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Trace Metal Pollution and Physicochemical Characteristics of Lake Kivu, Rwanda

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Abstract: Trace metal and physicochemical characteristics of Lake Kivu as index of pollution were investigated. Selected metal concentrations in water were determined by one – point calibration for quick concentration analysis using 2000 bulk scientific atomic absorption spectrophotometer. Mean metal concentrations in water (ppm) were Zn (4.22); Se (0.30); Cu (0.17); Fe (2.53) and Mn (3.33). Arsenic, cadmium and lead were not detected. Metal level in water exceeded limit prescribed by WHO for surface waters. Physicochemical variables determined were within the range conducive for the survival of aquatic organisms. The water was moderately hard with mean total alkalinity of 88.1±1.63 mg l^{-1}; 79.7±2.36 and 81.0±2.46 mg l^{-1}; alkaline with pH of 8.87±0.07; 8.86±0.06 and 8.91±0.06 in Gisenyi, Kibuye and Cyangugu, respectively. Mean TDS were above 500 mg l^{-1} prescribed by WHO. Mean BOD was within range for unpolluted or moderately polluted lake. The water showed mineralization with mean conductivity of 1058 -1184 µS/cm, 1058 - 1147 µS/cm and 1031 - 1116 µS/cm in Gisenyi, Kibuye and Cyangugu, respectively. Mean dissolved oxygen was above 5 mg l^{-1} recommended by WHO for fresh water fish species. The lake water must however, be constantly monitored to mitigate hazardous build up of metals and ions.

Key words: Trace metals · Physicochemical parameters · Pollution · Lake Kivu · Rwanda

INTRODUCTION

The world's ever growing population and its progressive adoption of an industrially based lifestyle has inevitably led to an increased anthropogenic impact on the biosphere [1]. The side effect of urbanization is pronounced in many developing countries. Rapid built-up of pollutants from different sources in the environment, increase in volume and diversity of solid wastes and sewage generated, eutrophication of water bodies, obstruction of fisheries and decrease in the aesthetic and recreational values of water resources are the side effects that cause a shift in the balance of nature and alteration of the course of evolution [2]. These processes result to simplify the community structure through the elimination of more sensitive species, cause changes in the species cycles and subsequently affect the composition of the community [2].

Pollution through mining activities, agricultural chemicals and industrial effluents and fossils fuels has considerably increased global level of heavy metals. Although many of these metals are essential for growth of organisms at lower concentration they are poison when their concentration exceeds certain levels [3]. Several disasters of these metal poisoning have been recorded from time to time which have caused great ecological damage and led to a large number of human causalities. A typical example of these is the Minamata bay disaster in Japan [3]. Heavy metals are dangerous because they tend to bioaccumulate in aquatic organisms along the food chain. Slightly elevated metal levels in natural waters may also cause sub-lethal effects in aquatic organisms [4]. Poor physicochemical parameters, dissolved oxygen and heavy metal concentrations are the possible causes of periodic fish kills in Lake Victoria [5]. A number of factors influence water chemistry [6]. The influence of geology on chemical water quality is widely recognised [7, 8]. The influence of soils on water quality is very complex and can be ascribed to the processes controlling the exchange of chemicals between the soil and water [9]. Apart from natural factors influencing water quality, human activities such as domestic and agricultural practices impact

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negatively on river quality [6]. The characteristic features of water bodies determine its quality and biological condition. The quality of water plays a vital role in the productivity of aquatic habitat [10].

Lake Kivu supports very important fisheries that provide livelihood to hundreds of people and contribute significantly to food supply as a prime source of animal protein [11].

An estimated 2 million people who live around the lake draw their drinking water from the lake without treatment. The major environmental concern in the lake area are erosion, siltation and pollution of the water through garbage, human wastes and excreta deposition; effluents from industries, restaurants, motor garages and mechanical shops. Agricultural activities also contribute to the pollution of the lake.

Information on physicochemical characteristics and trace metal concentrations in the lake is very scanty, therefore this study was undertaken to produce baseline information on these pollution variables as a means for monitoring pollution and also for effective management of the lake biota. The study also investigated the interplay of physicochemical parameters and trace metal concentration in the ambient water.

