

# **An overview of the present status of Water Quality of Lake Victoria, Kenya: A limnological perspective**

P. G. Njuru

Ministry of Environment and Natural Resources, LVEMP Water Quality Component,  
P O Box 1922 Kisumu, Tel +254 35 42350 Fax +254 35 44584, E-Mail [gikuma@hotmail.com](mailto:gikuma@hotmail.com)

## **Abstract**

Sampling for nutrients, Chlorophyll-a and total suspended solids was done in 9 in-lake stations in the Kenyan part of Lake Victoria between December 2000 and October 2001. In-situ measurements of temperature, dissolved oxygen and water transparency were also carried out. PO<sub>4</sub>-P was found to range from 0.007mg/l to 0.057 mg/l and was higher in the pelagic stations than in littoral stations. NO<sub>3</sub>-N concentrations of 0.005-0.037 mg/l were recorded and were found to be relatively higher in the littoral stations than in the pelagic stations. TN:TP ration of the lake was found to be 6.78 indicating a possibility of heterocystous blue-green algae dominating. The ratio of 8.6 in the littoral stations showed a potential for higher photosynthetic rates in this part of the lake than in the pelagic zones.

SRSi levels in the pelagic zones were found to have reduced significantly compared to those reported by Talling (1965), whereas those in the littoral zone was within the reported range. Water temperature was found to have increased and transparency values decreased compared to those measured by Worthington (1930) for both the open waters and within the gulf. Anoxic conditions (DO <1mg/l) were measured in depths of up to 30m.

**Keywords:** Pelagic, Littoral, Nutrients, Water Quality, Kenya, Lake Victoria

## **Introduction**

The Kenyan waters of Lake Victoria lie just south of the equator between 0° 6' S-0° 32'S and 34° 13'E/ 34° 52'E at an altitude of 1134 m asl and cover an area of 4128 sq. Km (approximately 6% of the whole lake) of which 1400 sq. Km comprises the Nyanza Gulf (Fig 1). It has a catchment area of 3600 Km<sup>2\*\*\*</sup>, which is drained, by 5 major rivers (Nzoia, Kuja, Nyando, Yala and Sondu) through which it contributes approximately 30% of total riverine inflow into Lake Victoria. The catchment falls in some of the most agriculturally productive areas in the country with extensive use of agro-chemicals and has several major urban centers including Kisumu. Increased agricultural and municipal in-put into the lake has continued to endanger the environmental health of the lake and continue to raise concern (Chege, 1995).

The first report on the water quality monitoring of the Kenyan part of Lake Victoria was by Worthington after his 1927 to 1928 surveys under Michael Graham (Worthington, 1930). Measurements were done in a station between Homa Bay (Ulambwi Bay) and Uyoma point within the Nyanza Gulf. Despite its key contribution to the hydrology and water quality of the Lake Victoria, the Kenyan part of the lake did not receive an early scientific attention compared to the Uganda part of the lake, which could be attributed to its size and the fact that the East African Fisheries Research Organization (EAFRO), where most of the lake research activities were undertaken, was based in Jinja, Uganda. It was only from the mid-eighties that scientific publications appeared on this part of the lake. A group of local and international scientists undertook baseline study on Kenyan

part of Lake Victoria in 1984 and produced a report on the status of the lake (Foxal et al, 1984). Ochumba (1987) reported on periodic fish kills in the Kenyan part of the Lake Victoria, which together with the latter work on the massive fish kills in the Nyanza gulf (Ochumba, 1990) may have contributed to a heightened awareness on the serious threats to the lake water quality and the economic implications. Calamari et al (1995) did an extensive work on the pollution input into the Nyanza gulf and did in-lake measurements of some physico-chemical and water quality parameters. Kibaara & Ochumba (1989) reported on the observation of the blue-green algae and measured other related water quality aspects of the Kenyan Lake Victoria. Other studies on phtoplankon (Ochumba & Kibaara, 1989; Lungaiya et al 2000), Zooplankton (eg Mavuti & Litterick, 1992) have been carried out and have covered a few of other water quality parameters.

