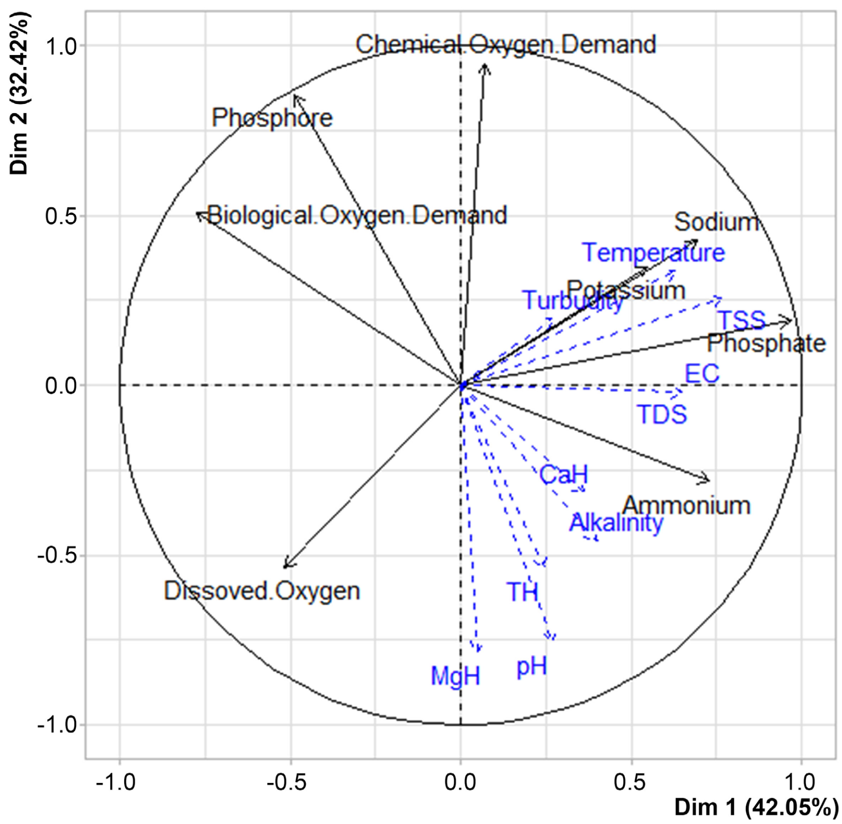

Figure 5. Principal component analysis of the different physico-chemical parameters studied at Lake Albert.