MATERIALS AND METHODS

Study Area: Lake Kivu is one of the smaller lakes of the East African Lakes region. It is situated on the boarder 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 [12]. It is a deep (maximum 489m), meromictic lake, with oxic mixolimnion up to 70m and a deep monimolimnion rich in dissolved gases, particularly methane [13]. The average daily temperature in the lake area is 23°C (73°F); relative humidity range between 59-83% while the average yearly rainfall is 1300mm [14, 15].

Sampling Procedure: The lake was sampled bi – monthly for a period of 24 months at three major towns namely Gisenyi, Kibuye and Cyangugu (Figure 1). The towns were chosen based on anthropogenic activities going on in them. Three locations, which were stratified into four sampling points, were chosen on the lake in each of the towns. Water samples for water quality parameters assessment were collected in previously acid leached sampling bottles of 600ml capacity.

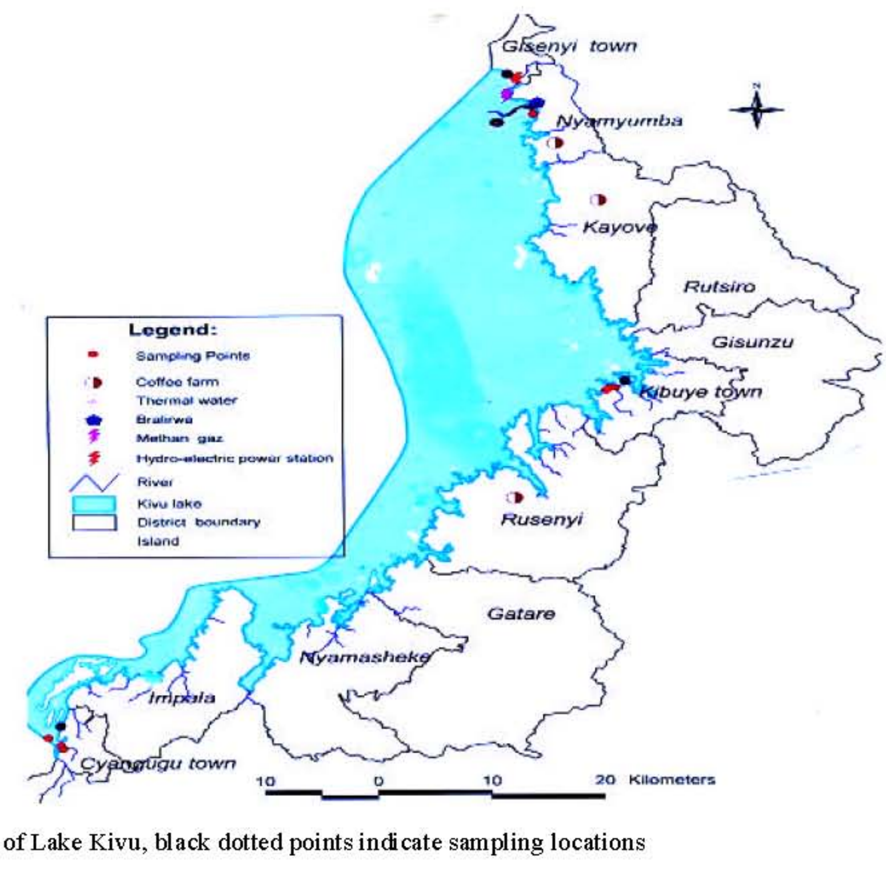

Fig. 1: Map of Lake Kivu, black dotted points indicate sampling locations

The following parameters were determined after [16, 17] – dissolved oxygen (DO), alkalinity, biological oxygen demand (BOD), dissolved organic matter (DOM), free carbon ($F - CO_2$), phosphate – phosphorus, transparency; nitrate – nitrogen and conductivity. The transparency of the lake water was determined with the aid of secchi disc. The calibrated 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°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°C) and dissolved in distilled water. Buffer (pH 9.2) was prepared by dissolving 3.80g of $Na_2B_4O_7.1OH_2O$ (air-dried) in 1000ml of distilled water [16]. 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 [17]. 100ml fixed samples showing brown precipitate of oxidized manganous ion was dissolved by the addition of 2ml concentrated sulphuric 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 as below:

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

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°C for five days after which the dissolved oxygen concentration was determined.