Among other issues, the reported periodic and massive fish kills (Ochumba 1987, 1995) and the increased algal blooms in lake waters have raised concern locally and internationally on the deteriorating water quality of the Lake Victoria and brought to focus the need for a more holistic and all inclusive management strategy. The need for this management approach of the lake and its resources is underscored by the complexity of the cause-effect of the deterioration of the lake ecosystem and the magnitude of threat to the socio-economic base of the lake (World Bank, 1996). The need for more comprehensive data and information on the lake status, changes and possible causes of these changes has been appreciated as mandatory for a proper and workable management strategy to be put in place for the restoration of the lake ecosystem and sustainable utilization of the lake resources. The Water Quality Management Component of the Lake Victoria Environmental Management Programme (LVEMP) has for the last two years been undertaking comprehensive integrated in-lake studies, aimed at collecting data and information for the understanding and sustainable management of the lake ecosystem.

This paper present the preliminary findings on the water quality of the Kenyan part of Lake Victoria and suggests the way forward in the continuing studies and in the restoration and management of the lake ecosystem.

## **Materials and methods**

### **Study Area**

The study was carried out in the Kenyan part of Lake Victoria both in the Nyanza Gulf and in the open lake. A total of 9 stations were established for water quality monitoring and sampling (Figure 1). The stations, which were categorized as either pelagic (KP) or littoral (KL) were selected so as to fall within the lake-wide transects which connect other stations in the Tanzanian (TP, TL) and Ugandan (UP, UL) waters and form a basis for integrated regional water quality monitoring/study.

### **Sampling and Laboratory Analysis**

Field sampling and measurements in the nine stations were carried out between December 2000 and October 2001 with a total of 6 cruises being undertaken during the months of December 2000, January, April, May, August and October 2001. In-situ

measurements of temperature, dissolved oxygen, conductivity, pH, water transparency (secchi depth) and turbidity were carried out in each station and samples were

