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Assessment of Physico-Chemical Characteristics of Water at Selected Stations of Lake Tanganyika, Africa with Special Emphasis on Pisciculture Purposes

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Abstract—*The current limnological study was carried out on Lake Tanganyika in 4 sampling sites to assess the physico-chemical properties and trophic status for pisciculture purpose. The estimated values of physical and chemical parameters of water samples were compared to the desirable, permissible and acceptable ranges for pisciculture recommended standards. In this regards, 9 physico-chemical parameters have been analyzed and the results of the comparative analysis showed that most of the water quality parameters were suitable for fish culture because 7important parameters (77.8%) were within the permissible limits and 2parameters (22.2%) were found inappropriate for pisciculture. The values of transparency, chlorophyll a and Total phosphorus revealed clearly that all sampling stations were in hypereutrophic status which indicate eutrophication phenomenon.*

Keywords*: Limnology, Lake Tanganyika, Pisciculture.*

1. INTRODUCTION

Water quality is the major limiting factor in the productivity of aquatic ecosystems, including fish resources. The health of an aquatic ecosystem depends on its physicochemical and biological characteristics (Watson and John,2003; Venkatesharaju et al.,2010). Adverse changes in water quality of aquatic ecosystems are reflected in the biotic community structure and the most sensitive species often act as sentinels of water quality. Therefore, water quality monitoring is vital for conservation of water resources and their sustainable use for drinking water supply, irrigation and fish farming.

Lake Tanganyika is one of the largest lakes of Africa which is second largest in terms of area following Lake Victoria. At the world level, Lake Tanganyika is the longest freshwater lake and holds second position in terms of volume and depth after Lake Baïkal (Wetzel,1983). It serves as the life support for the four neighboring African countries namely Burundi, Democratic Republic of Congo, Tanzania and Zambia sharing its entire perimeter. Apart from many economic activities, Lake Tanganyika supports the livelihood to a vast majority of the population of these countries through fishing. It has been estimated that Lake Tanganyika provides up to 60% of the animal protein to the people of the region (Jensen, 2016; McGrath, 2016) with up to 200000 tons of fish catch (Jensen, 2016).

Climate change driven rise in global temperature over the years has been identified as one of the major causes for the rapid decline in the productivity of Lake Tanganyika (O'Reilly et al., 2003). Besides, increasing urbanization and consequent discharge of harmful effluents from large cities is continually altering the quality water and productivity of Lake Tanganyika (Wetzel, 2001) jeopardizing its sustainability. In the present study we have analyzed the water quality at four selected locations with varying human activities along the cost of Burundi. The study is limited to physico-chemical characteristics and the findings are compared to reference values recommended for fish farming.

2. MATERIALS AND METHODS

As the lake has a long perimeter (1838km) shared between four countries (Burundi, Tanzania, Democratic Republic of Congo and Zambia), the present study was carried out at 4 sampling sites (Kajaga, Nyamugari, Rumonge and Mvugo) belonging to the Burundian Littoral (figure 1).

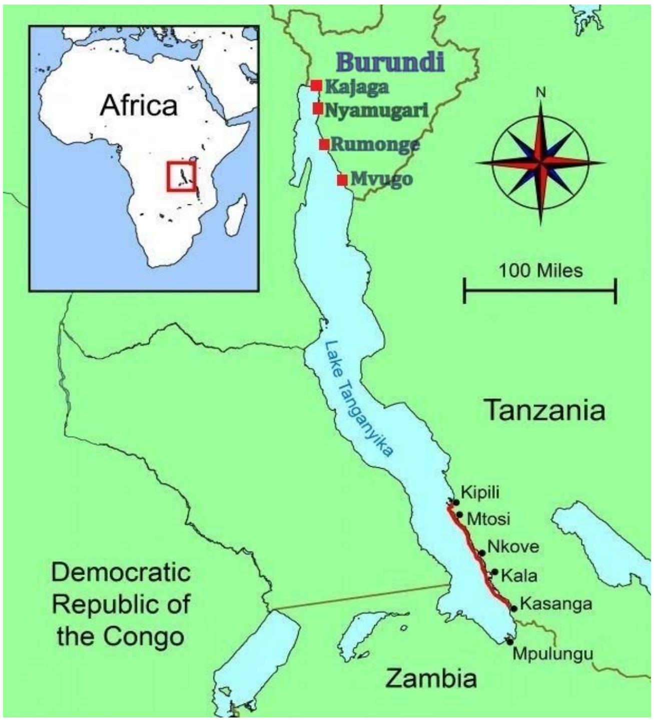

Figure 1: Map of the study area showing the sampling sites

The field data collection has lasted 4months (January and February of both 2017 and 2018) and the various outings were always conducted in the morning time. The water samples for Physical and chemical analyses were collected with plastic containers in the morning time and all samples were adequately labeled and transported immediately to the laboratory for analysis. The physical and chemical parameters evaluated were Transparency (Tr), Temperature (Te), Potential of Hydrogen (pH),Total Dissolved Solids (TDS), Total Phosphorus (TP), Dissolved Oxygen(DO), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) and Chlorophyll a(Chl a).