The biological oxygen demand (BOD) in mg l^{-1} of dissolved oxygen was calculated by subtracting the mg l^{-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 according to Boyd (1979). 100ml of filtered water samples were distilled in a Kjeldah flask using 1g MgO. 25ml of the distillate was collected thereafter. 1g of Devarda`s alloy 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 [18]. To a 100ml of water sample, a drop of phenophthalin 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 reappear.

Concentration of selected trace metals viz: Cadmium (Cd), lead (Pb), Manganese (Mn), Copper (Cu), Zinc (Zn), Arsenic (As) Selenium (Se) and Iron (Fe) in the lake were determined in water. Water samples for trace metal analysis were filtered and collected into previously acid-cleaned polyethylene bottles. The samples were thereafter acidified with concentrated HNO_3 to reach a final 1% prior to analysis [19] and kept in a refrigerator at 4°C. One –point calibration for quick direct concentration analysis was employed. 10ppm standard was used under scale expansion [20].

Statistical Analysis: Results of water quality parameters were analysed using basic statistics such as mean and standard deviation. Analysis of variance (ANOVA) was used to find level of significance in seasonal variation in water quality parameters. Inter - correlation between physicochemical factors and metals was determined [21].

RESULTS

The results of the mean bi – monthly values (± SD) of the selected trace metals and physico – chemical parameters of the three sampling locations are given in table 1. Mean differences in parameters monitored existed in conductivity, pH and total alkalinity, TDS, DO, NO_3 –N, PO_4 - P and SO_4. The correlation matrix of the mean values of measured selected trace metals and physicochemical parameters is presented in table 2. Comparison of mean values of selected trace metals and physicochemical parameters obtained with water quality criteria are presented in table 3. Mean surface water temperature (24.7°C ±0.58) was highest in Kibuye and lowest (24.5°C ±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 0.191 mg l^{-1} while 0.18 mg l^{-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 2.40 mg l^{-1} and 5.70 mg l^{-1} and did not varied significantly with location and sampling period.

Table 1: Mean seasonal values of some trace metals and physicochemical parameters of Lake Kivu in sampling locations

	Gisenyi			Kibuye			Cyangugu			
Parameters	Mean	±SD	Range	Mean	±SD	Range	Mean	±SD	Range	ANOVA
Zn (ppm)	4.76a	1.13	3.07-6.90	3.68ac	0.94	3.07-6.13	4.22ab	1.45	1.54-6.13	NS
Se (ppm)	0.40a	0.57	0.00-1.61	0.32ab	0.42	0.00-0.81	0.16ac	0.34	0.00-0.81	NS
Cu (ppm)	0.11b	0.13	0.00-0.37	0.02c	0.06	0.00-0.19	2.37a	6.90	0.00-22.0	*
Fe (ppm)	2.36b	0.96	1.35-4.04	2.62a	1.43	0.02-12.1	2.63a	3.36	0.02-12.1	*
Mn (ppm)	0.85ab	0.83	0.22-3.12	0.69ab	0.42	0.22-1.78	8.45a	24.1	0.45-76.9	NS
Pb (ppm)	ND	ND	ND	ND	ND	ND	ND	ND	ND	
Cd (ppm)	ND	ND	ND	ND	ND	ND	ND	ND	ND	
As (ppm)	ND	ND	ND	ND	ND	ND	ND	ND	ND	
Temperature (°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
Conductivity. (iS/cm)	1082.4a	45.5	1058-1184	1078.3b	25.9	1058-1147	1082.1a	42.6	1031.-1158	*
pH	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
Alkalinity. (mg l^1)	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 (mg l^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 (mg l^1)	1147.0a	10.38	1081-1163	1125.2c	24.0	1025-1163	1128.1b	19.2	1103-1199	*
DO (mg l^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 (mg l^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 (mg l^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 (mg l^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	*
$S0_4$ (mg l^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 some trace metals and Physico-chemical Parameters in the sampling Locations (P< 0. 05)