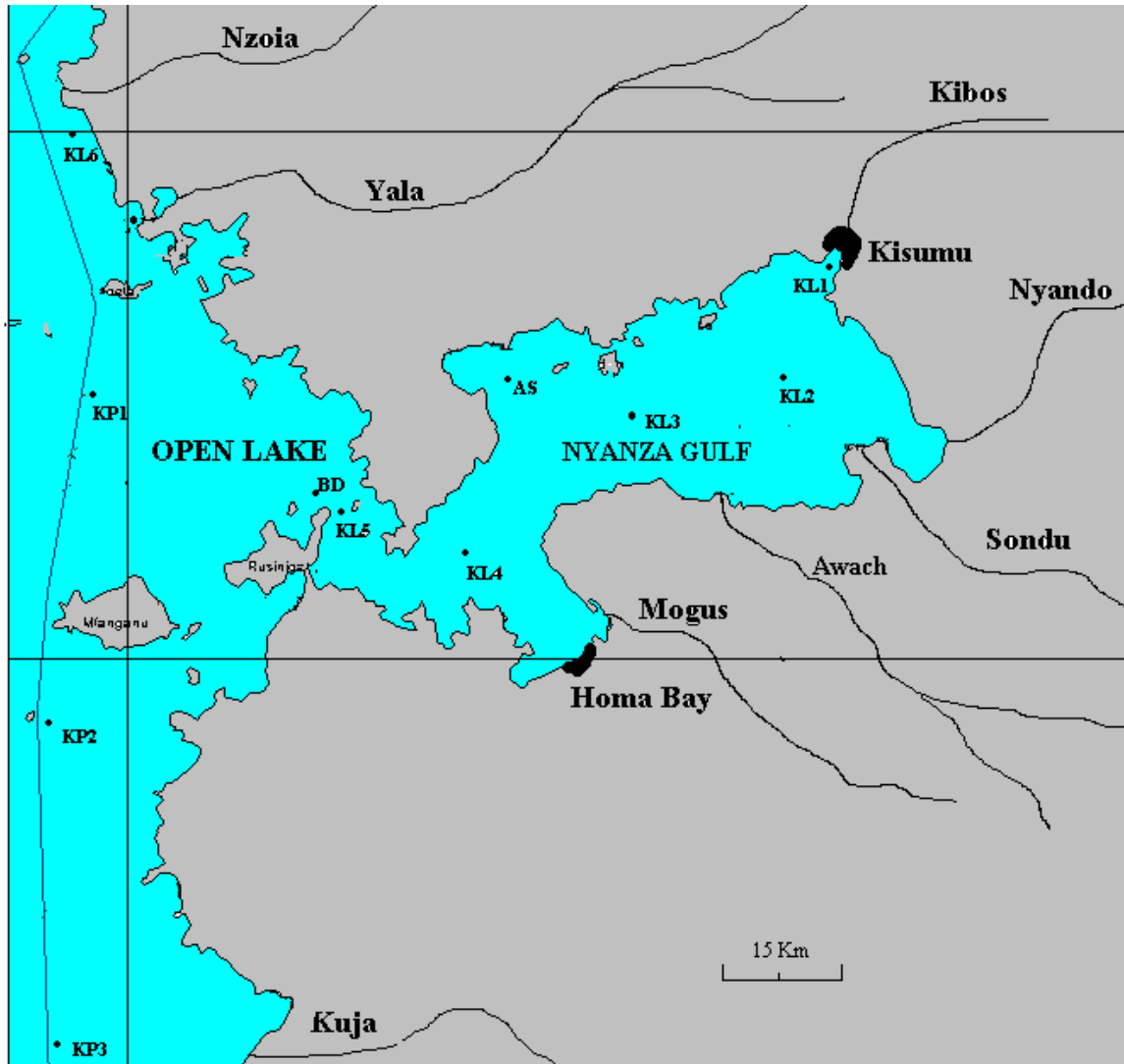


Figure 1 Map showing the Kenyan part of Lake Victoria and the Sampling Stations

collected for analysis of nutrients (P, N and Si components), algal biomass (chlorophyll-a), total suspended solids, alkalinity and organic carbon.

Lake water samples were collected at predetermined depths using a 2-liter plastic Van Dorn sampler, which closes at the desired depth through a messenger. Samples for the analysis of dissolved nutrient were immediately filtered through cellulose acetate membrane filters with pore size of 0.45  $\mu\text{m}$ . During the transportation to the laboratory and before analysis the samples (filtered and unfiltered) were kept in an ice cooler box with temperature maintained below 4  $^{\circ}\text{C}$ . For the analysis of chlorophyll-a, 200ml of the fresh sample was filtered using membrane filters of pore size 0.45 $\mu\text{m}$ . The filter papers were folded on absorbent pads and put in labeled aluminum foil and kept in a darkened

desiccator. The samples were kept in frozen conditions awaiting analysis in the laboratory, which was done immediately after delivery.

In the laboratory, the filtered samples were allowed to attain room temperature and divided into appropriate amounts for use in the analysis of the nutrients using spectrophotometric methods as outlined in Wetzel & Likens 1991, Mackereth et al (1978) and APHA (1995). Phosphate-phosphorus was analyzed as soluble reactive phosphate using the ascorbic method, nitrate-nitrogen using cadmium reduction and diazoic complex method and dissolved silica using heteropoli blue method. Chlorophyll-a pigment was extracted, in the laboratory, using 90% alkaline acetone and analyzed using spectrophotometric methods as recommended in Wetzel & Likens (1991).

A Conductivity–Temperature–Depth (CTD) Probe with additional sensors (Hydrolab Survey II) was used to measure temperature, pH, dissolved oxygen, turbidity and conductivity at different depths down the water column. The CTD sensors were calibrated frequently in the laboratory before and during the sampling trip using known freshly made standards. Light penetration was estimated with a 25cm diameter white Secchi disc. The disc was lowered from the side of the boat away from direct sunlight and the depth of disappearance and reappearance taken from a calibrated lowering line.

## **Results and discussions**

Past studies have shown a difference in nutrient levels between stations within the Nyanza gulf (referred here as littoral) and those in the open lake (referred here as pelagic). Mavuti & Litterick (1992) measured higher levels of  $\text{PO}_4\text{-P}$  in the open lake than in the gulf, whereas Calamari et al (1995) measured higher values in the gulf than in the open lake. Concentration of soluble silicates has been reported to be higher in the gulf than in the open lake (Lungaiya et al, 2000; Njuru, 2001).

During the present study, nitrate values were found to be higher in the littoral stations than in the pelagic stations with KL4 having the highest value of 0.037 mg/l and KP3 having the lowest value of 0.005 mg/l (Figure 1). Ochumba & Kibaara (1989) reported values of up to 0.513 mg/l whereas Mavuti & Litterick (1992) measured values between 0.056 mg/l and 0.106mg/l. Total nitrogen values followed the same trend as those of  $\text{NO}_3\text{-N}$  and ranged between 0.509 mg/l (KP1) and 1.447 mg/l (KL3). Values for dissolved organic nitrogen (DON) and ammonium nitrogen are presented in figure 2.