In fact, water temperature, pH and Dissolved Oxygen have been measured in-situ using electrometric method based respectively on the temperature sensitive electrodes with a Pt-Rh probe coupled to a pH electrode and oxygen meter while the remaining parameters were determined in the Laboratory using the standard methods according to APHA (2005), Trivedy and Goel (1986). Transparency was recorded using Secchi Disk, Total Dissolved Solids was determined by Gravimetric method, Biochemical Oxygen Demand was measured in Incubator after 5 days of incubation at 20^{o}C followed by titration, and Chemical Oxygen Demand was determined by Digestion followed by titration, Total. Phosphorus was measured by Spectrophotometer after Digestion by ascorbic acid and Chlorophyll a was determined by Extraction in 80% acetone followed by reading in spectrophotometer the absorption at 660 nm and 620 nm.

3. RESULTS AND DISCUSSION

3.1 Physico-chemical parameters

The analysis of physico-chemical properties of water is the first considerations to decide about its best utilization and is helpful in the understanding of the interaction between the climatic and biological process in the water. The results showing spatio-temporal variation of physico-chemical parameters, the descriptive statistics and the International Standards of water quality required for pisciculture in comparison to the results of the present study are presented in the table1.

Table 1: Spatio-temporal variation in physico-chemical characteristics of water in comparison to International Standards of water quality required for pisciculture.

Parameters	Kajaga			Nyamugari			Rumonge			Mvugo			Descriptive Statistical		Suitable (Yes or No)	Standards of water quality suitable for Pisciculture
	2017	2018	Mean	2017	2018	Mean	2017	2018	Mean	2017	2018	Mean	G M	SD		
Te (°C)	28.1	27.1	27.6	27.9	28	27.95	28.1	29.8	28.95	27.8	29.4	28.6	28.28	0.57	Yes	25^0C – 30^0C (FAO, 2006)
Tr (cm)	190	210	200	110	130	120	161	175	168	143	180	161.5	162.38	30.44	No	30 – 40 (ICAR,2007)
PH	8.85	8.85	8.85	8.88	8.88	8.88	8.6	8.82	8.71	8.7	8.5	8.60	8.76	0.12	Yes	6–9 (Davis, 1993)
TDS (mg.L^{-1})	453.59	443.54	448.57	453.59	444.88	449.24	448.9	440.86	444.88	448.9	442.87	445.89	447.14	1.93	Yes	< 500 (USA-EPA,2006)
TP (mg.L^{-1})	1.71	1.57	1.64	1.56	1.67	1.62	0.93	0.79	0.86	0.79	0.69	0.74	1.21	0.45	Yes	0.01–3 (Piper et al, 1982)
Chl-a (mg.L^{-1})	0.32	0.29	0.31	0.17	0.18	0.18	0.15	0.28	0.22	0.28	0.47	0.38	0.27	0.08	No	<0.0025 (UNECE, 1994)
DO (mg.L^{-1})	7.71	7.51	7.61	7.47	7.39	7.43	7.35	7.16	7.26	7.19	7.21	7.2	7.38	0.17	Yes	≥ 4 (ICAR, 2007)
COD (mg.L^{-1})	60	75	67.5	26	30	28	18	25	21.5	15	25	20	34.25	20.77	Yes	< 50 (ICAR,2007)
BOD (mg.L^{-1})	13	15	14	10	10.6	10.3	7	8	7.5	5	7.5	6.25	9.51	3.18	Yes	3 – 20 (Boyd, 2003)

Transparency: It measures the depth of light penetration into the water and shows how clear are the water. In Lake Tanganyika, transparency of the waters varies greatly from one location to another. During the present study, the values obtained ranged from 110 to 210cm with a general mean of 162.38 ±30.44cm , The highest value was recorded at Kajaga site in February 2018 and lowest value was at Nyamugari site in January 2017. Lower transparency observed at Nyamugari site is due to high turbidity, wastewater discharges from Mugere hydroelectric dam and surface run-off filled with organic matter (soil, dead leaves etc.,) and other effluents into Lake Tanganyika. According to Bhatnagar et al. (2004), the range of 30-80 cm is suitable for health of fish; in intensive culture system the range of 15-40cm is ideal and transparency <12cm is stressing. Santhosh and Singh (2007) stipulated that secchi disk transparency ranging from30 to 40 cm is indicative of optimum productivity in fish ponds. So the results found were not in accordance with the standards required for fish culture.