Parameter	Months	Zn	Se	Cu	Fe	Mn	Temp	Cond	pH	Transp	Salinity	Alkal	DOM	TDS	DO	BOD	NO_3-N	PO_4-P	SO_4
Months	1.00																		
Zn (ppm)	0.18																		
Se (ppm)	-0.01	0.10																	
Cu (ppm)	0.04	0.30	-0.13																
Fe (ppm)	-0.01	0.18	-0.03	0.86*															
Mn (ppm)	-0.29	-0.28	-0.12	-0.03	-0.10														
Temp (°C)	-0.13	0.07	0.11	0.01	0.17	0.01													
Cond. (µS/cm)	0.67*	-0.04	0.09	-0.18	-0.18	-0.12	0.07												
pH	0.25	–0.03	-0.34	-0.16	-0.23	-0.08	-0.40*	0.14											
Transp. (m)	-0.17	-0.45*	-0.20	0.04	0.12	-0.01	-0.12	-0.11	0.20										
Salinity	0.04	–0.04	–0.25	–0.01	-0.06	-0.09	-0.35	0.10	0.18	-0.09									
Alkalinity (‰)	-0.37*	0.35	0.24	0.26	0.14*	0.01	0.24	-0.44*	-0.45*	-0.13	-0.07								
DOM (mg/L)	0.07	-0.20	-0.19	0.27	0.22	0.24	-0.17	0.31	-0.17	-0.10	0.22	0.11							
TDS (mg/L)	-0.10	0.06	0.17	-0.27	-0.19	0.02	-0.24	0.03	0.29	-0.14	-0.02	0.19	0.05						
DO (mg/L)	-0.02	–0.25	-0.02	-0.14	-0.02	-0.18	0.23	-0.09	-0.07	0.32	0.21	0.20	0.17	0.03					
BOD (mg/L)	0.13	–0.36*	-0.26	-0.18	-0.16	-0.01	-0.17	0.13	0.12	-0.26	0.40*	-0.28	0.14	-0.11	0.68*				
NO_3-N (mg/L)	0.56*	0.28	-0.05	0.22	0.12	-0.16	-0.27	0.02	0.38*	-0.15	0.08	-0.06	-0.05	0.13	0.04	0.12			
PO_4-P (mg/L)	0.80*	0.20	-0.08	-0.14	-0.17	-0.18	0.03	0.51*	0.17	-0.32	-0.05	-0.37*	-0.03	-0.23	-0.07	0.11	0.43*		
SO_4 (mg/L)	0.80*	0.24	-0.08	0.15	0.10	-0.22	-0.06	0.35	0.17	-0.23	0.09	0.08	0.14	-0.11	0.17	0.19	0.77*	0.73*	0.73

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

		Mean value of Samples					
Parameters	Range ppm	Gisenyi	Kibuye	Cyangugu	WHO (1998)	FEPA (1991) Aquatic life	FAO (1991)
ZN	3.07-6.90	4.76	3.68	4.22	3.0	NS	2.0
Se	0.00-1.61	0.40	0.32	0.16	0.01	-	0.02
Cu	0.00-0.37	0.11	0.02	2.37	2.0	0.002-0.004	0.1
Fe	1.35-4.04	2.36	2.62	2.63	0.3^d	1.0	5.0
Mn	0.22-3.12	0.85	0.69	8.45	0.5	-	0.2
Temperature (°C)	23.6-26.0	24.6	24.7	24.5	15.0-29.4	20-33	25-30
Conductivity (µS/cm)	1031-1184	1082.4	1078.3	1082.1	-	-	-
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)	0.00-4.50	3.11	3.67	3.55	500	-	-
Salinity (‰)	0.50-0.67	0.60	0.59	0.61	-	-	-
Alkalinity (mg l^{-1})	51.7-95.4	88.1	79.7	81.0	30-500	-	NS
DOM (mg l^{-1})	2.40-5.70	4.29	3.92	4.68	-	-	-
TDS (mg l^{-1})	1025-1199	1147.0	1125.2	1128.1	500	-	-
Dissolved Oxygen (mg l^{-1})	2.80-6.80	5.10	5.10	5.15	3-4	6.8	NS
BOD (mg l^{-1})	1.90-6.40	3.03	3.28	3.37	>4.0	4.0	-
NO_3-N (mg l^{-1})	0.00-0.38	0.11	0.11	0.13	10	NS	-
PO_4-P (mg l^{-1})	0.00-0.91	0.06	0.07	0.05	0.1	NS	-
SO_4 (mg l^{-1})	0.00-23.7	12.8	12.5	12.7	<0.025	-	NS

Sources: Odiete, W.O, 1999. Environmental physiology of animals and pollution [22]
Kortatsi, B.K, 2007. West African Journal of Applied Ecology, Vol. 11 [23] (d)-desirable.