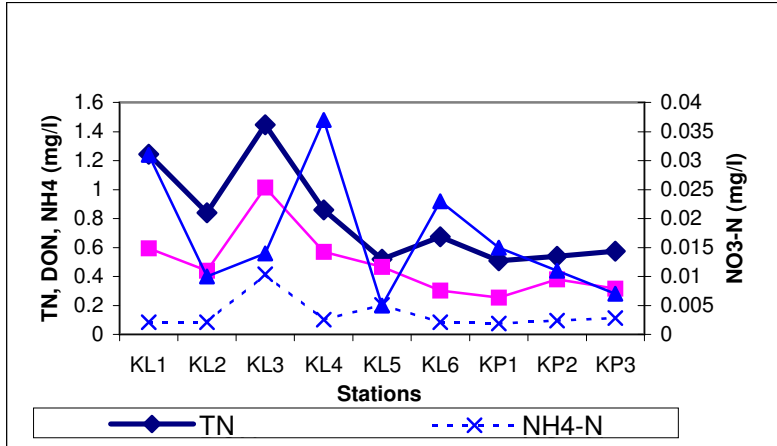


Fig. 2: Variation of TN, DON, NO<sub>3</sub>-N and NH<sub>3</sub> along the stations.

In figure 3, a plot of concentrations of PO<sub>4</sub>-P, Total Phosphorus (TP) and Dissolved Organic Phosphorus (DOP) is presented for the stations. PO<sub>4</sub>-P values ranged between 0.007 mg/l (KL3) and 0.057 mg/l (KL6) and showed an increasing trend from the gulf littoral stations to the pelagic stations. KL6, the only littoral station outside the gulf had the highest PO<sub>4</sub>-P value. Apart from KL6 the other values fall within the range measured by Mavuti & Littereck (1992) (and showed the same trend) and those measured by Ochumba & Kibaara (1989) and Calamari et al (1995) (0.007-0.016 mg/l, 0.004-0.037 mg/l and 0.002-0.029 mg/l respectively). DOP showed the same increasing trend from the littoral to the pelagic stations whereas TP was higher in the littoral stations than in the pelagic ones. This indicates that the littoral stations had more particulate bound phosphorus than that in the pelagic stations.

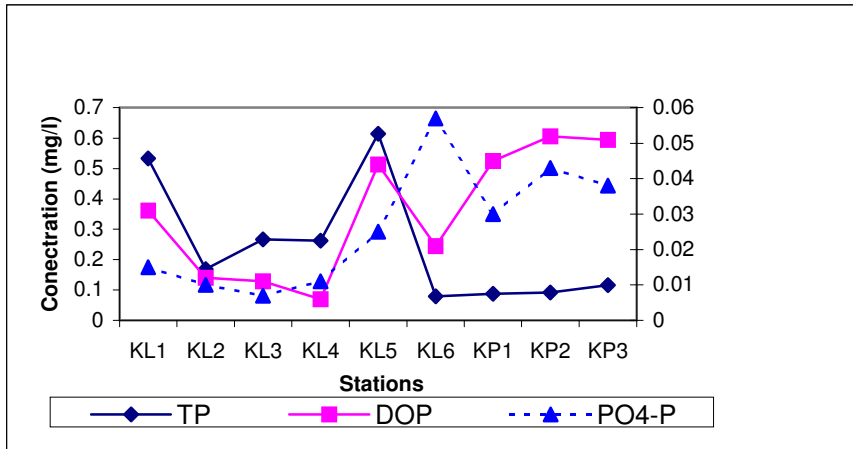


Fig. 3: Plot of variation of TP, DOP and PO<sub>4</sub>-P

TN:TP ratio was found to be 6.78 which is an indicator that the lake has a higher possibility of being dominated by heterocystous blue-green algae. The ratio was higher in the littoral stations (8.6) than in the pelagic stations (4.88) indicating higher photosynthetic rates in the littoral parts of the lake than in the pelagic areas (Crul, 1995).