Temperature: Temperature expresses the level of coldness or hotness in living organism body either on earth or in water (Lucinda and Martin, 1999). Temperature values recorded for the present investigation ranged from 27.1^{0}C to 28.95^{0}C with a general mean of 28.28±0.57^{0}C. The found values from all stations were in accordance with the standards values of 25^{0}C to 30^{0}C suitable for optimum productivity recommended in fish culture by FAO (2006).

Total Dissolved Solids: TDS is the remaining residue obtained after evaporating the water and drying the residue at 103°C to 105°C up to a constant weight. The values of TDS found in the present study fluctuated from 440.86 to 453.59 mg.L^{-1} with a general mean of 447.141±1.93 mg.L^{-1}. Maximum value was recorded at kajaga and Nyamugari stations and minimum value was found at Rumonge station. The TDS for all study stations were found in accordance with the standard range (<500mg.L^{-1}) suitable for fish farming set by the US.Environmental Protection Agency (Charkhabi and Sakizadeh, 2006).

Potential of Hydrogen: pH expresses the level of basic or acidic character of a solution at a given temperature. During the present study, pH values ranged from 8.5 to 8.88 with a general mean of 8.76±0.12 considering all study sites. These results indicated alkaline nature during the study period at all study sites and were found within the Standards of water quality required in fish culture recommended by Davis (1993). The pH of water influences many biological and chemical processes in water. For the major freshwater species, a pH ranging from 6.5 to 9 is appropriate, but most of marine animals are not tolerant to a wide range of pH as freshwater animals. Thus the optimal pH ranges usually between7.5 and 8.5 (Boyd, 1998). Below pH 6.5, some species growth slowly (Lloyd, 1992) and at lower pH, the capacity of organism to preserve its salt equilibrium is affected (Lloyd, 1992) and reproduction stops. At pH ≤ 4 and pH ≥11, most of species die.

Biochemical Oxygen Demand: BOD reflects the dissolved oxygen amount needed by aerobic organisms to breakdown organic matter occurring in water at a given temperature, for a specified time. BOD is an indicator of sewage and industrial pollution. The BOD content of various study sites ranged from 5 to 15mg.L^{-1} with a general mean of 9.51±3.18 mg.L^{-1}. Kajaga and Nyamugari stations appeared to be polluted as they have high BOD Concentration with respective averages of 14 and 10.3mg.L^{-1}. Rumonge and Mvugo stations show low mean value of 7.5 and 6.25mg.L^{-1} respectively. The BOD values recorded from all sites were within the standards range of 3-20 mg.L^{-1} recommended by Boyd (2003). The BOD of unpolluted water is less than 1mg.L^{-1}, moderately polluted water has the BOD range of 2-9 mg.L^{-1} while heavily polluted water have BOD value more than 10 mg.L^{-1}(Adakole, 2000). The present study revealed that water of Mvugo and Rumonge stations falls under moderately polluted category, while Kajaga and Nyamugari were under heavily polluted category.

Chemical Oxygen Demand:COD determines the oxygen amount needed for oxidizing the biodegradable and non-biodegradable organic matter in water by a strong chemical oxidant (Mahananda et al., 2010) under specific conditions of oxidizing agent, temperature and time. This is an indication of both sewage and industrial pollution. The standards value required in fish culture should be <50 mg.L-1(Santhosh and Sing, 2007). In the present study, the COD value ranged from 15-75mg.L-1 and the general mean was 34.25±20.77mg.L-1. Kajaga station appeared to be polluted as it showed high COD value with average of 67.5mg.L-1 which is not desirable for fish farming. Nyamugari, Rumonge and Mvugo stations showed respective mean values of 28mg.L-1, 21.5mg.L-1 and 35mg.L-1 which are within the standards range (<50mg.L-1) recommended by Santhosh and Sing (2007). Since COD range in unpolluted surface water is ≤ 20 mg.L-1(Chapman, 1997), mean values showed that all stations were polluted and Kajaga station cannot be recommended for fish culture purposes if only COD is considered,while the three others stations are considered suitable for pisciculture.