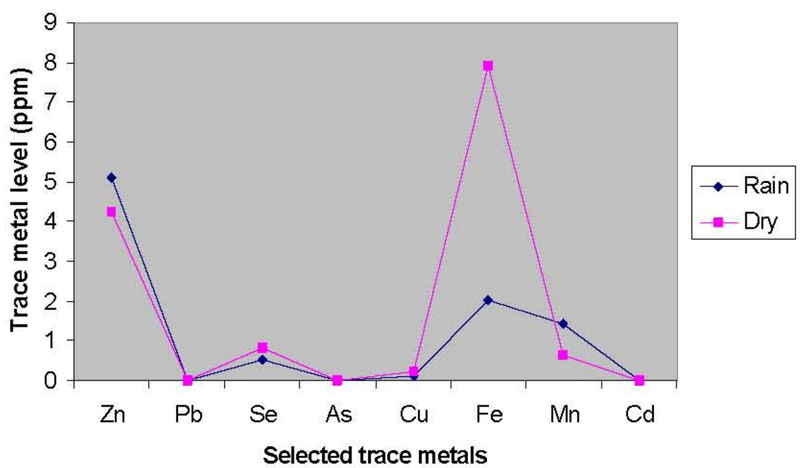

Fig. 2: Mean seasonal concentration of selected trace metals in Gisenyi.

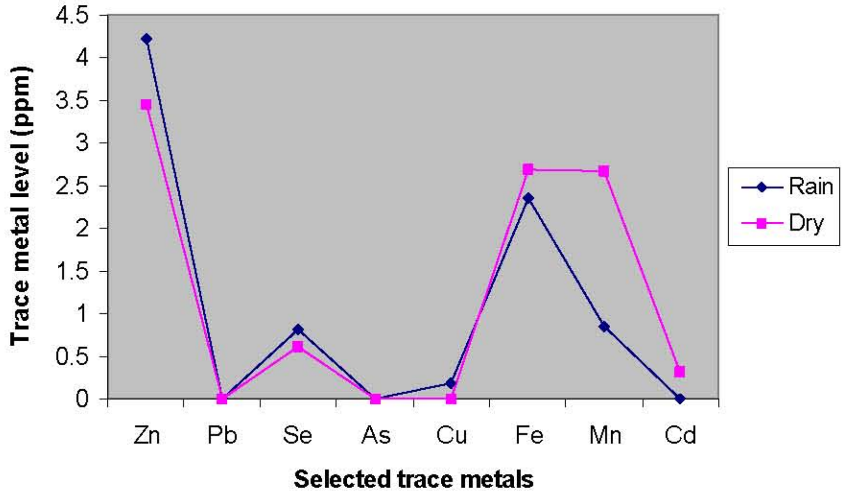

Fig. 3: Mean seasonal concentration of selected trace metals in Kibuye

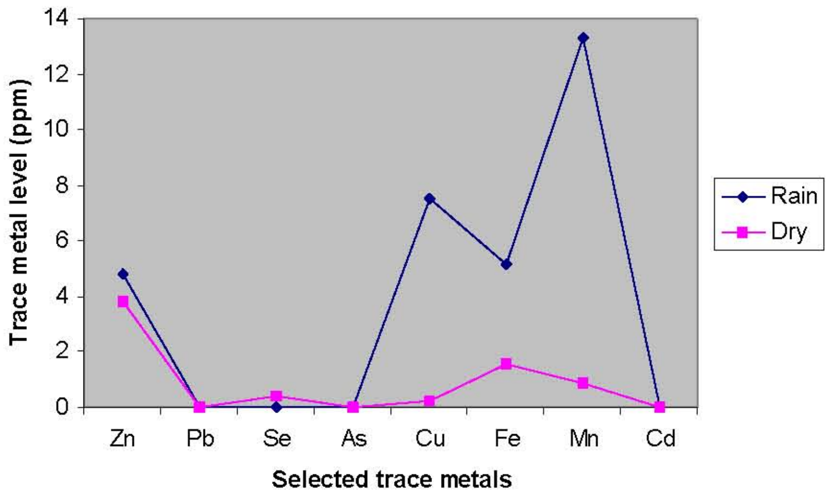

Fig. 4: Mean seasonal concentration of selected trace metals in Cyangugu.