Soluble reactive silica (SRSi) values were found to be higher in the littoral stations than in the pelagic ones, and ranged from 0.429 mg/l at KP2 to 3.664 mg/l at KL1 (Figure 4). The SRSi values were within the range measured by Lungaiya et al (2000) (0 to 4 mg/l) in similar stations but were far much lower (for pelagic stations) than those reported in Talling (1965) and hence confirming the earlier observations of reduced SRSi levels in Lake Victoria (Heckey & Bugenyi, 1992; Lowe-McConnel, 1994). The difference in SRSi values in the littoral and pelagic stations can in part be attributed to the higher uptake by the diatoms (Crul, 1995), which dominate the pelagic zones of the lake (Ochumba & Kibaara, 1989; Lungaiya et al, 2000) and possible loading from the surface inflow in the gulf. Particulate biogenic silica (PBSi) did not show any distinct trend and had a highest value of 0.105mg/l in KL6 and lowest value of 0.026 mg/l at KP1.

Water transparency (secchi depth) was higher in the open lake than in the littoral stations and ranged between 0.66 m (in KL1) and 2.83 m (in KP2) (Figure 5). Worthington (1930) reported values of between 1.1 m to 1.6 m within the Nyanza gulf

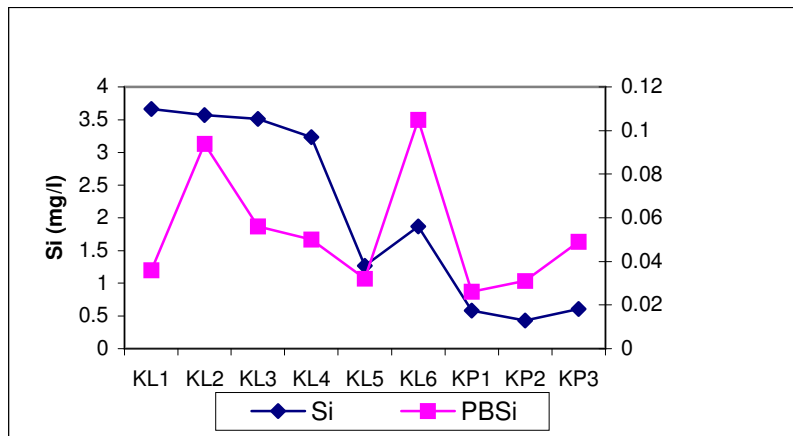


Fig. 4: Variation of SRSi and PBSi in the sampling stations

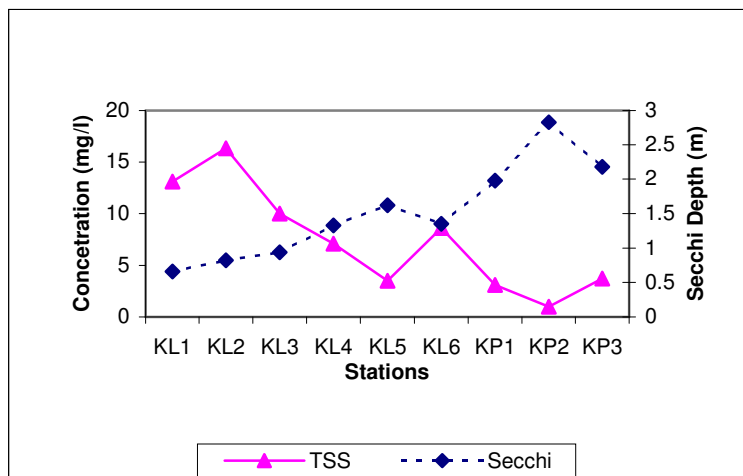


Fig. 5: TSS and secchi depth variation during the study period

(around KL4) and between 7.7 m to 7.9 m in the eastern offshore. Although transparency within the gulf has not changed much the offshore values have significantly reduced (with more than 50%) and can be attributed to increased productivity in the lake during the past 3 decades (Heckey & Bugenyi, 1992, Ochumba & Kibaara, 1989). A plot of the variation of water transparency and total suspended solids (TSS) is shown in figure 5. The two water quality parameters showed opposite trend, with transparency increasing from the littoral to the pelagic stations. A regression of the two parameters gave  $R^2 = 0.808$ . Worthington (1930) attributed the higher degree of turbidity (corresponding to low transparency) in the gulf to the abundance of phytoplankton and stirring of water by regular breezes resulting to re-suspension of bottom silt. Phytoplankton biomass (chlorophyll-a) was found to be higher in the littoral stations than in the pelagic ones and was between  $11.0 \text{ mg/m}^3$  (KL6) to  $3 \text{ mg/m}^3$  (KP3) (Figure 6). Chlorophyll-a and secchi depth were found to have a logarithmic relationship (Figure 7).