Dissolved oxygen (DO): It determines the gaseous oxygen amount dissolved in water serving as fundamental role in the life of cultured organisms (Dhawan and Karu, 2002). DO content recorded during the investigation ranged from 7.162 to 7.71mg.L^{-1} with general mean of 7.375±0.17mg.L^{-1}considering all the stations. According to Santhosh and Sing (2007), DO ≥4mg.L^{-1} is suitable for fish culture. Yovita John Mallya (2007) stipulated that Cold water fish requires 6mg.L^{-1}, Tropical freshwater fish need 5mg.L^{-1} and Tropical marine fish need 5 mg.L^{-1}. Thus, DO values obtained in the current investigation were within the desirable limits recommended by Santhosh and Sing (2007).

Total Phosphorus: Phosphorus is considered as vital element required for algal growth that heavily affects eutrophication process in lakes. According to Piper et al. (1982), Total phosphorus content ranging from 0.01 to 3mg.L^{-1} is suitable for pisciculture. Stone and Thomforde (2004) stated that phosphate content ≤ 0.06 mg .L^{-1} is suitable for pisciculture. According to Bhatnagar et al. (2004), the optimum and productive phosphorus values for fish farming range from 0.05 to 0.07mg.L^{-1}. In the present study, Total Phosphorus values ranged from 0.69 to 1.71mg.L^{-1} with general average of 1.21±0.45mg.L^{-1}. High Total Phosphorus concentrations were observed at Kajaga and Nyamugari stations with respective averages of 1.64 and 1.62mg.L^{-1}.The values found from all stations were in accordance with the standards range reported by Piper et al. (1982), hence suitable for fish culture.

Chlorophyll a: having the chemical formula $C_{55}H_{72}MgN_4O_5$ is the principal pigment providing green colour to plants and algae. This pigment allows plants and algae to make photosynthesis using the sun's energy to convert water and carbon dioxide into oxygen and cellular material (Sugar) following this reaction: ***Light energy+$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$.*** According to the United Nations Economic Commission for Europe (UNECE, 1994), Chlorophyll a Concentration in water must be less than 0.0025mg.L^{-1}. In the present study, Chlorophyll a value ranged from 0.15 to 0.47mg.L^{-1}. Mean Concentrations per stations were 0.31mg.L^{-1} for Kajaga site, 0.18mg.L^{-1} for Nyamugari site, 0.22mg.L^{-1} for Rumonge site and 0.38mg.L^{-1} for Mvugo site with General mean of 0.27±0.08mg.L^{-1}. For all study stations, the values obtained were higher than the standards reported by UNECE (1994) and hence not suitable for pisciculture purposes.

3.2 Pearson's correlation (r) among physico-chemical parameters

In the present study, the calculation of correlation coefficient (r) among every parameter pairs was performed by considering mean values as shown in the table2.

Table 2: Correlation Coefficient (r) among Physico-chemical parameters.

Plot	Te	PH	Tr	TDS	TP	DO	COD	BOD	Chl a
Te	1								
PH	-0.778	1							
Tr	-0.134	-0.144	1						
TDS	**-0.932***	0.852	-0.227	1					
TP	**-0.920***	**0.962***	-0.054	**0.944***	1				
DO	**-0.923***	0.854	0.327	0.809	**0.926***	1			
COD	-0.817	0.59	0.658	0.576	0.709	**0.920***	1		
BOD	**-0.904***	0.837	0.375	0.774	**0.906***	**0.998****	**0.935***	1	
Chl a	0.026	-0.636	0.557	-0.278	-0.412	-0.175	0.159	-0.161	1

** Correlation is significant at the 0.01 level (1-tailed)
* Correlation is significant at the 0.05 level (1-tailed).

A significant and strong positive correlation at the 1% level (1-tailed) is established between Dissolved Oxygen and Biochemical Oxygen Demand ($r=0.998$, $p<0.01$).

A significant and strong positive correlation at the 5% level (1-tailed) is observed between: pH and Total phosphorus ($r=0.962$, $p<0.05$), Total phosphorus and Biochemical Oxygen Demand ($r=0.906$, $p<0.05$), Chemical Oxygen Demand and Dissolved Oxygen ($r=0.920$, $p<0.05$), Biochemical Oxygen Demand and Chemical Oxygen Demand ($r=0.935$, $p<0.05$) , Total Dissolved Solids and Total phosphorus ($r=0.944$, $p<0.05$), Dissolved Oxygen and Total phosphorus ($r=0.926$, $p<0.05$).

At the 5% level (1-tailed), Temperature showed a significant and strong negative correlation with Total Dissolved Solids ($r=-0.932$, $p<0.05$), Dissolved Oxygen ($r=-0.923$, $p<0.05$), Biochemical Oxygen Demand ($r=-0.904$, $p<0.05$) and Total phosphorus ($r=-0.920$, $p<0.05$).

