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ANTHROPOGENIC POLLUTION IMPACT ON PHYSICO - CHEMICAL CHARACTERISTICS OF LAKE KIVU, RWANDA

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ABSTRACT

Anthropogenic activities such as industrial effluent, domestic and agricultural waste disposal constitute major sources of pollution in water. The effects of these pollutants on the physico-chemical properties of Lake Kivu, Rwanda were investigated at three locations (Gisenyi, Kibuye and Cyangugu) between February 2005 and December 2006. Water samples used for physico-chemical analysis were collected from 12 stratified points on the lake. Samples collected were analysed and interpreted using appropriate international procedures. The physico-chemical properties measured were temperature, conductivity, pH, transparency, salinity, total alkalinity, dissolved organic matter (DOM), total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), nitrate – nitrogen, phosphate – phosphorus and sulphate. Mean water temperature measured (24.7 $\pm$ 0.58^{o}C) was highest in Kibuye and lowest (24.5 $\pm$ 0.31^{o}C) in Cyangugu. The lake water was moderately hard with mean total alkalinity values of 88.1 ± 1.63mgL^{-1}; 79.7 ± 2.36mgL^{-1} and 81.0 ± 2.46mg L^{-1} recorded in Gisenyi, Kibuye and Cyangugu respectively; salty and alkaline with mean pH values of 8.87 ± 0.07 in Gisenyi; 8.86 ± 0.06 in Kibuye and 8.91 ± 0.06 in Cyangugu. Total dissolved solids (TDS) level in the lake was above the 500mg L^{-1} prescribed by WHO while the mean biochemical oxygen demand (BOD) reading was within the range for unpolluted or moderately polluted lake. Water from the lake showed mineralization with mean conductivity values ranging from 1058 - 1184µScm^{-1} in Gisenyi; 1058 - 1147µScm^{-1} in Kibuye and 1031 - 1116µScm^{-1} in Cyangugu. The mean dissolved oxygen values were below the 5mgl^{-1}limit recommended by WHO for fresh water fish species. SO_{4-} $^{-2}$ and NO_3 – N concentration in the lake water does not constitute any serious health risk to both man and the aquatic organisms it supports. However, there is the need to constantly monitor the lake water to mitigate any build up of the ions to a hazardous level.

Key words: Anthropogenic, Physico-chemical, Lake Kivu, Rwanda

INTRODUCTION

Water resources have been the most exploited natural system since man strode the earth. Rapid population growths, increasing standards, wide spheres of human activities and industrialization have resulted in greater demand for good water and thus increasing the pollution of water steadily [1]. A number of factors influence water chemistry [2]. Rock weathering, atmospheric precipitation, evaporation and crystallization control the chemistry of surface water [3]. The influence of geology on chemical water quality is widely recognised [4, 5]. Soils influence on water quality is very complex and can be ascribed to the processes controlling the exchange of chemicals between the soil and water [6].

Apart from natural factors influencing water quality, human activities such as domestic and agricultural practices impact negatively on river quality [2].The quality of water plays a vital role in the productivity of aquatic habitat. The understanding of the water chemistry serves as basis for considering whether the water is rich or poor in biological production. The physical and chemical properties of water greatly influence the uses, the distribution and richness of the biota [7]. The technique of using physical and chemical properties to assess water bodies is essential; it reveals the concentration of known environmental contaminant which could render such water unfit for human consumption and other uses [7]. It is therefore necessary to develop a means and methods of protecting water against biodegradable and biological pollutants and also against non - biodegradable wastes and toxic inorganic compounds.

This study was undertaken to assess the physico–chemical properties of Lake Kivu as a means of evaluating its pollution status. The results of this study will provide information on the physico – chemical parameters of the lake at the epilimnion.

MATERIALS AND METHODS

Study Area

Lake Kivu is one of the smaller lakes of the East African Lakes region. It is situated on the border between Rwanda and Democratic Republic of Congo. Together with lakes Albert, Edward-George and Tanganyika, it forms the western loop of the East African rift valley system [8]. It is a deep (maximum 489m), meromictic lake, with oxic mixolimnion up to 70m and a deep monimolimnion rich in dissolved gases, particularly methane [9]. The average daily temperature in the lake area is 23^{o}C (73^{o}F); relative humidity range between 59 – 83% while the average yearly rainfall is 1300mm [10, 11].

Sampling Procedure

The lake was sampled bi – monthly for a period of 24 months at three major towns, Gisenyi, Kibuye and Cyangugu (Figure 1). The towns were chosen based on anthropogenic activities going on in them. Water samples for physicochemical parameters were collected sub-facially at between 0 – 30cm. Water samples for water quality parameters assessment were collected in previously acid leached sampling bottles of 600ml capacity. The following parameters – Surface water temperature, pH, Dissolved oxygen (DO), Alkalinity, Biological oxygen demand (BOD), Dissolved organic matter (DOM), Free carbon (F – CO_2), Phosphate – phosphorus, Transparency, Total dissolved solids (TDS), Salinity, Nitrate – nitrogen and Conductivity were determined [12,13,14].

The transparency of the lake water was determined with the aid of the secchi disc at the stratified points. The disc was lowered into the water and the depth at which it disappeared was observed and recorded. It was thereafter gradually withdrawn from the water and the depth at which it became visible was noted and recorded. The transparency of the water body was calculated as the mean of the two readings. Hanna comb meter (Model HI 8915) and a dipping thermometer (0-50^{0}C) were used interchangeably to determine the surface temperature of the lake water. The meter sensor was dipped into the water and the temperature reading was recorded after the meter had stabilized. The hydrogen ion concentration (pH) was determined in-situ using a standard laboratory meter – Hanna comb meter (Model HI 8915) that was first standardized with two buffers (6.9 and 9.2). The buffer (pH 6.9) was prepared using 3.388g of KH_2PO_4 and 3.533g of Na_2HPO_4 (dried at 130^{0}C) and dissolved in distilled water. Buffer (pH 9.2) was prepared by dissolving 3.80g of $Na_2B_4O_7.10H_2O$ (air-dried) in 1000ml of distilled water [12]. Alkalinity was estimated titrimetrically using 0.02N H_2SO_4 with phenolphthalein and methyl orange as indicators. The level of dissolved oxygen in the Lake water was determined at a depth of 30cm using the standard Winkler method [13]. Fixed samples (100ml) showing brown precipitate of oxidized manganous ions was dissolved by the addition of 2ml concentrated suphuric acid. This oxidizes the manganous iodide into iodine. The amount of iodine liberated was determined by titrating 100ml of the sample with standard 0.025ml sodium thiosulphate ($Na_2S_2O_3$) solution. A starch indicator was used to determine the end point of the titration. A change from blue colour to colourless liquid indicated the end point.

The dissolved oxygen concentration was calculated using the following formula.

$$\text{Dissolved Oxygen (DOmgl}^{-1}) = \frac{\text{(ml titrant) (N) (1000) (8) ml}}{\text{Sample vol. in ml x 4}}$$

Where ml titrant = volume of $Na_2S_2O_3$ used in titration
N = Normality of $Na_2S_2O_3$
8 = Oxygen concentration equivalent 1ml of 1N $Na_2S_2O_3$
1000 = conversion factor to 1 litre.