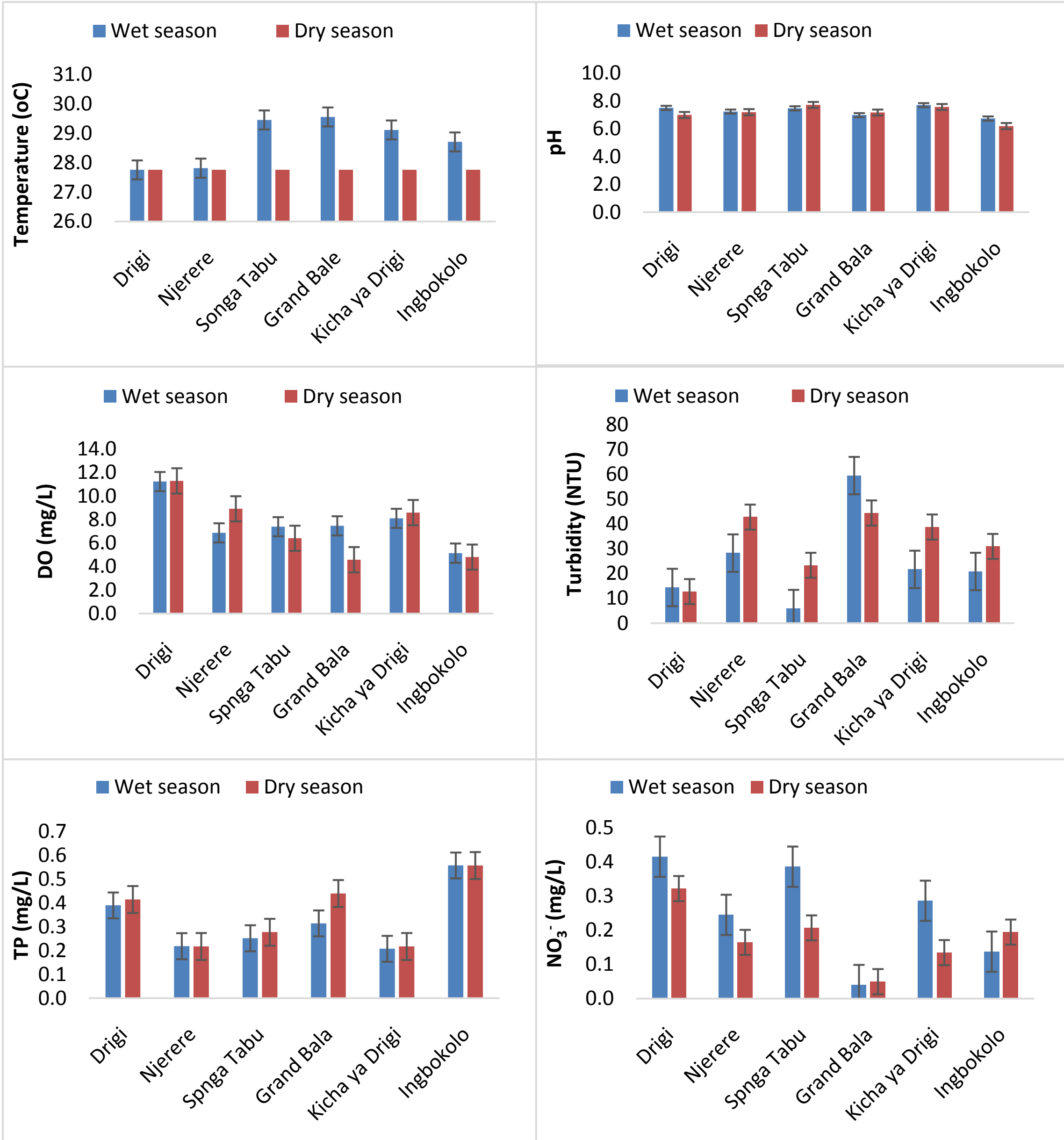

Figure 6. Seasonal variation of some physicochemical parameters of water quality in 6 stations of DRC Part of Albert Lake.

water is in contact with and how long it takes for water to percolate into the underground aquifer before to reach the lake (Lide, 1992) [26]. Water flowing in the Lake Albert basin tends to react with feldspath minerals mainly consisting of potassium, sodium and aluminum silicates before entering in the lake via rivers or groundwater (Wetzel, 2001) [27]. These tend to increase levels of dissolved ions in water (Hem, 1985) [24]. The low turbidity levels in underground water are attributed to the fact that silt sand and mud are trapped by the overlying rocks which act as a sieve. On the other hand, surface water had higher values of turbidity due to surface run-offs that carry silt and organic matter into the lake from streams and rivers (Karume *et al.*, 2019 [23]; Muraga *et al.*, 2017 [28]).

According to WHO drinking water guidelines, drinking water should have turbidity levels of below 5 NTU (WHO, 2006) [20]. The high levels of total dissolved solids (TDS) were attributed to the geology of the area of study that had high levels of sodium, calcium, carbonates and sulphates (Muraga *et al.*, 2017) [28]. The standards require that water which is deemed safe for drinking should have TDS levels of less than 500 mg/L (UNECE, 1994) [19].

Generally, DO > 4 mg/L is suitable for drinking purposes and it was considered as 6 mg/L for the healthy aquatic life and metabolic activities of microorganisms (Pant and Adhikari, 2015) [29]. The direct diffusion from air and photosynthesis activity of autotrophs maintains the DO in water bodies (Pal *et al.*, 2019).

Chloride levels in the Lake Albert surface water is between the standard acceptable limit of 250 mg/L (UNECE, 1994) [19]. The concentration of Cl^- in some sampling point could be due to anthropic activities like bathing, and others activities around the lake as found also by Khadka *et al.* (2021) [4] in Nepal. The Cl^- concentration in water is the indicator of anthropic disturbance and excessive chloride but this was not indicated in this study which can increase the level of TDS in water as observed by Pant *et al.*, (2020) [30] in the Gandaki River, Central Himalaya Nepal. As also found in other lakes in the region as Lake Kivu and Lake Edward (Bagalwa *et al.*, 2014 [31]; Karume *et al.*, 2016 [32]; Bahaya *et al.*, 2021 [33]). The fluoride levels were lower than those recommended by WHO of 1.5 ppm in water for human consumption (WHO, 2006) [20]. The Fluoride levels in the lake at these concentrations is essential in the formation of enamel in children, studies have shown that daily intake of fluoride at concentration above 0.5 mg/L could lead to mild dental fluorosis in children. The high levels of sulphates compared to different sites in surface water of Lake Albert could be attributed to anthropogenic activities and runoff from bedrocks. Whereas there is no known health risk associated with high intake of sulphates, it is recommended that drinking water should not exceed 500 mg/L of sulphate it would increase the risk of gastrointestinal effects such as diarrhea (WHO, 2006) [20].

Eutrophication is the major problem found in lakes due to phosphorous and nitrogen compounds. Their excessive concentration may lead to the growth of plants and algae and threaten the sustainability of the lake environment. Nitrates and Phosphates levels were lower at all the stations in the Lake. Concentration of nitrates and phosphates in surface water could be due to inorganic nitrate fertilizers or from contamination from human and animal wastes as a result of oxidation of ammonia by anaerobic bacteria and find their way in into waterways through surface run-offs (Bagalwa *et al.*, 2015 [34]; Karume *et al.*, 2016 [32]), the water indicating relatively moderate eutrophication as found also by Khadka *et al.*, (2021) [4] in Jhilmila Lake, Kanchanpur, Nepal. The sources of PO_4^{3-} in the lake water could be from the anthropic activities.