3.3 Determination of the trophic status of the water

Carlson's Trophic Status Index (TSI) is used to characterize the trophic status of the water of the sampling stations. TSI combines information about nutrient status and algal biomass and provide a basis for assessment of the trophic status trend for management. This method uses a logarithmic transformation (Ln) of chlorophyll a concentration (Chl .a) in microgram per liter, Secchi disc depth (SD) in meter and the total phosphorus (TP) in microgram per liter according the following equation (Carlson, 1977):

$$\text{TSI (SD)} = 10*\left(6 - \frac{\ln SD}{\ln 2}\right) = 60 - 14.41 \ln SD\ (m)$$

$$\text{TSI (Chl.a)} = 10*\left(6 - \frac{2.04 - 0.68 \ln Chl.a}{\ln 2}\right)$$

$$= 9.81 \ln \text{Chl-a}\ (\mu g.L^{-1}) + 30.6$$

$$\text{TSI (TP)} = 10*\left(6 - \frac{\ln \frac{48}{TP}}{\ln 2}\right)$$

$$=14.42 \ln TP\ (\mu g.L^{-1}) + 4.15$$

$$\text{Carlson's TSI} = \frac{TSI(Chl.a)+TSI(TP)+TSI(SD)}{3}$$

For the present study, TSI was calculated using mean values.The table3 shows the trophic state index according to Carlson (1977) while the results obtained for Lake Tanganyika are presented in the table 4.

Table 3: Carlson's trophic state index values and classification of lakes (Carlson, 1977).

Classification system of Lakes based on TSI	TSI ranges	Trophic Status
Carlson's Index, 1977	< 30	Oligotrophic
	30 - 40	Oligo- Mesotrophic
	40 - 50	Mesotrophic
	50 - 60	Mesotrophic- Eutrophic
	60 - 70	Eutrophic
	70 – 80	Hypereutrophic
	> 80	Hypereutrophic

Table 4: Trophic status of Lake Tanganyika

Sampling Stations	Transparency		Chlorophyll a		Total Phosphorus		Carlson's TSI	Related Trophic Status
	Values (m)	TSI (SD)	Values ($\mu g.L^{-1}$)	TSI (Chl.a)	Values ($\mu g.L^{-1}$)	TSI (TP)		
Kajaga	2	50.012	305	86.716	1641	110.902	82.543	Hypereutrophic
Nyamugari	1.2	57.373	175	81.267	1615.5	110.676	83.105	Hypereutrophic
Rumonge	1.68	52.524	215	83.286	859	101.568	79.126	Hypereutrophic
Mvugo	1.615	53.093	375	88.743	739.5	99.408	80.415	Hypereutrophic

The results regarding the trophic status Index presented in the Table 4 reflected that all sampling stations were in Hypereutrophic status. These conditions show in general that the eutrophication process is taking place and therefore, urgent management of the lake is necessary to control the sources of eutrophication. The pollution sources include mainly the excessive amounts of nutrients (Total Phosphorus, Total Nitrogen and total carbon) entering lake Tanganyika from rivers and through multiple human activities such as agricultural fertilizers, industrial and municipal sewage treatment. In fact, the trophic status data obtained in this study may not be generalized for whole Lake Tanganyika because the transparency and nutrient loadings of the water vary according to the sampling location. The water samples for the current study was taken from surface water at 50 meters far away from the shoreline and was subject to contain a lot of nutrients than the deep waters or the waters taken in the middle of the lake.

4. CONCLUSIONS

The present investigation attempt to assess the physico-chemical characteristic of water of Lake Tanganyika with reference to its suitability for fish culture purposes. Nevertheless, a total of 9 physico-chemical parameters have been analyzed and the results of comparative analysis indicate that the Lake has a high piscicultural potential as the most important of the water quality parameters were suitable for fish culture. Indeed, 7parameters (77.8%) such as Temperature, pH, Total Dissolved Solids, Total phosphorus, Dissolved Oxygen, Chemical Oxygen Demand and Biochemical Oxygen Demand, were found within the permissible

Limits for fish culture whereas Transparency and Chlorophyll a (22.2%) were found inappropriate for pisciculture during the investigation period. Furthermore, it has been realized that the fish productivity of the study areas can be improved, if all physico-chemical parameters are maintained at required levels. Regarding the trophic status, the values of transparency, chlorophyll a and nutrients (total phosphorus) revealed clearly that the study stations were in hypereutrophic status which indicate eutrophication phenomenon and therefore alerts to conserve and manage urgently the affected stations.

5. CONFLICT OF INTEREST STATEMENT

The Authors declare that there is no conflict of interest to report.

6. ACKNOWLEDGEMENTS

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