Duplicate water samples were incubated in the dark in a coated container at 25^{o}C for five days after which the dissolved oxygen concentration was determined.
The biological oxygen demand (BOD) in mgl^{-1} of dissolved oxygen was calculated by subtracting the mgL^{-1} of dissolved oxygen in incubated sample bottles from the dissolved oxygen in initial bottles.

$$\text{BOD mg/l} = DO_1 - DO_2$$

DO_1 = Dissolved Oxygen in the initial sample before incubation
DO_2 = Dissolved Oxygen in the incubated sample

Salinity was determined using standard laboratory conductimeter (Hanna Instrument Model HI 8033). Nitrate-Nitrogen was estimated titrimetrically using the method of [13]. Filtered water samples (100ml) were distilled in a Kjeldah flask using 1g MnO as catalyst. And thereafter 25ml of the distillate was collected into conical flask. Devarda`s alloy (1g) was added to the remaining samples and were further distilled. Another 25 samples of the distillate were collected into a different flask. The distillate fractions contained NO_3-N.

Calculation:

Amount of Ammonia/Nitrate-Nitrogen (ppm)
= Number of matching division of the standard disc x 10 x 0.001 (standard of each disc division).

The phosphate-phosphorus was determined by using the stannous chloride method [14]. To a 100ml of water sample, a drop of phenolphthalein indicator was added. A strong acid (HNO_3) was added drop wise to discharge the pink colour of the sample. 4.0ml- molybdate reagents was added to this sample and mixed again. Absorbance was measured at 420nm on spectrophotometer (Cecil – CE 2041 – 2000series) and the results were compared with a calibration curve using distilled water blank and known phosphate standards treated through the same procedure used for the sample. Total dissolved solids (TDS) were measured using standard laboratory equipment, conductimeter (Inolab- Hach product, Germany).

50ml of filtered water sample was poured into a 250ml conical flask and acidified by adding 5ml of dilute H_2SO_4. 10ml of standard $KMNO_4$ solution was added to the sample and kept on water bath for half an hour. Thereafter, 10ml of ammonium oxalate solution was added, the pink colour of permanganate disappeared. 10ml of $KMNO_4$ was added drop wise with a pipette until the pink colour just reappeared.