Most of the sampling sites showed total NH_4^+ contents lie in permissible WHO guidelines. However, the NH_4^+ contents were found comparatively more in some sampling points ($t = 2.958$; $p < 0.05$) in the lake could be due to sewage contaminations and natural degradation of organic matters, within the WHO guidelines for drinking water (<75 mg/L). Comparison of the physicochemical parameters of different sites was significative difference between them ($F = 20.8$; $p < 0.05$) mining that they have different water quality. This was also observed by Horsak *et al.*, (2007) [35] on modern distribution patterns of snails and plants (Boukari *et al.*, 2022) [36].

A principal component analysis (PCA) was carried out in order to highlight the relationships that may exist between the different parameters at the sampling points (**Figure 5** and **Figure 6**). The factorial design summarized 74.47% of the overall information. The F1 axis, with 42.05% of the total variance is represented by Sodium, Potassium, Phosphate, Ammonium; Temperature, Turbidity, TSS, Conductivity, STD, CaH, Alkalinity, TH, MgH and pH. The groupings of these parameters in the two opposite poles of this axis show that the composition of the water is influenced by two different phenomena. The parameters salinity, conductivity and TDS provide information on the degree of mineral pollution of the water. There is an increasing mineralization gradient from the positive to the negative pole of the axis. The parameters temperature and SS determine the degree of organic pollution of the water. An increasing organic pollution gradient is created from the negative pole to the positive pole. Most of the information provided by the F2 axis (32.42% of variance) is explained by phosphorus, biological oxygen demand and dissolved oxygen (**Figure 6**).

4.2. Seasonal Change of Physicochemical Parameters

Temperature shows a seasonal variation in wet season but no variation ($p > 0.05$) was recorded in dry season but is within the ranges UNECE, (1994) [19]. Temperature has a pronounced effect on the rate of chemical and biological processes in water; no other single factors affect development and growth of fish as much as water temperature (Babalola and Agbedi, 2013 [37]; Bagalwa *et al.*, 2014 [31]; Odjohou *et al.*, 2020 [38]). Based on the guideline of UNECE, (1994) [19], the pH of Lake Albert water has not adversely affected in aquatic ecosystem. This was also obtained in Lake Edward as recorded by Bagalwa *et al.*, (2014) [31].

DO concentration in the lake is one of the important parameters in water quality assessment. It reflects the physical and biological processes prevailing in the water. High concentration of DO was recorded in wet and dry season compared to Lake Edward (Bagalwa *et al.*, 2014 [31]; Ciwanine *et al.*, 2020 [39]). The site Drigi has high DO levels during the period of sampling compared to other sites ($p < 0.05$). The site Ingbokolo has low DO compared to all other sites. Turbidity was high in Grand Bale in wet and Njerere and Kicha ya Digri in dry. According to Mbalassa *et al.*, (2014) [13], transparency varied significative in Lake Edward as we recorded also in the Lake Albert during our sampling period. The turbidity affects the penetration of light underwater reduce the fish production, visibility but also the others biodiversity (Ali *et al.*, 2000 [22]; Kamelan *et al.*, 2022).

Nutrients are required to sustain life, but excess nutrient loads can upset the nutrient cycle balance resulting in changes in water quality harmful to organisms (Aldous *et al.*, 2005) [40]. Nitrate and phosphorous concentration recorded in the water are washed from the basis of the lake as observed also in Lake Kivu (Bagalwa *et al.*, 2015) [34]. There is a seasonal variation in some sites in the lake for the phosphorus and nitrate.

As most of African lakes at have been monimonitored, the concentration of physicochemical parameters is due to activities around their basin due to agriculture and urbanization. Lake Albert water quality is still pristine since concentration of phosphorus and nitrogen are not under the critical rates of eutrophication in the lake. The results suggest that although physicochemical parameters in these habitats were suitable for most aquatic species (UNECE, 1994 [19]; Soro *et al.*, 2021 [41]) especially to *Bargus bayad*, they were subject to high spatial variations. The variations detected could reach adverse conditions if any measure is not taken to regulate agricultural activities in the basin of Lake Albert.

5. Conclusion

The current study provided useful information about the water quality of different sites in Lake Albert where the fish species *Bagrus bayad* was recorded. The physicochemical parameters considered in this investigation were within the limits for aquatic life of biodiversity in aquatic ecosystem especially for survival and reproduction of aquatic species. It is therefore evident that communities living in these areas used the lake water for drinking. The results suggest that although physicochemical parameters are within the limits for aquatic life, they are suggesting to high variation during the time. The change in land use and land cover around the basin and the pollution due to rivers tributaries to the Lake Albert can be fatal to the life of biodiversity in long time. A regular assessment of physicochemical parameters and land use and land cover are useful in the basin to check the water from further deterioration. This must be taken into account to ensure the conservation of these critical aquatic ecosystems.

Authors' Contributions

JMM was involved in all phases of the study. This includes study design, data collection, data processing, data analysis and writing of this manuscript; GMO, GK, JJB, was involved in study design, data processing, data analysis and writing of this manuscript. MM, VMN, PA, HN, JCM, GN, JJ and SIL were involved in the design of the study and the editing of the manuscript.

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Conflicts of Interest

The authors declare that there are no conflicts of interest.

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