The oxygen level in a water bodies is not only a measure of the environmental health of the aquatic ecosystem, but is also the lifeline of the aquatic life. Dissolve oxygen (DO) levels were found to have a maximum of  $11.3 \text{ mg/l}$  in the littoral stations and in lower depth (<30 m) levels of less than  $1 \text{ mg/l}$  were measured. Occurrence of frequent fish kills in the lake has been attributed to increased development of anoxia in the water column (Ochumba, 1987; Ochumba, 1990). Anoxic levels in lakes result mainly from increased bio-degradation of organic matter and stratification, which hinders re-oxygenation of hypolimnion (Wetzel, 1990). According to Ochumba (1996), anoxic water flow daily in and out of the Nyanza gulf at 17:00hr and 24:00hr respectively. This would indicate that continued lowering of the anoxic depth in the open lake would exert serious environmental pressure on the relatively shallow gulf waters, hence affecting fishery and other aquatic life.

Table 1 – Water quality levels values from different authors and present study

Source/Author	PO <sub>4</sub> (mg/l)	NO <sub>3</sub> (mg/l)	Si (mg/l)	Secchi (m)	Temp. °C
Talling (1966)	0.071	0	3.63		
Ochumba & Kibaara (1989)	0.004-0.037	0.513			23.5-28.0
Heckey & Bugenyi (1992)	0.022	0.012	0.369		
Mavuti & Litterick (1992)	0.007-0.016	0.056-0.106		1.5-2.8	23.6-24.5
Calamari et al (1995)	0.002-0.029			0.6 –2.3	
Worthington (1930)				0.5-7.9	23.3-26.7
Present	0.007-0.057	0.005-0.037	0.429-3.664	0.66-2.83	23.29-28.81

Within the gulf, temperatures ranging between  $24.07 \text{ }^{\circ}\text{C}$  and  $28.81 \text{ }^{\circ}\text{C}$  were recorded and in the pelagic stations the range was between  $23.29 \text{ }^{\circ}\text{C}$  and  $26.62 \text{ }^{\circ}\text{C}$ . These were within the range reported by Ochumba & Kibaara (1989) ( $23.5 \text{ }^{\circ}\text{C}$  -  $28.0 \text{ }^{\circ}\text{C}$ ) but had higher maximum range than those reported by Worthington (1930) for a station near KL4 and

one near KP2 (24.8 °C - 26.7 °C; 23.75 °C – 24.45 °C respectively). Akiyama et al (1976) reported values ranging between 22.0 °C and 26.0 °C for Mwanza gulf, which are lower than the present values. Comparing the present temperature values with those earlier measured, by Worthington in the same areas it is evident that the average maximum temperature in the lake water has increased. This could be as a result of the general global warming or/and increased suspended matter in the water column resulting in increased heat capacity of the water. Water temperature is an important driving force in the lake dynamics since it is the dominant factor in the stratification phenomena and column mixing (Wetzel, 1990; Ochumba, 1996). Increased heating will result to increased stability of stratified water column and hence reducing mixing depth. Ochumba (1996) reports low oxygen levels in the lower depth in month of July, when typically the column mixes throughout. Table 1 presents values of different parameters from different authors together with those from the present study.