Mean seasonal trace metal concentrations at the three sampling locations for water are presented in figures 2 - 4. Lead, cadmium and arsenic were not detected throughout the assessment period in the water column.

DISCUSSION

The results of this study showed that the trace metal contents of the lake were generally high. The mean monthly concentration of Manganese and Selenium in water in the three locations were above the World Health Organisation maximum acceptable limits of 0.05 and 0.01 mg l^{-1}. Cadmium and arsenic were not detected in water column throughout the sampling period [24]. The concentration of iron and copper in water exhibited significant temporal variation, which implies that weathering, erosion and other climatically induced factors may play an important role in the availability of heavy metals in the lake. Manganese exhibited significant seasonal variation in the sampled locations. Zinc and copper were the most concentrated in the water column. The physicochemical parameters measured in this study with the exception of TDS are within the range recommended for a normal aquatic habitat [24]. Mean temperature readings recorded were in the range of 8 and 30°C to which fish in the tropics is adapted. Transparency tended to increase during the dry season as a consequence of different degrees of light penetration [25]. The highest pH (8.91) recorded in this study falls within the range of 9.1 in the oxic layer reported by [25]. Oxygen level recorded in all the locations were above the limit of 5 mg/L recommended by WHO for fish [26]. Conductivity was higher in dry season in the three sampling locations. Conductivity recorded in this study agrees with what was obtained in the oxic layer, which oscillates between 950 and 1300ìScm [25]. The alkalinity level observed in all the locations does not exceed the 30 – 500 mg/L recommended level [17]. There was marked variation in salinity level 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 [27]. 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 [28]. However, the salinity level recorded in this study is not critical for the growth of fresh water fish species.

BOD level in the sampling locations varied significantly. Waters with BOD less than 3 mg/L are known to have received no significant pollution discharges. BOD values of more than 8 mg/L are indicative of moderate pollution while BOD value of 12 mg/L or more are considered grossly polluted [17]. The BOD values that ranged between 1.9 – 4.2 mg/L 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 [29]. The Nitrate-nitrogen recorded in this study was below the guideline value of 50 mg/L recommended by European Union as cited by Odiete [23] and so does not pose any serious concern for both human and aquatic organisms. The phosphate - phosphorus is of great importance as an essential nutrient in aquatic system. Phosphate values of 40- 120 mg/L are high and can lead to environmental pollution [30]. However, the phosphate values of between 0.01and 0.85 mg/L represent the values that are attainable in a moderately polluted environment and these correspond to what was recorded in this study. 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 – 23.7 mg/L recorded in this study in Lake Kivu is below the limit of 250 mg/L recommended for drinking water [25]. 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 [17]. Regions with waters of low salinity, concentrations of sulphate often range between 1 and 5 mg/L, 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 [17].

Conclusively the physicochemical parameters monitored in this study are within the levels conducive for the survival of aquatic organism and does not pose any health risks to humans using the lake water, however there is the need to continue to monitor the trace metal levels to prevent undue build up in water and sediments and its eventual bioconcentration in aquatic organisms consumed by men.

REFERENCES

1. Mc Eldowney, D.J. Hardman and S. Waiter, 1993. *Pollution: Ecology and Biotreatment*. Longman Group Ltd, pp: 322.
2. Sikoki, F.D. and R.J. Kolo, 1992. Perspectives in water pollution and their implication for conservation of aquatic resources. Paper presented at the National Conference on the conservation of Aquatic Resources held in Calabar from May, 11: 14.
3. Goel, P.K., 2001. *Water Pollution*: Causes, Effects and Control. New age international (P) Limited Publishers, 4835/25, Ansari road, Daryaganj, New Delhi, pp: 110002.
4. Connell, D.W. and G.J. Miller, 1984. *Chemistry and Ecotoxicology of pollution*. John Wiley & N.Y. Sons.
5. Ochumba, P.B.O., 1987. Perio*dic massive fish kills in the Kenyan par*t of Lake Victoria. Water Qual. Bull., (112): 119-22: 130.
6. Karikari, A.Y., J.K. Bernasko and E.K.A. Bosque-Hamilton, 2007. An assessment of Water Quality of Angaw River in southern – eastern coastal plains of Ghana. West African J. Applied Ecol., II.
7. Langmuir, D., 1997. Aqueous Environmental Geochemistry. Prentice Hall, U.S.A.
8. Lester, J.N. and J.W. Birkett, 1999. Microbiology and Chemistry for Environmental Scientists and Engineers. 2nd edn. E&FN Spon, New York.
9. Hesterberg, D., 1998. Biogeochemical cycles and processes leasing to changes in mobility of chemicals in soils. Agric. Ecosyst. Environ., 67: 121-133.
10. Adama, S.B. and R.J. Kolo, 2006. Public Health implications of Gurara River around Izom environs, Niger State, Nigeria.