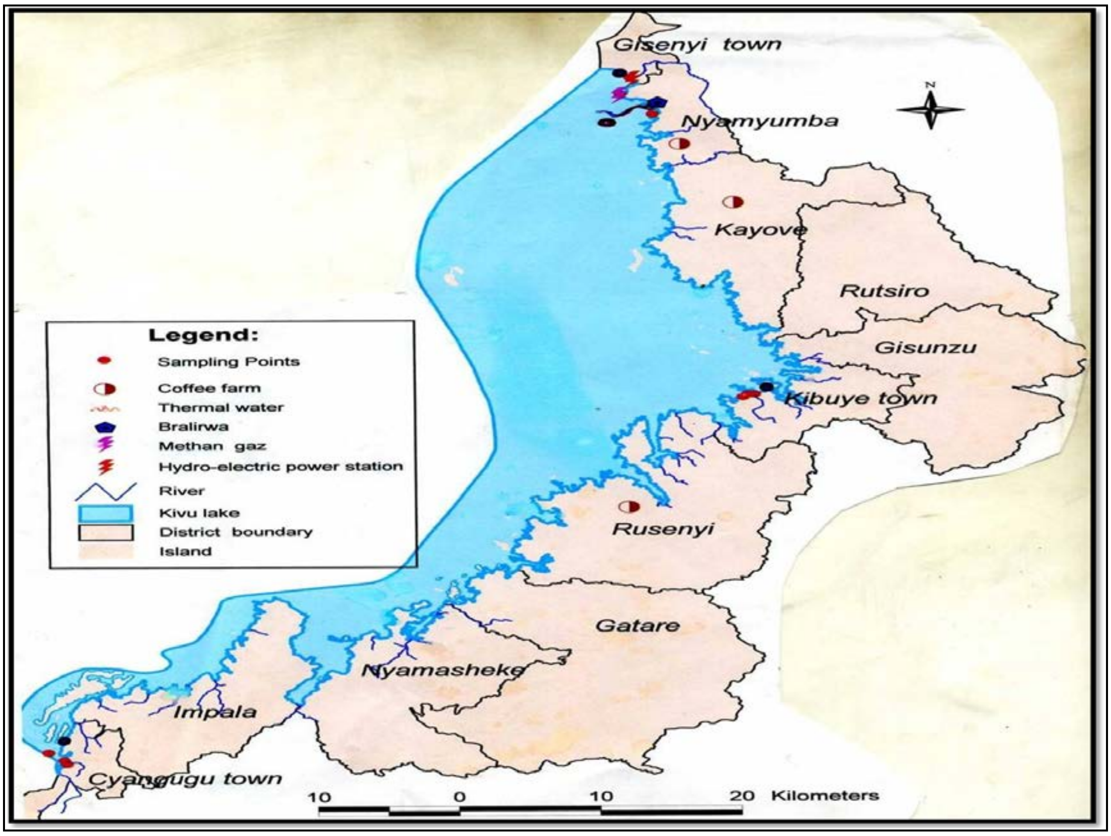

Figure 1: Map of Lake Kivu, black dotted points indicate sampling locations

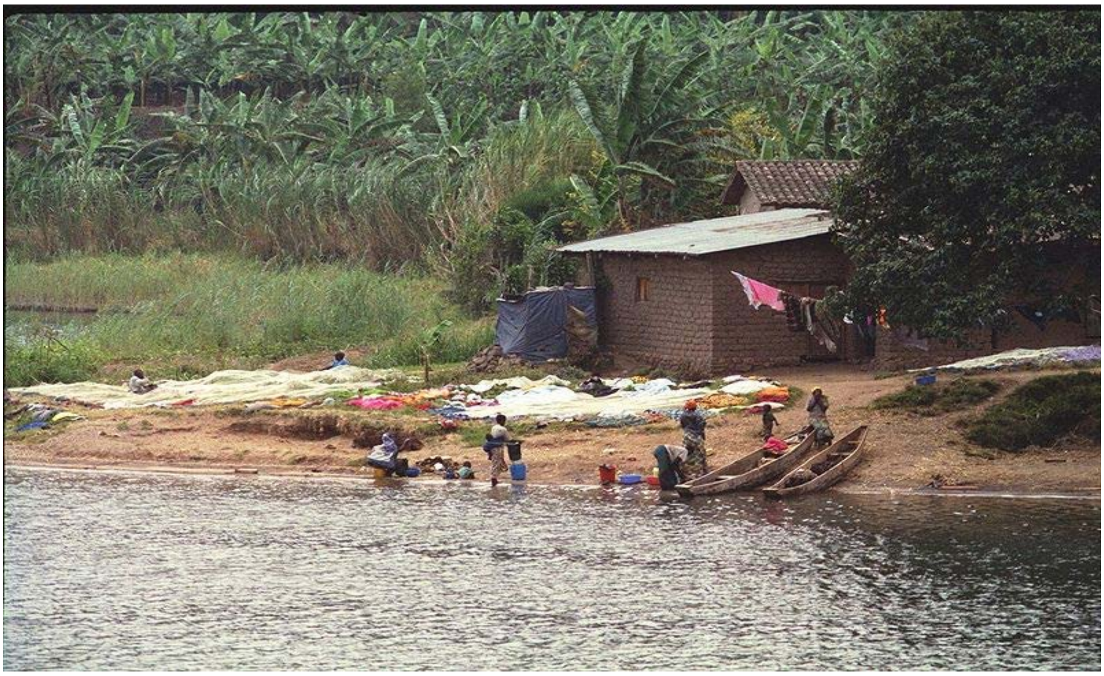

Plate 1: Women laundering at shoreline of Lake Kivu in Gisenyi. Residents in most of the villages here bath in the lake and defecate at the shoreline

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Statistical Analysis
Results of physicochemical parameters were analysed using basic statistics such as mean, standard deviation and descriptive statistics. Analysis of variance was used to find level of significance in seasonal variation in water quality parameters. Inter - correlation between physico - chemical factors and months of sampling was determined [15].

RESULTS

The results of the mean bi – monthly values (± SD) of the physico – chemical parameters of the three sampling locations are presented in Table 1. Table 2 shows the correlation matrix of the mean values of measured parameters while the mean water quality parameters at the sampling locations compared with water quality criteria for public surface water supplies (mgL^{-1}) are presented in Table 3. Mean seasonal variations in physicochemical parameters measured are represented in Figure 2 – 10. There were mean differences in conductivity, pH, and total alkalinity, TDS, DO, NO_3 –N, PO_4 - P and SO_4. Mean surface water temperature (24.7 ^oC ±0.58) was highest in Kibuye and lowest (24.5 ^oC ±0.31) in Cyangugu but there were no significant variations in values obtained in the three locations. Mean pH (8.91±0.20) was highest in Cyangugu and lowest (8.86±0.20) at Kibuye. Transparency in Cyangugu was slightly lower than in Gisenyi and Kibuye. Dissolved oxygen concentrations in all the locations were not significantly different. The mean seasonal total alkalinity recorded in all the locations showed that Gisenyi has the highest total alkalinity than Cyangugu and Kibuye respectively. Mean total dissolved solids were higher in Gisenyi than in Cyangugu and Kibuye respectively. Cyangugu had a higher BOD than Kibuye and Gisenyi. Phosphate value measured in the dry season for Kibuye and Gisenyi was $0.191mgL^{-1}$ while $0.18mgL^{-1}$ was recorded for Cyangugu in the same season. Phosphate varied significantly ($p<0.05$). It correlates positively with months, conductivity and NO_3 – N but correlates negatively with total alkalinity. Dissolved organic matter measured ranged between $2.40mgL^{-1}$ and $5.70mgL^{-1}$ and did not varied significantly with location and sampling period. Except for TDS, the values obtained were below the quality criteria for the respective parameters.

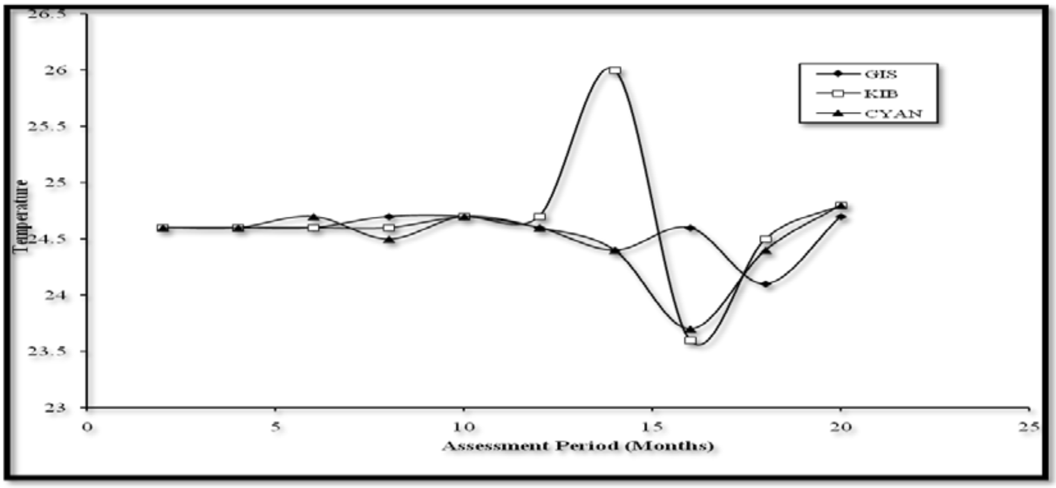

Figure 2: Mean water temperature at different location across period of assessment

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The mean surface water temperature is presented in Figure 2 above. Mean surface water temperature ranged from 24.1 – 24.7^{0}C in Gisenyi; 23.6 – 26.0^{0}C in Kibuye and 24.4 – 24.8^{0}C in Cyangugu during the experimental period. The highest water temperature recorded in the experiment was recorded in February and December in Kibuye. The lowest mean water temperature values recorded was also obtained in Kibuye in April of the sampling year. Water temperatures were generally average between minimum and maximum air temperature.

The mean *p*H value of 8.91± 0.06 obtained in cyangugu was higher than the 8.87 ± 0.07 in Gisenyi and 8.86 ± 0.06 in Kibuye (Figure 3). The highest values of 9.33, 9.31 and 9.30 units were recorded in Kibuye, Gisenyi and Cyangugu respectively. The lowest *p*H value of 8.63 units was recorded June in Kibuye. The results of analysis of variance of *p*H at the sampling locations showed significant difference ($p<0.05$) with months.