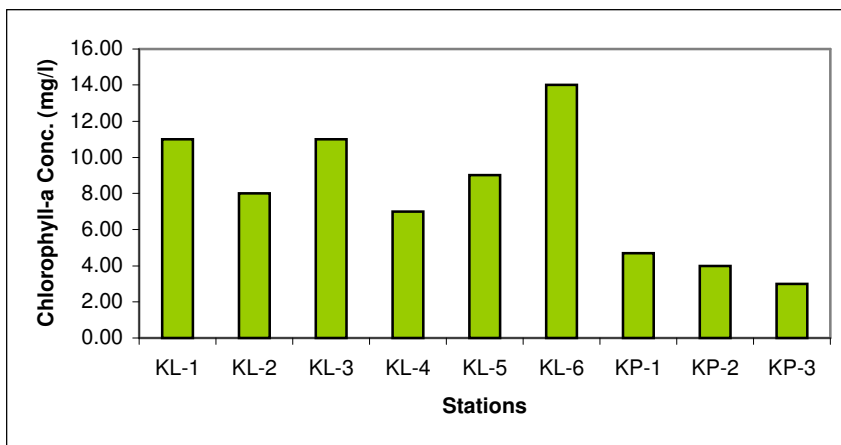


Fig. 6: Chlorophyll-a levels in the lake during sampling period

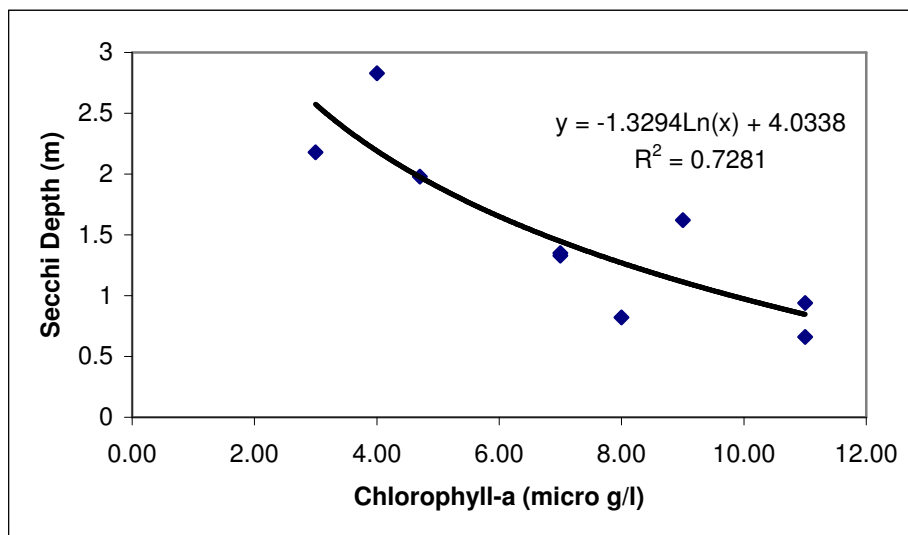


Fig. 7: Regression of Chlorophyll-a on water transparency (secchi depth)



## **Conclusions and Recommendations**

The following are conclusions and recommendations:

- Although soluble reactive silicates have reduced significantly in the open waters compared to those reported by Talling (1965) the littoral stations still had higher values, which are within the range of those of Talling. This may be explained by the increased differentiation of phytoplankton composition in both lake zones as reported by various authors.
- The TN:TP ratio in the littoral areas was found to be higher than that of the pelagic stations, indicating a difference in productivity and algal composition of the two zones. Phosphorus levels were correspondingly found to be higher in the pelagic stations than in the littoral ones.
- Compared to values reported by other authors the lake water, in both the littoral and pelagic zones, has higher temperatures, which may have in part contributed to the reported stabilization of the water column and consequently lowering the anoxic layer in the lake.
- The lower water transparency values reported during the study as compared to those reported by Worthington and Talling indicates a higher algal productivity and a marked increase in suspended solids. This may have resulted in an increased heat capacity of the water and hence contributing to the observed higher temperatures.
- More studies on nutrient dynamics in the Kenyan side of the lake should be undertaken so as to come up with local and relevant management strategy for the Kenyan waters. The lake is too big to have a generalized dynamics and management strategy.
- The management of the lake should be directed towards the reduction of nutrient input in the lake and reduction of sediment loading into the lake.
- The present study did not cover the period between June and early August, which falls during the lake mixing season and therefore did not capture the physico-chemical and biological dynamics associated with this important phenomena. This period falls in the transition of the government financial year and during when there normally a delay of flow funds which directly affect the in-lake monitoring work. For a successful and result oriented lake monitoring, it is recommended that flow of funds be de-linked from the normal financial flow system so as to avoid these monitoring gaps.

## **Acknowledgements**

This work was carried out as part of the on-going in-lake eutrophication studies in the Water Quality Management Component of Lake Victoria Environmental Management Project (LVEMP) funded by the World Bank through the Ministry of Environment and Natural Resources. I would like first to thank the Permanent Secretary, Ministry of Environment and Natural Resources for according me the opportunity to carry out this work and availing the necessary resources and facilitation. The project manager, water Quality Management Component is acknowledged for the management input during the undertaking of this work.