11. Fish base., 2003. Freshwater fish species in Lake Kivu (Rwanda and Zaire). http:// www/ ,mongabay.com/ fish/ data/ ecosystem/lake% 2 kivu. Htm.
12. Snoeks J., L. De Vos and D. Thys van den Audenaerde, 1997.The ichthyogeography of Lake Kivu. South African J. Sci., 93: 579-584.
13. Schmid, M., M. Halbwachs, B. Wehrli and A. Wuest, 2005. Weak mixing in lake Kivu: New insights indicate increasing risk of uncontrolled gas eruption. Geochem. Geophys. Geosyst., 6(1): 1-11.
14. Fegley, R.A., 2003. Rwanda, Microsoft (R) Encarta (R) P 1- 8 Encyclopedia 2003.
15. Kaplan, E., 2003. Rwanda Aquaculture. An assessment of three Tilapia farms in Rwanda. pp: 1- 6.
16. A.O.A.C, 1990. Official Methods of Analysis. 15th edn. Association of Analytical Chemists. Washington.
17. Boyd, C.E., 1979. Water Quality in Warm Water Fish Ponds. Auburn University Press.Alabama, pp: 359.
18. APHA, 1990. Standard methods for the examination of water and wastewater. A.P.H.A. 16th ed. Washington D.C, Mcgraw – Hill.
19. Podda, Fi., P. Zuddas, A. Minacci, M. Pepi and F. Baldi, 2000. Heavy metal coprecipitation with Hydrozincite [Zn_5 $(CO^3)_2$ $(OH)_6$] from mine waters caused by photosynthetic microorganisms. Appl. Environ. Mcrobiol., pp: 1-11.
20. Welz, B., 1985. Atomic Absorption Spectroscopy. Published by Weinheim and Deerfield Beach, FL, pp: 506.
21. SAS. 1998. SAS users Guide statistics ver 7. SAS Inst., Inc. Cary New California U.S.A.
22. Kortatsi, B.K., 2007. Groundwater Quality in the Wassa West District of the Western Region of Ghana. W. Afri. J. Appl. Eco., pp: 11.
23. Odiete, W.O., 1999. Environmental Physiology of Animals and Pollution. Inno. Obbona and Associates, Lagos. pp: 261.
24. World Health Organization (WHO), 1998. Guidelines for drinking water.
25. World Health Organization Health Criteria and other supporting information WHO, Geneva. pp: 62-315.
26. Sarmento, H., M. Isumbisho and Jean-Pierre, Descy 2006. Phytoplankton ecology of Lake Kivu (easternAfrica). http// plankt.oxfordjournals.org/ cgi/ content/ abstract/28/9/815
27. World Health Organisation 1993. Guidelines for Drinking Water Quality. World Health Organisation, Geneva, Switzerland.
28. Degens, E., R.P. Herzen, H.K. Wong, G.D. Werner and W.J. Holger, 1973. Lake Kivu: Structure, chemistry and biology of an East African Rift lake. Geol. Rundsch, 62: 245-277.
29. Blaber, S.J.M., 1997. Physical factors affecting distribution. In: Fish and Fisheries of Tropical Estuaries. pp: 111-145. London, Capman and Hall.
30. Bilger, R.W. and Atkinson, M.J. Atkinson, 1997. Effect of nutrient loading on mass transfer rates of coral-reef community. Limnol. Oceanogr., 49(2): 279-289.
31. Ajani, E.K., 2001. Effects of biotic and abiotic component of the habitat on fish productivity in Lagos Lagoon, Nigeria, Ph.D Thesis 2001 University of Ibadan. pp: 241.