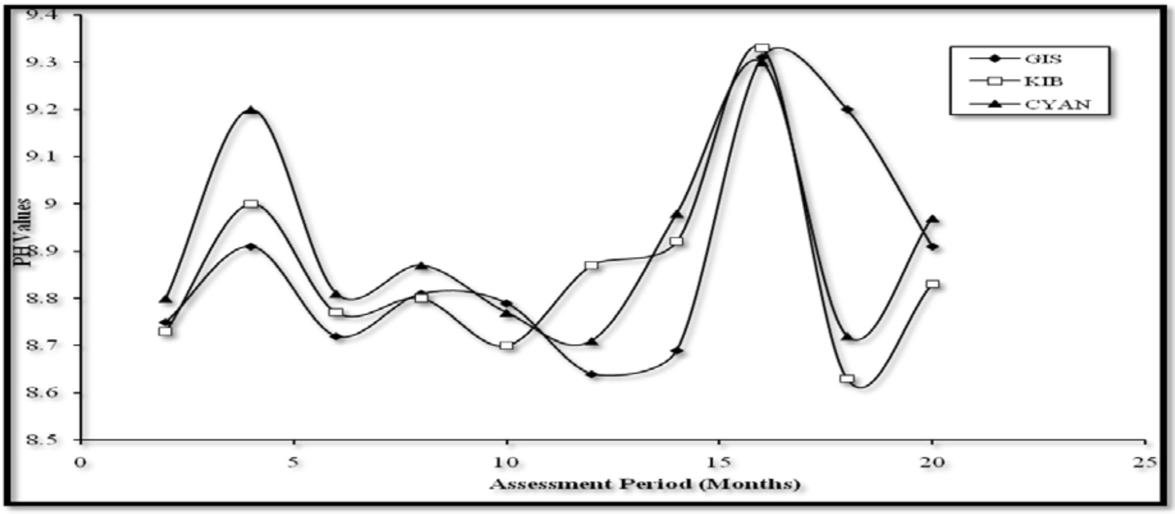

Figure 3: Mean *p*H at different location across period of assessment

Mean dissolved oxygen value was 5.15 ± 0.49mgL^{-1} in Cyangugu. This value was not different from 5.10 ± 0.613mg/L and 5.10 ± 0.58 mgL^{-1} recorded for Kibuye and Gisenyi. Maximum value of 6.20mgL^{-1} was recorded in August, for Kibuye, Gisenyi and Cyangugu. There were significant variations ($p<0.05$) in oxygen content with respect to period of assessment. However, variation in oxygen content was not significant between locations. Analysis of variance of DO content in the lake showed significant differences ($p<0.05$) with months of sampling locations (Figure 4).

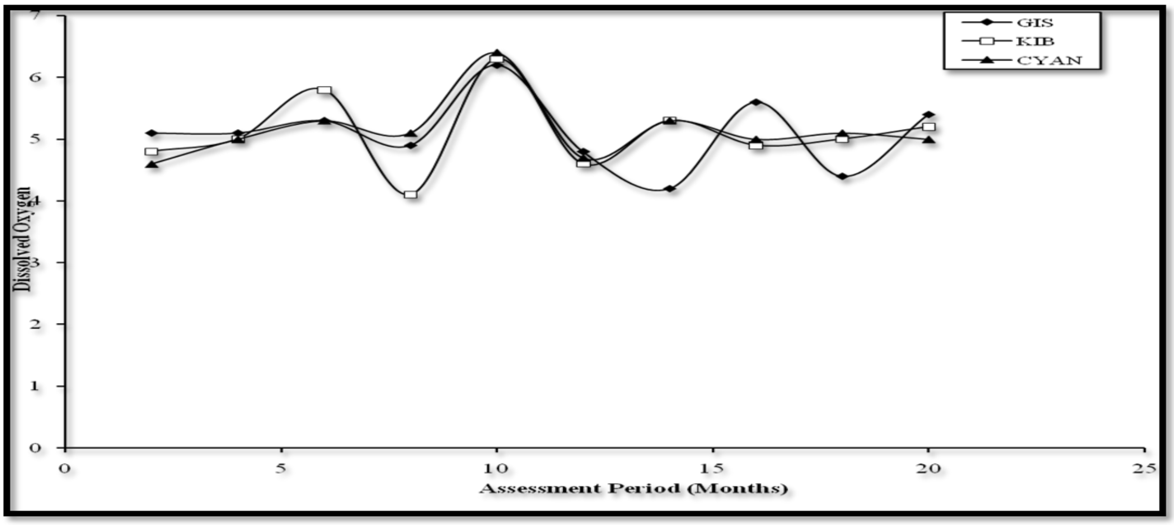

Figure 4: Mean Dissolved Oxygen at different location across period of assessment

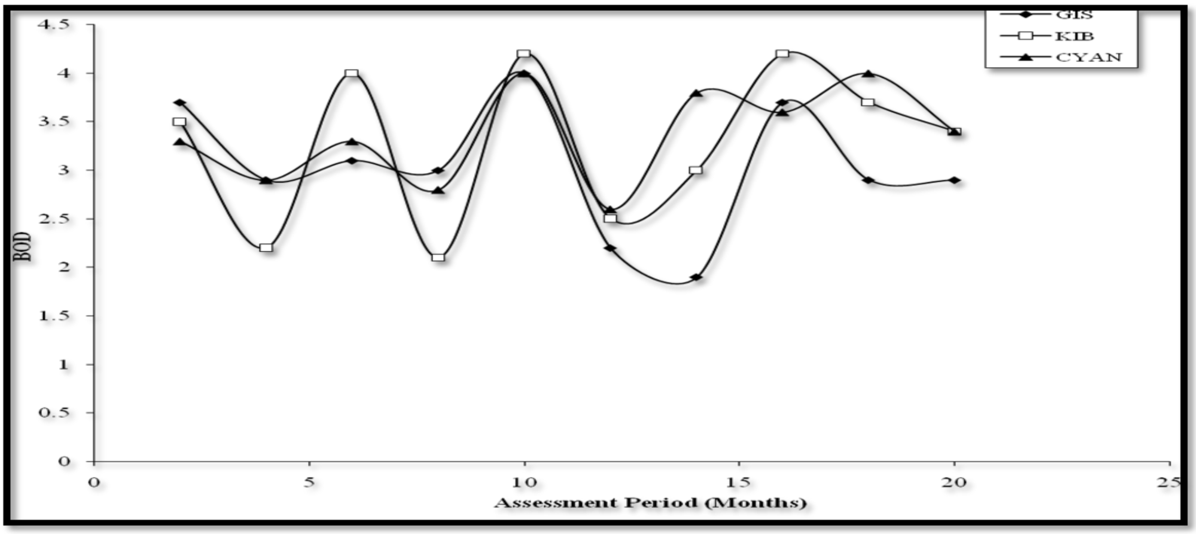

Figure 5: Mean Biological Oxygen Demand at different location across period of assessment

Mean BOD values 3.03 ± 0.65mgL^{-1}: 3.28 ± 0.80mgL^{-1} and 3.37±0.49mgL^{-1} was recorded for Gisenyi, Kibuye and cyangugu respectively (Figure 5). These values were not significantly different ($p>0.05$) however there was significant difference ($p<0.05$) with months of sampling. Maximum BOD value of 4.20mgL^{-1} was recorded in Kibuye in October and April; and 4.00mgL^{-1} in Cyangugu in October and June of the two sampling years. Minimum values of 1.9mgL^{-1}, 2.1mgL^{-1} and 2.8mgL^{-1} were recorded in Gisenyi in February and August in Kibuye and Cyangugu respectively.