My colleagues in the high waters, O. Masongo, C. Kanyugo, and M. J. Maina are acknowledged for their in-put during field sampling and laboratory analysis. Lona of DHI, Denmark is acknowledged for her great in-put during the laboratory analysis of the samples.

The Deputy Director (Inland Waters) Kenya Marine and Fisheries Research Institute is acknowledged for availing the Institute's research vessel, crew and equipment during the in-lake sampling. Finally I would like to appreciate Ipsen, N. and Nick, A. of DHI and Warren, R. of COWI for their technical and scientific in-put during the study.

## References

American Public Health Association (APHA), 1995. *Standard Methods for Analysis of Water and Wastewater*, 18<sup>th</sup> edition. Port City Press, Baltimore,MD.

Bootsma, H. A. and R. E. Heckey, (1993). Conservation of the African Great Lakes: A Limnological Perspective. *Conservation Biology* Vol. 7, No. 3. 644-656

Calamari, D., M. O. Akech, and P. B. O. Ochumba, (1995). Pollution of Winam Gulf, Lake Victoria, Kenya: A case study for preliminary assessment. *Lakes and reservoirs: Research and management* 1: 89 – 106

Chege, N., (1995). Lake Victoria: a sick giant. *People & Planet* Vol. 4 No. 2.14-17

Crul, R. C. M., (1995). *Limnology and hydrology of Lake Victoria*. UNESCO/IHP-IV Project M-5.1, UNESCO Publishing, Paris.

Foxall, C., M. R. Litterick, and S. N. Njuguna, (1984). *Lake Victoria baseline study to water quality*. (Unpublished report).

Lowe-McConnel, R. H. (1994). The changing ecosystem of Lake Victoria, *East Africa. Freshwater Forum*. 4 (2): 76-89

Lung'aiya, H. B. O., A. M'Harzi, M. Tackx, J. Gichuki, and J. J. Symoens, (2000). Phytoplankton Community Structure and Environment in the Kenyan Waters of Lake Victoria. *Freshwater Biology* 43: 529-543.

Mackereth, F. J. H., J. Heron, and J. F. Talling, (1978). *Water Analysis. Some revised methods for limnologists*. Scientific Publications of the Fresh Water Biological Association, Ambleside, Cumbria, U.K. No. 36, pp. 1-120.

Mavuti, K. M, M. R. Litterick, (1991). Composition, distribution and ecological role of zooplankton community in Lake Victoria, Kenyan waters. *Verh. Interat. Verein. Limnol.* 24: 1117-1122.

Njuru, P. G., (2001). *Physico-chemical Environment of Nyanza Gulf of Lake Victoria (Kenya) and Impact of Closure of Mbita Passage*. MSc. Thesis, unpublished. IHE, Delft, The Netherlands.

Ochumba, P. B. O., (1987). Periodic massive fish kills in the Kenyan Lake Victoria. *Water Quality Bulletin*, **12**:119-122

Ochumba, P. B. O. (1990). Massive fish kills within Nyanza Gulf of Lake victoria, Kenya. *Hydrobiologia*. **208**: 93-99

Ochumba, P. B. O., (1996). Measurement of Water Currents, Temperature, Dissolved Oxygen and Winds on the Kenyan Lake Victoria. pp 155-167, in: Johnson J.C. & Odada E.O. (eds). *The Limnology, Climatology and Paleoclimatology of the East African Lakes*. Gordon and Breach Publishers, Amsterdam.

Ochumba, P. B. O., and I. I. Kibaara, (1989). Observations on blue-green algal blooms in the open waters of Lake Victoria, Kenya. *African Journal of Ecology*. **27**: 23-34

Wetzel, G. R. and G. E. Likens, (1991). *Limnological analysis*. 2<sup>nd</sup> edition. Springer-Verlag, New York, Inc. 391pp.

Wetzel, R. G., (1983). *Limnology*, Second Edition. Sanders College Publishing, USA. 763pp

World Bank, (1996). *Final project funding proposal for Lake Victoria Environmental Management Programme*.

Worthington, E. B., (1930). Observations on the temperature, hydrogen-ion concentration, and other physical conditions of the Victoria and Albert Nyanzas. *Internationale revue der Gesamten HydroBiologie Und Hydrography*. 328-357