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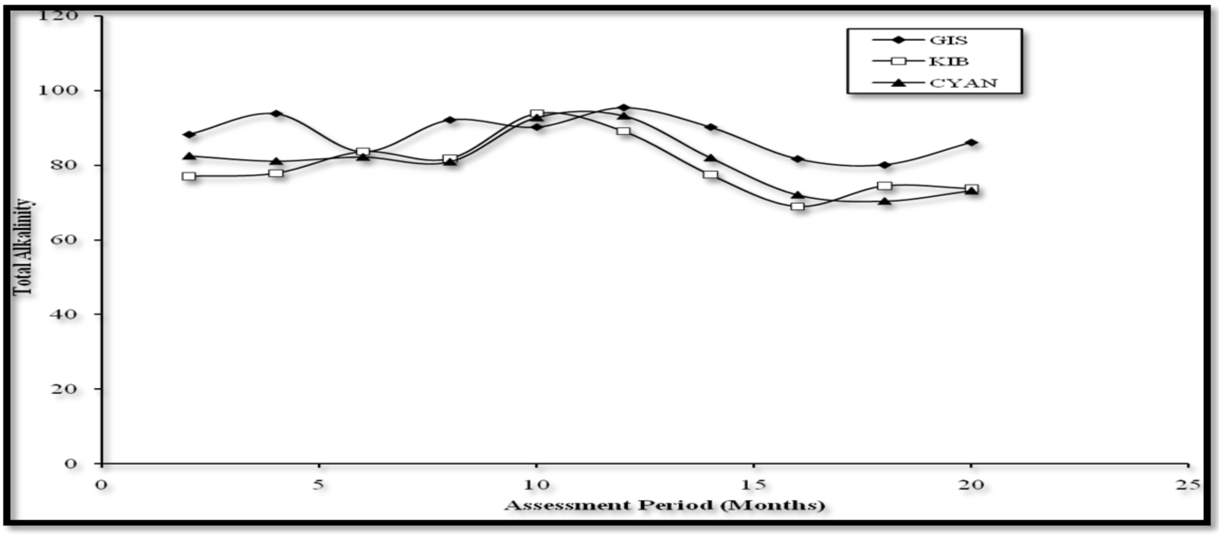

Figure 6: Mean Total Alkalinity at different location across period of assessment

Mean total alkalinity variations in the sampling locations are presented in Figure 6. Mean total alkalinity values of 88.1 ± 1.63 mgL^{-1}; 79.7 ± 2.36mgL^{-1} and 81.03 ± 2.46 mgL^{-1} were recorded in Gisenyi, Kibuye and Cyangugu respectively. The alkalinity concentration values ranged from 68.9mgL^{-1} $CaCO_3H$ to 95.4mgL^{-1} $CaCO_3H$. The LSD test showed significant variation in mean monthly total alkalinity concentration and it negatively correlate significantly with months, conductivity, pH and Fe ($P < 0.05$; r = –0.37*; -0.44*; -0.45* and –0.14* respectively). The result of analysis of variance showed that total alkalinity was significantly different with months and locations of sampling ($p<0.05$).

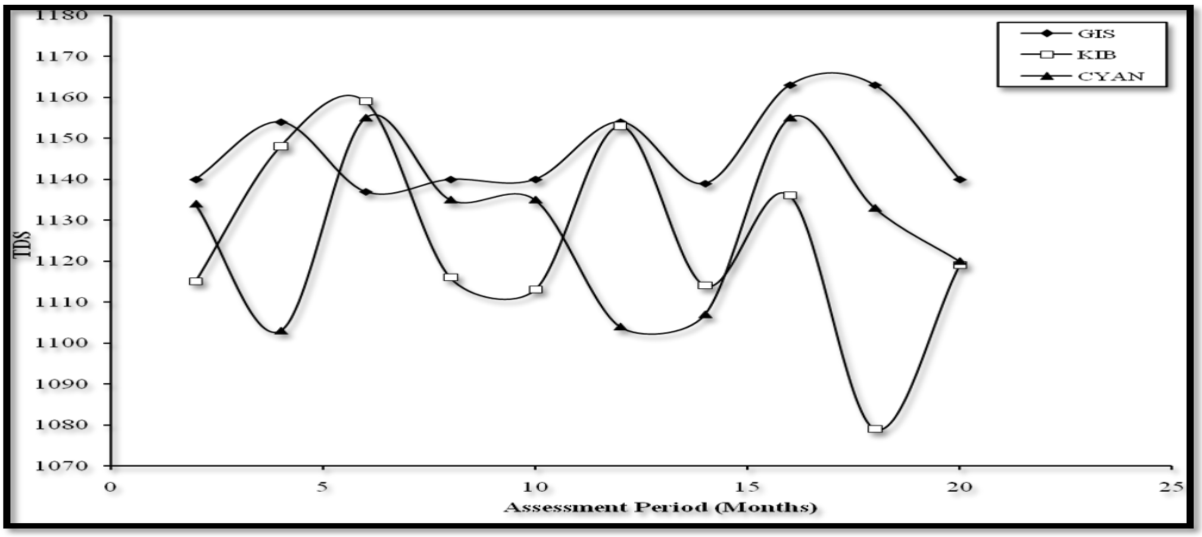

Figure 7: Mean Total Dissolved Solids at different location across period of assessment

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The variation in the total dissolved solids content recorded in the three locations across the period of assessment is presented in Figure 7. Mean TDS value of 1147.0 ± 3.28 mgL^{-1}; 1125.2 ± 7.59 mgL^{-1} and 1128.1 ± 6.08 mgL^{-1} were recorded for Gisenyi, Kibuye and Cyangugu respectively. Analysis of variance for TDS was significantly different ($p < 0.05$) with assessment period but was not significantly related to sampling locations. LSD test showed no significant difference ($p > 0.05$) between Kibuye and Cyangugu.

The dissolved organic matter content of the Lake water is presented in Figure 8. High mean dissolved organic matter values of 5.60mgL^{-1}; 5.40mgL^{-1} and 5.70mgL^{-1} were recorded in Gisenyi, Kibuye and Cyangugu respectively. There were no significant differences in the mean values of dissolved organic matter recorded in the sampling locations.

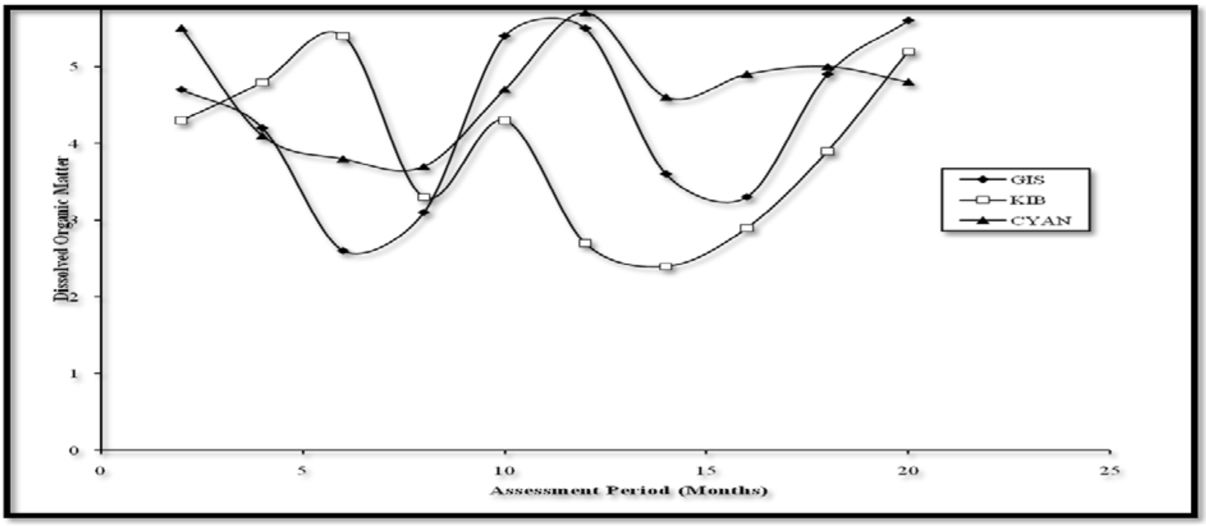

Figure 8: Mean Dissolved Organic Matter at different location across period of assessment

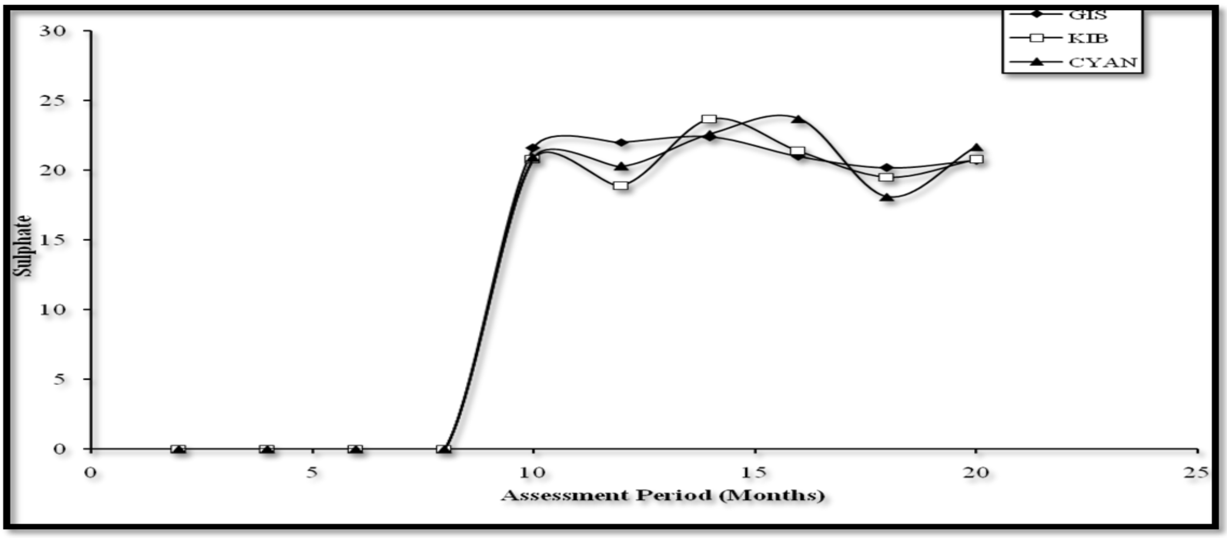

Figure 9: Mean sulphate at different location across period of assessment

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Sulphate values at the sampling locations are presented in Figure 9. The mean sulphate concentration was not significantly different with location but differed significantly ($p<0.05$) with months. Mean values of 12.8 ± 3.49 mgL^{-1}; 12.5 ± 3.43mgL^{-1} and 12.7 ± 3.49 mgL^{-1} were recorded in Gisenyi, Kibuye and Cyangugu respectively during the sampling period. The highest sulphate value of 23.2mgL^{-1} as shown above was recorded in Gisenyi in October while 23.7 mgL^{-1} was recorded in Kibuye and Cyangugu in February and April respectively.

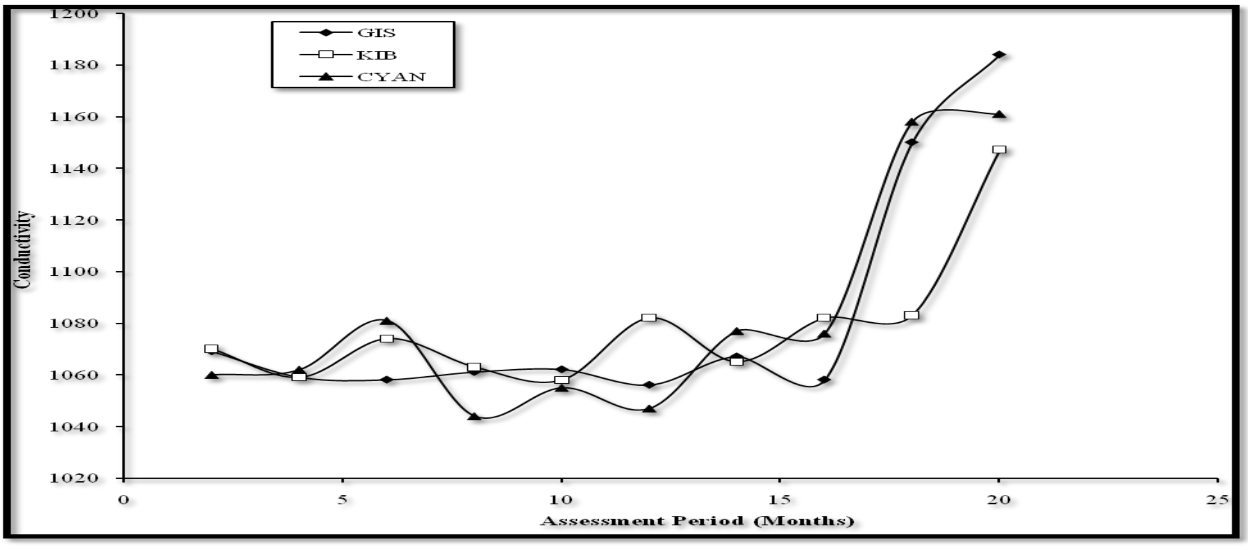

Figure 10: Mean conductivity at different location across period of assessment

The range of conductivity in Gisenyi, Kibuye and Cyangugu were 1058 – 1184 μScm^{-1}, 1058 – 1147 μScm^{-1} and 1031 – 116μScm^{-1} respectively. The mean values of 1082.4 ± 45.48 μScm^{-1} in Gisenyi and 1082.1 ± 13.48μScm^{-1} in Cyangugu were not significantly higher than 1078.3 ± 8.20 μScm^{-1} in Kibuye . Conductivity values recorded in this study was not significantly different ($p>0.05$) with location but was however significantly different ($p<0.05$) with months. There was a positive correlation between conductivity and months of sampling ($r = 0.70$).

DISCUSSION

The physicochemical parameters measured in this study with the exception of TDS are within the range recommended for a normal aquatic habitat [16]. Mean temperature readings recorded were in the range of 8°C and 30°C to which fish in the tropics is adapted. The mean temperature recorded in this study agreed with those of [17, 18]. Transparency in Cyangugu was slightly lower than in Gisenyi and Kibuye. The erosive materials and household wastes entering the lake from Rwanda (Gisenyi, Kibuye and Cyangugu) and Congo (Goma and Bukavu) could be responsible for this. Transparency tended to increase during the dry season as a consequence of different degrees of light penetration [17]. Water transparency is also known to be dependent on the nature, size and number of suspended particles; concentrations and chemical characteristics of dissolved substances; the wavelength, intensity and angle of incidence of light [19]. As shown by the mean *p*H values obtained in this study, the surface waters were alkaline with *p*H range of 8.64 – 9.31 and this agreed with the values of 9.1 and 9.11 obtained at the epilimnium by [9, 17]. *p*H is known to be controlled at a specific temperature by the dissolved chemical compounds and the biological processes in the solution. The spatial homogeneity and low seasonal variation of *p*H at each sampling location indicate that the lake water is well mixed and buffered and it is also a measure of the oligotrophic nature of the lake. The level of oxygen recorded for all the locations sampled were above the critical level of $3mgL^{-1}$ for fish [20]. The lake recorded high dissolved oxygen concentration in the rainy season than in the dry season. Dissolved oxygen deficiency of water is often caused by pollution of biodegradable organic substances including wastewaters from agriculture, the food industry and public sewage. These substances are decomposed by bacteria, which use oxygen from water for this process [20]. Erosive wastewaters and public sewage are common pollutants in Lake Kivu. Conductivity was higher in dry season in the three sampling locations. Conductivity is an indicator of dissolved salts in water and higher values are known to be unfavourable to the growth of sensitive plants. The spatial variation in conductivity in each location may likely indicate differences in pollution load and evaporative concentration of ions. Conductivity recorded in this study agrees with what was obtained in the oxic layer, which oscillates between 950 and $1300\mu Scm^{-1}$ [17].

The mean seasonal total alkalinity recorded in all the locations showed that Gisenyi has highest total alkalinity than Cyangugu and Kibuye respectively. Alkalinity is a measure of the buffering capacity of lake water [18]. Total alkalinity levels of natural waters may range from less than $5mgL^{-1}$ to several hundred milligrams per litres. Natural waters that contain $40mgL^{-1}$ or more total alkalinity as equivalent $CaCO_3$ are considered as hard waters [13]. At the *p*H values of Lake Kivu this parameter equals the concentration of the bicarbonate ion – (HCO_3^-). Water containing more than $40mgL^{-1}$ or more of total alkalinity is considered useful in biological purposes. This agreed with alkalinity range of 68.9 – $95.4mgL^{-1}$ recorded in this study. The alkalinity level observed in all locations in this study does not exceed the level recommended by WHO [16].

Mean total dissolved solids were higher in Gisenyi than in Cyangugu and Kibuye. Higher TDS values were recorded in the rainy season than in the dry season. Total dissolved solids are made up of inorganic matter and dissolved materials like chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium [13]. Presence of excess of such dissolved solids could lead to unwanted taste, corrosion and encrustation of equipments [20]. The Total dissolved solids recorded in this study is greater than the $500\mu Scm^{-1}$ recommended by WHO [16].

The salinity level recorded in this study does not show marked variation with seasons and this is probably due to the homogenous mixing of the lake as a result of tidal motions and also as a result of the high annual rainfall in the Lake Kivu area. Salts are supplied mainly by hydrothermal discharges at the bottom of the lake [21]. Salinity is an important ecological parameter that influences the biotic life of aquatic organisms as different organisms have the optimum salinity level through which they operate

[22]. The salinity level recorded in this study is not critical for the growth of fresh water fish species.

Cyangugu had a higher BOD than Kibuye and Gisenyi. The BOD recorded in this study varied significantly. Fluctuation in DO and BOD between seemingly physiologically stressful concentrations and relatively high mean DO content than BOD suggest a cleansing effect by the tidal fluxes. The importance of BOD in pollution monitoring has been well established [23].

Waters with BOD less than 3mgL^{-1} are known to have received no significant pollution discharges. BOD values of more than 8mg/l are indicative of moderate pollution while BOD value of 12mgL^{-1} or more are considered grossly polluted [13]. The BOD values that ranged between 1.9 – 4.2mgL^{-1} recorded in this study are within the acceptable limit for a moderately polluted lake. Mean Nitrate-nitrogen values were higher in Cyangugu than in Kibuye and Gisenyi. Nitrate-nitrogen is generally the product of organic matter decomposition by bacteria and that under normal condition the nitrate content of the surface water occur in trace amount but the value is enhanced by the inputs from other sources such as surface run off, that shift fertilizer and decomposing organic matters into the water [24]. The Nitrate-nitrogen recorded in this study was however below the guideline value of 50mgl^{-1} and so does not pose any serious concern for both human and aquatic organisms [16].

The phosphate - phosphorus is of great importance as an essential nutrient in aquatic system. Phosphate values of 40-120 mgL^{-1} are high and can lead to environmental pollution [25]. However, the phosphate values of between 0.01mgL^{-1} and 0.85mgl^{-1} represent the values that are attainable in a moderately polluted environment. The phosphate values recorded in this study were within the range that is attainable in a moderately polluted environment. The dissolved organic matter values recorded in this study ranged between 2.40 and 5.70 and did not varied significantly with location and sampling period.

The sulphate value of 0.000 – 23.7mgL^{-1} recorded in this study in Lake Kivu is below the limit of 250mgL^{-1} recommended for drinking water [26]. The low sulphate concentration recorded in this study could be attributed to the high rainfall in the study area and the high tidal motion of the lake water. Sulphate concentration in Rivers, Ponds, Streams and Lakes vary with the nature of geological materials in the watershed and with hydrological conditions [13]. Regions with waters of low salinity, concentrations of sulphate often range between 1 and 5mgL^{-1}, as sulphur while regions with higher salinity and particularly in arid regions sulphate concentration is much greater. Sulphate pollution can lead to severe eutrophication and sulphide toxicity [13].

CONCLUSION

This study has provided information about the water quality status of Lake Kivu as indicated by its physico-chemical characteristics. Lake Kivu receives anthropogenic pollution from both autochthonous and allochthonous sources. These anthropogenic pollutants no doubt influence the physico-chemical characteristics of the lake water. The physico-chemical parameters monitored in the study are within the range conducive for the survival of aquatic organisms and do not constitute any health risks to humans using the lake as a source of domestic water supply. Transparency values obtained at the three sampling locations were however lower for a lake of immense vastness and depth. Transparency in water is a product of high organic load, suspended particles; concentration and chemical characteristics of dissolved organics. Erosive waste waters, organic slurry and domestic household wastes deposition are common features in the studied areas. High TDS values obtained in this study which is higher than the recommended value of WHO corroborate the relatively low transparency observed in the three locations. TDS are made up of inorganic matter and dissolved materials like Chloride, Sulphate, Nitrate, Sodium, Calcium and Magnesium. On the basis of results obtained in this study, there is the need to sensitize stakeholders around the lake on the need to prevent undue influx of biodegradable wastes and toxic inorganic compounds in the lake which in the long run have the tendencies to exacerbate undue ionic build up in water to a level that may pose serious health risk to man and also capable of affecting negatively aquatic productivity.

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Table 1: Mean seasonal values of physicochemical parameters in Lake Kivu

Parameters	Gisenyi			Kibuye			Cyangugu			ANOVA
	Mean	+SD	Range	Mean	+SD	Range	Mean	+SD	Range	
Temp (°C)	24.56a	0.18	24.1 – 24.7	24.67a	0.58	23.6 – 26.0	24.5a	0.31	24.4 – 24.8	NS
Cond. (µScm)	1082.4a	45.5	1058 - 1184	1078.3b	25.9	1058 - 1147	1082.1a	42.6	1031. - 1158	*
*p*H	8.87a	0.22	8.64 – 9.31	8.86b	0.20	8.63 – 9.33	8.91b	0.20	8.60 – 9.30	*
Transparency (m)	3.11ac	1.10	0.00 – 4.50	3.67a	0.23	3.10 – 4.20	3.55ab	0.58	2.00 – 4.10	NS
Salinity (‰)	0.60a	0.01	0.50 – 0.62	0.59a	0.02	0.57 - 0.62	0.61a	0.04	0.55 – 0.67	NS
Alkalinility	88.14a	5.16	51.7 – 95.4	79.7bc	7.48	68.9 – 93.8	81.03b	7.77	70.4 – 93.2	*
DOM (mgl^1)	4.29ab	1.09	2.60 – 5.60	3.92ac	1 06	2.40 – 5.40	4.68a	0.66	3.60 –5.70	NS
TDS (mgl^1)	1147.0a	10.38	1081 - 1163	1125.2c	24.0	1025 - 1163	1128.1b	19.2	1103 - 1199	*
DO (mgl^1)	5.10b	0.58	4.20 – 6.20	5.10b	0.80	4.10 - 6.80	5.15a	0.49	2.80 – 4.00	*
BOD (mgl^1)	3.03a	0.65	1.90 – 4.20	3.28a	0.80	2.10 – 4.20	3.37a	0.49	4.60 – 6.40	NS
NO_3-N (mgl^1)	0.11b	0.13	0.00 – 0.25	0.11b	0.14	0.00 – 0.35	0.13a	0.14	0.00 – 0.38	*
PO_4-P (mgl^1)	0.07a	0.06	0.00 – 0.91	0.07a	0.08	0.00 – 0.19	0.05b	0.07	0.00 – 0.18	*
$S0_4$ (mgl^1)	12.79a	11.03	0.00 – 23.2	12.51c	10.84	0.00 – 23.7	12.73b	11.05	0.00 – 23.7	*

Means with the same letter along the same horizontal row are not significantly different (P>0.05).

SD = Standard Deviation; *= Significance; ND = Not detected; NS = Not significant

Table 2: Correlation Matrix of X-Values of mean data of Physicochemical Parameters in Lake Kivu (P< 0. 05)

Parameter	Months	Temp ^{0}C	Cond μScm^{-1}	pH	Transp (m)	Salinity (‰)	Alkalinity (mgL^{-1})	DOM (mgL^{-1})	TDS (mgL^{-1})	DO (mgL^{-1})	BOD (mgL^{-1})	NO_3-N (mgL^{-1})	PO_4-P (mgL^{-1})	SO_4 (mgL^{-1})
Months	1.00													
Temperature	-0.13													
Conductivity	0.67*	0.07												
pH	0.25	-0.40*	0.14											
Transparency	-.017	-0.12	-0.11	0.20										
Salinity	0.04	-0.35	0.10	0.18	-0.09									
Alkalinity	-0.37*	0.24	-0.44*	-0.45*	-0.13	-0.07								
DOM	0.07	-0.17	0.31	-0.17	-0.10	0.22	0.11							
TDS	-0.10	-0.24	0.03	0.29	-0.14	-0.02	0.19	0.05						
DO	-0.02	0.23	-0.09	-0.07	0.32	0.21	0.20	0.17	0.03					
BOD	0.13	-0.17	0.13	0.12	-0.26	0.40*	-0.28	0.14	-0.11	0.68*				
NO_3-N	0.56*	-0.27	0.02	0.38*	-0.15	0.08	-0.06	-0.05	0.13	0.04	0.12			
PO_4-P	0.80*	0.03	0.51*	0.17	-0.32	-0.05	-0.37*	-0.03	-0.23	-0.07	0.11	0.43*		
SO_4	0.80*	-0.06	0.35	0.17	-0.23	0.09	0.08	0.14	-0.11	0.17	0.19	0.77*	0.73*	1.00

P<0.05 – significantly different; * -significantly correlate (either negative or positive); DOM – dissolved organic matter; TDS – total dissolved solids; DO – dissolved oxygen; BOD – biological oxygen demand; NO_3-N – nitrate nitrogen; PO_4-P – phosphate phosphorus; ‰ – part per thousand; SO_4^- - sulphate

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Table 3: Water Quality of Lake Kivu in comparison with World Health Organization (WHO), FAO and FEPA

Parameters	Range	Mean values of sampled locations			*WHO	*FEPA Aquatic Life	*FAO
		Gisenyi	Kibuye	Cyangugu			
Temperature (°C)	23.6 - 26.0	24.6	24.7	24.5	15.0 - 29.4	20 -33°C	25 – 30
Conductivity (µScm^{-1})	1031 – 1184	1082.4	1078.3	1082.10	---		-
pH (units)	8.60 – 9.33	8.87	8.86	8.91	6.5 – 9.5	6.0 – 9.0	6.5 – 8.5
Transparency (m)	0.0 – 4.50	3.11	3.67	3.55	500		-
Salinity (‰)	0.50 – 0.67	0.60	0.59	0.61	-		-
Alkalinity (mgL^{-1})	51.7 – 95.4	88.1	79.7	81.0	30 – 500		200
DOM (mgl^{-1})	2.40 – 5.70	4.29	3.92	4.68	-		-
TDS (mgL^{1})	1025 – 1199	1147.00	1125.2	1128.10	500		-
Dissolved Oxygen (mgL^{-1})	2.80 – 6.80	5.10	5.10	5.15	3 – 4	6.8	NS
BOD (mgL^{-1})	1.90 – 640	3.03	3.28	3.37	>4.0	4.0	-
NO_3-N (mgL^{-1})	0.0 – 0.38	0.11	0.11	0.13	10	NS	
PO_4-P (mgL^{-1})	0.0 – 0.91	0.06	0.07	0.05	0.1	NS	NS
SO_4 (mgL^{-1})	0.00 – 23.7	12.8	12.5	12.7	<0.025		

*Source: WHO 1998; FEPA 1991; FAO 1997

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